Chapter 21. Regional Context

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Executive Summary

There has been an evolution in the treatment of regional aspects of climate change in IPCC reports from a patchwork of case examples in early assessments towards recent attempts at a more systematic coverage of regional issues at continental and sub-continental scales (21.2.2). Key topics requiring a regional treatment include: changes in the climate itself and in other aspects of the climate system (such as the cryosphere, oceans, sea level and atmospheric composition), climate change impacts on natural resource sectors and on human activities and infrastructure, factors determining adaptive capacity for adjusting to these impacts, emissions of greenhouse gases and aerosols and their cycling through the Earth system, and human responses to climate change through mitigation and adaptation.

A good understanding of decision-making contexts is essential to define the type and scale of information on climate change related risks required from physical climate science and impacts, adaptation and vulnerability assessments (21.2.1) (*high confidence*). This is a general issue for all impacts, adaptation and vulnerability assessments, but is especially important in the context of regional issues. Many studies still rely on global datasets, models and assessment methods to inform regional decisions. However, tailored regional approaches are often more effective in accounting for variations in trans-national, national and local decision-making contexts, as well as across different groups of stakeholders and sectors. There is a growing body of literature offering guidance on how to provide the most relevant climate risk information to suit specific decision-making scales and processes.

A greater range of regional scale climate information is now available which provides a more coherent picture of past and future regional changes with associated uncertainties (21.3.3). More targeted analyses of reference and projected climate information for impact assessment studies have been carried out. Leading messages include:

- Significant improvements have been made in the amount and quality of climate data that are available for establishing baseline reference states of climate-sensitive systems (21.5.3.1). These include new and improved observational datasets, rescue and digitisation of historical datasets, and a range of improved global reconstructions of weather sequences.
- A larger set of global and regional (both dynamical and statistical) model projections allow a better characterization of ranges of plausible climate futures than in the AR4 (21.3.3), and more methods are available to produce regional probabilistic projections of changes for use in IAV assessment work (21.5.3).
- Better process understanding would strengthen the emerging messages on future climate change where there remains significant regional variation in their reliability (21.3.3).
- Confidence in past climate trends has different regional variability and in many regions there is higher confidence in future changes, often due to a lack of evidence on observed changes (21.3, Box 21-4).

In spite of improvements, the available information is limited by the lack of comprehensive observations of regional climate, or analyses of these, and different levels of confidence in projected climate change (*high confidence*). Some trends that are of particular significance for regional impacts and adaptation include (21.3.3.1; WG I SPM):

- The globally averaged combined land and ocean surface temperature data show a warming of 0.85 [0.65 to 1.06] °C, over the period 1880–2012. There is regional variation in the global trend, but overall the entire globe has warmed during the period 1901-2012. (WGI SPM) Future warming is *very likely* to be larger over land areas than over oceans. (WGI SPM)
- Averaged over mid-latitude land areas, precipitation has increased since 1901(*medium confidence* before and *high confidence* after 1951), but for other regions there is low confidence in the assessment of precipitation trends (WGI SPM).
- There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. The frequency or intensity of heavy precipitation events has *likely* increased in North America and Europe. In other continents, confidence in changes in heavy precipitation events is at most *medium*. The frequency and intensity of drought has *likely* increased in the Mediterranean and West Africa and *likely* decreased in central North America and north-west Australia.
- The annual mean Arctic sea ice extent decreased over the period 1979–2012 with a rate that was *very likely* in the range 3.5 to 4.1% per decade. Climate models indicate a nearly ice-free Arctic Ocean in September before mid-century is *likely* under the high forcing scenario RCP8.5 (*medium confidence*).
- The average rate of ice loss from glaciers worldwide, excluding those near the Greenland and Antarctic ice sheets, was *very likely* 275 [140 to 410] Gt yr^{-1} over the period 1993-2009. By the end of the 21st century, the volume of glaciers (excluding those near the Antarctic ice sheet), is projected to decrease by 15 to 55% for RCP2.6, and by 35 to 85% for RCP8.5, relative to 1986-2005 (*medium confidence*).
- The rate of global mean sea-level rise during the 21st century is *very likely* to exceed the rate observed during 1971–2010, under all RCP scenarios (21.3.3.5; WG I SPM). By the end of the 21st century it is *very likely* that sea level will rise in more than about 95% of the ocean area, with about 70% of the global coastlines projected to experience a sea level change within 20% of the global mean change. Sea-level rise along coasts will also be a function of local and regional conditions, including land subsidence or uplift and patterns of development near the coast.

There is substantial regional variation in observations and projections of climate change impacts, both because the impacts themselves vary, and because of unequal research attention (21.3.1). Evidence linking observed impacts on biological, physical and (increasingly) human systems to recent and ongoing regional temperature and (in some cases) precipitation changes have become more compelling since the AR4. This is due both to the greater availability of statistically robust, calibrated satellite records, and to improved reporting from monitoring sites in hitherto under-represented regions, though the disparity still remains large between data rich and data-poor regions. Regional variations in physical impacts such as vegetation changes, sea-level rise, and ocean acidification are increasingly well documented, though their consequences for ecosystems and humans are less well studied or understood. Projections of future impacts rely primarily on a diverse suite of biophysical, economic and integrated models operating from global- to site-scales, though some physical experiments are also conducted to study processes in altered environments. New research initiatives are beginning to exploit the diversity of impact model projections, through cross-scale model inter-comparison exercises.

There are large variations in the degree to which adaptation processes, practices and policy have been studied and implemented in different regions (21.3.2) (*high confidence*). Europe and Australia have had extensive research programs on climate change adaptation, while research in Africa and Asia has been dominated by international partners and relies heavily on case studies of community-based adaptation. National adaptation strategies are common in Europe, and adaptation plans are in place in some cities in Europe, the Americas and Australasia, with agriculture, water and land use management the primary sectors of activity. However, it is still the case that implementation lags behind planning in most regions of the world.

Contested definitions and alternative approaches to describing regional vulnerability to climate change pose problems for interpreting vulnerability indicators (21.3.1.2; 21.5.1.1). There are numerous studies that use indicators to define aspects of vulnerability, quantifying these across regional units (e.g. by country or municipality), often weighting and merging them into vulnerability indices and presenting them regionally as maps. However, methods of constructing indices are subjective, often lack transparency and can be difficult to interpret. Moreover, indices commonly combine indicators reflecting current conditions (e.g. of socio-economic capacity) with other indicators describing projected changes (e.g. of future climate or population), and have failed to reflect the dynamic nature of the different indicator variables.

Hotspots draw attention, from various perspectives and often controversially, to locations judged to be especially vulnerable to climate change (21.5.1.2). Identifying hotspots is an approach that has been used to indicate locations that stand out in terms of impacts, vulnerability or adaptive capacity (or combinations of these). The approach exists in many fields and the meaning and use of the term hotspots differs, though their purpose is generally to set priorities for policy action or for further research. Hotspots can be very effective as communication tools, but may also suffer from methodological weaknesses. They are often subjectively defined, relationships between indicator variables may be poorly understood and they can be highly scale-dependent. In part due to these ambiguities, there has been controversy surrounding the growing use of hotspots in decision making, particularly in relation to prioritising regions for climate change funding.

Cross-regional phenomena can be crucial for understanding the ramifications of climate change at regional scales, and its impacts and policies of response (21.4) (*high confidence*). These include global trade and international financial transactions, which are linked to climate change as a direct or indirect cause of anthropogenic emissions, as a predisposing factor for regional vulnerability, through their sensitivity to climate trends and extreme climate events, and as an instrument for implementing mitigation and adaptation policies. Migration is also a cross-regional phenomenon, whether of people or of ecosystems, both requiring trans-boundary consideration of their causes, implications and possible interventions to alleviate human suffering and promote biodiversity.

Downscaling of global climate reconstructions and models has advanced to bring the climate data to a closer match for the temporal and spatial resolution requirements for assessing many regional impacts, and the application of downscaled climate data has expanded substantially since AR4 (21.3.3; 21.5.3). This information remains weakly coordinated, and current results indicate that high resolution downscaled reconstructions of the current climate can have significant errors. The increase in downscaled data sets has not narrowed the uncertainty range. Integrating these data with historical change and process based understanding remains an important challenge.

Characterization of uncertainty in climate change research on regional scales has advanced well beyond quantifying uncertainties in regional climate projections alone, to incorporating uncertainties in simulations of future impacts as well as considering uncertainties in projections of societal vulnerability (21.3.3, 21.5.3, 21.5.1. 21.5.2). In particular, intercomparison studies are now examining the uncertainties in impacts models (e.g., AgMIP and ISIMIP) and combining them with uncertainties in regional climate projections. Some results indicate that a larger portion of the uncertainty in estimates of future impacts can be attributed to the impact models applied rather than to the climate projections assumed. In addition, the deeper uncertainties associated with aspects of defining societal vulnerability to climate change related to the alternative approaches to defining vulnerability are becoming appreciated. As yet there has been little research actively to quantify these uncertainties or to combine them with physical impact and climate uncertainties.

Studies of multiple stressors and assessments of potential global and regional futures using scenarios with multiple, non-climate elements are becoming increasingly common (21.5.3.2; 21.5.3.3). Non-climatic factors relevant to assessing a system's vulnerability generally involve a complex mix of influences such as environmental changes (e.g. in air, water and soil quality, sea level, resource depletion), land use and land cover changes, and socio-economic changes (e.g. in population, income, technology, education, equity, governance). All of these non-climate factors have important regional variations. There is significant variation in vulnerability due to variability in these factors.

21.1. Introduction

This chapter serves as an introduction to Part B of this volume. It provides context for an assessment of regional aspects of climate change in different parts of the world, which are presented in the following nine chapters. While the main focus of those chapters is on the regional dimensions of impacts, adaptation and vulnerability, this chapter also offers links to regional aspects of the physical climate reported by Working Group I and of mitigation analysis reported by Working Group III. The chapter frames the discussion of both global and regional issues in a decision-making context. This context identifies different scales of decisions that are made (e.g. global, international, regional, national, subnational, local) and the different economic or impact sectors that are often the objects of decision-making (e.g. agriculture, water resources, energy).

Within this framing, the chapter then provides three levels of synthesis. First there is an evaluation of the state of knowledge of changes in the physical climate system, and associated impacts and vulnerabilities, and the degree of confidence that we have in understanding those on a regional basis as relevant to decision-making. Second, the regional context of the sectoral findings presented in Part A of this volume is discussed. Third, there is an analysis of the regional variation revealed in subsequent chapters of Part B. In so doing, the goal is to examine how the chapters reflect differences or similarities in how decision-making is being addressed by policy and informed by research in different regions of the world, and whether there is commonality of experience among regions that could be useful for enhancing decisions in the future.

Having analyzed similarities and differences among IPCC regions, the chapter then discusses trans-regional and cross-regional issues that affect both human systems (e.g. trade and financial flows) and natural systems (e.g. ecosystem migration). Finally, the chapter evaluates methods of assessing regional vulnerabilities and adaptation, impact analyses, and the development and application of baselines and scenarios of the future. These evaluations provide guidance for understanding how such methods might ultimately be enhanced, so that the confidence in research about possible future conditions and consequences might ultimately improve.

21.2. Defining Regional Context

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 regional or local in their occurrence, character and implications. Moreover, the decisions that are or could be taken on the basis of climate change science play out on a range of scales, and the relevance and limitations of information on both biophysical impacts and social vulnerability differ strongly from global- to local-scale, and from one region to another. Explicit recognition of geographical diversity is therefore important for any scientific assessment of anthropogenic climate change. The following sections emphasize some of the crucial regional issues to be pursued in Part B of this report.

21.2.1. Decision-Making Context

A good understanding of decision-making contexts is essential to define the type and resolution and characteristics of information on climate change related risks required from physical climate science and impacts, adaptation and vulnerability assessments (e.g. IPCC, 2012a). This is a general issue for all impacts, adaptation and vulnerability assessments (cf. the chapters in Part A), but is especially important in the context of regional issues. Many studies still rely on global datasets, models and assessment methods to inform regional decisions. However, tailored regional approaches are often more effective in accounting for variations in trans-national, national and local decision-making contexts, as well as across different groups of stakeholders and sectors. There is a growing body of literature offering guidance on how to provide the most relevant climate risk information to suit specific decision-making scales and processes (e.g., Willows and Connell, 2003; ADB, 2005; Kandlikar *et al.,* 2011).

Table 21-1 illustrates the range of actors involved in decision-making to be informed by climate information at different scales in different sectors, ranging from international policy makers and agencies, to national and local government departments, to civil society organizations and the private sector at all levels, all the way to communities and individual households. The table illustrates how policy makers face a dual challenge in achieving policy integration – vertically, through multiple levels of governance, and horizontally, across different sectors (policy coherence).

[INSERT TABLE 21-1 HERE
Table 21-1: Dimensions of the institutions and actors involved in climate change decision-making, including example entries referred to in chapters of this volume. Vertical integration can occur within as well as between levels. Decison-making domains are illustrative. Modified and extended from Mickwitz (2009).]

Many climate change risk assessments have traditionally been undertaken either in the context of international climate policy-making (especially the United National Framework Convention on Climate Change – UNFCCC), or by (or for) national governments (e.g. CCRA, 2012; SEI, 2009; GCAP, 2011; Roshydromet, 2008). In those cases, climate risk information commonly assumes a central role in the decision-making, for instance to inform mitigation policy, or for plans or projects designed specifically to adapt to a changing climate. In recent years, increasing attention has been paid to more sector- or project-specific risk assessments, intended to guide planning and practice by a range of actors (e.g. Liu *et al.,* 2008; Rosenzweig *et al.,* 2011). In those contexts, climate may often be considered as only one contributor among a much wider set of considerations for a particular decision. In such cases, there is uncertainty about not only the future climate, but also many other aspects of the system at risk. Moreover, while analysts will seek the best available climate risk information to inform the relative costs and benefits of the options available to manage that risk, they will also need to consider the various constraints to action faced by the actors involved.

Some of these decision-making contexts, such as the design of large infrastructure projects, may require rigorous quantitative information to feed formal evaluations, often including cost-benefit analysis (e.g. PriceWaterHouseCoopers, 2010; and see chapter 17). Others, especially at local level, such as decision-making in traditional communities, are often made more intuitively, with a much greater role for a wide range of social and cultural aspects. These may benefit much more from experience-based approaches, participatory risk assessments or story-telling to evaluate future implications of possible decisions (e.g. Van Aalst *et al.,* 2008, World Bank, 2010). Multi-criteria analysis, scenario planning, and flexible decision paths offer options for taking action when faced with large uncertainties or incomplete information, and can help bridge adaptation strategies across scales (in particular between the national and local level). In most cases, an understanding of the context in which the risk plays out, and the alternative options that may be considered to manage it, are not an afterthought, but a defining feature of an appropriate climate risk analysis, which requires a much closer interplay between decision-makers and providers of climate risk information than often occurs in practice (e.g., Cardona *et al.,* 2012; Hellmuth *et al.,* 2010; Mendler de Suarez *et al.,* 2012).

The different decision-making contexts also determine the types of climate information required, including the climate variables of interest and the geographic and time scales on which they need to be provided. Many climate change impact assessments have traditionally focused on changes over longer time horizons (often out to 2100, though recently studies have begun to concentrate more on mid-century or earlier). In contrast, most decisions taken today have a planning horizon ranging from a few months to about two decades (e.g. Wilby et al., 2009). For many such shorter-term decisions, recent climate variability and observed trends are commonly regarded as sufficient to inform adaptation (e.g. Hallegatte, 2009). However, in so doing, there is often scope to make better use of observed climatological information as well as seasonal and maybe also decadal climate forecasts (e.g. Wang *et al*., 2009;

Ziervogel *et al*., 2010; Mehta *et al*., 2011; Kirtman *et al*., 2014., HLT, 2011). For longer-term decisions, such as decisions with irreversible long-term implications and investments with a long investment horizon and substantial vulnerability to changing climate conditions, longer-term climate risk information is needed (e.g. Reeder and Ranger, 2010). However, while that longer-term information is often used simply to plan for a best-guess scenario to optimize for most probable conditions, there is increasing attention for informing concerns about maladaptation (Barnett and O'Neill, 2010) and sequencing of potential adaptation options in a wider range of possible outcomes, requiring a stronger focus on ranges of possible outcomes and guidance on managing uncertainties, especially at regional, national and sub-national levels (Hall *et al*., 2012; Gersonius *et al*., 2013).

Section 21.3 summarizes different approaches that have been applied at different scales looking at vulnerabilities and impacts, adaptation, and climate science in a regional context, paying special attention to information contained in the regional chapters.

21.2.2. Defining Regions

There has been an evolution in the treatment of regional aspects of climate change in IPCC reports (Table 21-2) 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 have also addressed regional issues in various chapters, using different methods of mapping, statistical aggregation and spatial averaging to provide regional information.

[INSERT TABLE 21-2 HERE
Table 21-2: 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.]

Part B of this WG II Fifth Assessment (AR5) is the first to address regional issues treated in all three WGs. It comprises chapters on the six major continental land regions, Polar Regions, Small Islands and The Ocean. These are depicted in Figure 21-1.

[INSERT FIGURE 21-1 HERE
Figure 21-1: Specification of the world regions described in chapters 22-30 of this volume.]

Some of the main topics benefiting from a regional treatment are:

- *Changes in climate*, typically represented over sub-continental regions, a scale at which global climate models simulate well the pattern of observed surface temperatures, though more modestly the pattern of precipitation (Flato *et al.,* 2014). While maps are widely used to represent climatic patterns, regional aggregation of this (typically gridded) information is still required to summarise the processes and trends they depict. Examples, including information on climate extremes, are presented elsewhere in this chapter, with systematic coverage of all regions provided in supplementary material. Selected time series plots of temperature and precipitation change from an atlas of global and regional climate projections accompanying the WG I report (Collins *et al*., 2014b) can also be found in several regional chapters of this volume. In Figure 21-1, the sub-continental regions used for summarising climate information are overlaid on a map of the nine regions treated in Part B.
- *Changes in other aspects of the climate system*, such as the cryosphere, oceans, sea level, and atmospheric composition. A regional treatment of these phenomena is often extremely important to gauge real risks, for example when regional changes in land movements and local ocean currents counter or reinforce global sea level rise (Nicholls *et al*., 2013).
- *Climate change impacts* on natural resource sectors, such as agriculture, forestry, ecosystems, water resources and fisheries, and on human activities and infrastructure, often with regional treatment according

to biogeographical characteristics (e.g. biomes, climatic zones, physiographic features such as mountains, river basins, coastlines or deltas, or combinations of these).
- *Adaptive capacity*, which is a measure of society's ability to adjust to the potential impacts of climate change, sometimes characterised in relation to social vulnerability (Füssel, 2010), and sometimes represented in regional statistics through the use of socio-economic indicators.
- *Emissions* of greenhouse gases and aerosols and their cycling through the Earth system (Blanco et al., 2014; Ciais *et al*., 2014).
- *Human responses to climate change through mitigation and adaptation*, which can require both global and regional approaches (e.g. Stavins *et al.,* 2014; Agrawala *et al.,* 2014; Somanathan *et al.,* 2014; and see chapters 14 to 16).

Detailed examples of these elements will be referred to throughout this chapter and the regional chapters that follow. Some of the more important international political groupings that are pertinent to the climate change issue are described and catalogued in Supplementary material (section SM21.1). Table SM21-1 in section SM21.1 lists UN member states and other territories, their status in September 2013 with respect to some illustrative groupings of potential relevance for international climate change policy making, and the regional chapters in which they are considered in this report.

Finally, new global socioeconomic and environmental scenarios for climate change research have emerged since the AR4 that are richer, more diverse and offer a higher level of regional detail than previous scenarios taken from the IPCC Special Report on Emissions Scenarios (SRES). These are introduced in Box 21-1.

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Box 21-1. A New Framework of Global Scenarios for Regional Assessment

The major socio-economic driving factors of future emissions and their effects on the global climate system were characterized in the TAR and AR4 using scenarios derived from the IPCC Special Report on Emissions Scenarios (SRES – IPCC, 2000). However, these scenarios are becoming outdated in terms of their data and projections, and their scope is too narrow to serve contemporary user needs (Ebi *et al*., 2013). More recently a new approach to developing climate and socio-economic scenarios has been adopted in which concentration trajectories for atmospheric greenhouse gases and aerosols were developed first (Representative Concentration Pathways or RCPs – Moss et al., 2010), thereby allowing climate modeling work to proceed much earlier in the process than for SRES. Different possible Shared Socio-economic Pathways (SSPs), intended for shared use among different climate change research communities, were to be determined later, recognizing that more than one socio-economic pathway can lead to the same concentrations of greenhouse gases and aerosols (Kriegler *et al.,* 2012).

Four different RCPs were developed, corresponding to four different levels of radiative forcing of the atmosphere by 2100 relative to pre-industrial levels, expressed in units of Wm^{-2}: RCP 8.5, 6.0, 4.5, and 2.6 (van Vuuren et al., 2012). These embrace the range of scenarios found in the literature, and all except RCP 8.5 also include explicit stabilization strategies, which were missing from the SRES set. An approximate mapping of the SRES scenarios onto the RCPs on the basis of a resemblance in radiative forcing by 2100 is presented in chapter 1 (this volume), pairing RCP 8.5 with SRES A2 and RCP 4.5 with B1 and noting that RCP 6.0 lies between B1 and B2. No SRES scenarios result in forcing as low as RCP 2.6, though mitigation scenarios developed from initial SRES trajectories have been applied in a few climate model experiments (e.g. the E1 scenario – Johns et al., 2011).

In addition, five SSPs have been proposed, representing a wide range of possible development pathways (van Vuuren et al., 2013). An inverse approach is applied, whereby the SSPs are constructed in terms of outcomes most relevant to IAV and mitigation analysis, depicted as challenges to mitigation and adaptation (Chapter 20, Figure 20-3). Narrative storylines for the SSPs have been outlined and preliminary quantifications of the socio-economic variables are underway (O'Neill et al., 2013). Priority has been given to a set of *basic* SSPs with the minimum detail and comprehensiveness needed to provide inputs to IAV and integrated assessment models, primarily at global or large regional scales. Building on the basic SSPs, a second stage will construct *extended* SSPs, designed for finer-scale regional and sectoral applications (O'Neill *et al*., 2013).

An overall scenario architecture has been designed for integrating RCPs and SSPs (Ebi et al., 2013; van Vuuren et al., 2013), for considering mitigation and adaptation policies using Shared Policy Assumptions (SPAs – Kriegler et al., 2013) and for providing relevant socio-economic information at the scales required for IAV analysis (van Ruijven et al., 2013). Additional information on these scenarios can be found in chapter 1 of this report (section 1.1.3) and elsewhere in the assessment (Blanco et al., 2014.; Collins et al., 2014a.; Kunreuther et al., 2014). However, due to the time lags that still exist between the generation of RCP-based climate change projections in CMIP5 (the Coupled Model Intercomparison Project – Taylor *et al*., 2012) and the development of SSPs, few of the IAV studies assessed in this report actively use these scenarios. Instead, most of the scenario-related studies in the assessed literature still rely on the SRES.

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21.2.3. Introduction to Methods and Information

There has been significant confusion and debate about the definitions of key terms (Janssen and Ostrom, 2006), such as vulnerability (Adger, 2006), adaptation (Stafford Smith *et al.,* 2011), adaptive capacity (Smit and Wandel, 2006) and resilience (Klein et al., 2003). One explanation is that the terms are not independent concepts, but defined by each other, thus making it impossible to remove the confusion around the definitions (Hinkel, 2011). The differences in the definitions relate to the different entry points for looking at climate change risk (IPCC, 2012).

Table 21-3 shows two ways to think about vulnerability, demonstrating that different objectives (e.g., improving well-being and livelihoods or reducing climate change impacts) lead to different sets of questions being asked. This results in the selection of different methods to arrive at the answers. The two approaches portrayed in the middle and right hand columns of Table 21-3 have also been characterised in terms of top-down (middle column) and bottom-up (right column) perspectives, with the former identifying physical vulnerability and the latter social vulnerability (Dessai and Hulme, 2004). In the middle column, the climate change impacts are the starting point for the analysis, revealing that people and/or ecosystems are vulnerable to climate change. This approach commonly applies global-scale scenario information and seeks to refine this to the region of interest through downscaling procedures. For the approach illustrated on the right, the development context is the starting point (i.e., social vulnerability), commonly focusing on local scales, on top of which climate change occurs. The task is then to identify what changes are needed in the broader-scale development pathways in order to reduce vulnerability to climate change. Another difference is a contrast in time-frames, where a climate change focused approach tends to look to the future to see how to adjust to expected changes, whereas a vulnerability focused approach is centred on addressing the drivers of current vulnerability. A similar approach is described by McGray *et al.* (2009).

[INSERT TABLE 21-3 HERE
Table 21-3: Two possible entry points for thinking about vulnerability to climate change (illustrative and adapted from Füssel 2007).]

The information assessed in this chapter stems from different entry points, framings and conceptual frameworks for thinking about risk. They merge social and natural science perspectives with transdisciplinary ones. There is no single "best" conceptual model: the approaches change as scientific thinking evolves. The IPCC itself is an example of this: IPCC SREX (IPCC, 2012) presented an approach that has been adjusted and adapted in Chapter 19 of this volume. Chapter 2 describes other conceptual models for decision making in the context of risk. While this diversity in approaches enriches our understanding of climate change, it can also create difficulties in comparisons. For instance, findings that are described as vulnerabilities in some studies may be classified as impacts in others; lack of adaptive capacity in one setting might be described as social vulnerability in another.

21.3. Synthesis of Key Regional Issues

This section presents information on vulnerabilities and impacts, adaptation, and climate science in a regional context. To illustrate how these different elements play out in actual decision-making contexts, Table 21-4 presents examples drawn from the regional and thematic chapters, which illustrate how information about vulnerability and exposure, and climate science at different scales, inform adaptation (implemented in policy and practice as part of a wider decision-making context). These show that decision-making is informed by a combination of different types of information. However, this section is organized by the three constituent elements: vulnerabilities and impacts; adaptation; and climate science.

[INSERT TABLE 21-4 HERE
Table 21-4: Illustrative examples of adaptation experience, as well as approaches to reduce vulnerability and enhance resilience. Adaptation actions can be influenced by climate variability, extremes, and change, and by exposure and vulnerability at the scale of risk management. Many examples and case studies demonstrate complexity at the level of communities or specific regions within a country. It is at this spatial scale that complex interactions between vulnerabilities, inequalities, and climate change come to the fore. At the same time, place-based examples illustrate how larger-level drivers and stressors shape differential risks and livelihood trajectories, often mediated by institutions.]

The following two sub-sections offer a brief synopsis of the approaches being reported in the different regional chapters on impacts and vulnerability studies (21.3.1) and adaptation studies (21.3.2), aiming to particularly highlight similarities and differences among regions. Table 21-5 serves as a rough template for organising this discussion which is limited to the literature that has been assessed by the regional chapters. It is organized according to the broad research approach applied, distinguishing impacts and vulnerability approaches from adaptation approaches; and according to scales of application ranging from global to local.

[INSERT TABLE 21-5 HERE
Table 21-5: Dimensions of assessments of impacts and vulnerability and of adaptation drawn upon to serve different target fields (cf. Table 21-1). Scales refer to the level of aggregation at which study results are presented. Entries are illustrations of different types of study approaches reported and evaluated in this volume, with references given both to the original studies and to the chapters in which they are cited. Aspects of some of the studies in this table are also alluded to in Section 21.5.]

Section 21.3.3 then provides an analysis of advances in understanding of the physical climate system for the different regions covered in chapters 22-30, introducing new regional information to complement the large-scale and process-oriented findings presented by Working Group I. Understanding the reliability of this information is of crucial importance. In the context of IAV studies it is relevant to a very wide range of scales and it comes with a similarly wide range of reliabilities. Using a similar classification of spatial scales to that presented in Table 21-5, Table 21-6 provides a summary assessment of the reliability of information on two basic climate variables of relevance, surface temperature and precipitation. It is drawn from the extensive assessment and supporting literature from the IPCC SREX (IPCC, 2012) and the AR5 WG1 reports. Some discussion of relevant methodologies and related issues and results are also presented in section 21.5.

[INSERT TABLE 21-6 HERE
Table 21-6: Reliability of climate information on temperature and precipitation over a range of spatial and temporal scales. Reliability is assigned to one of seven broad categories from Very High (VH) to Medium (M) through to Very Low (VL).]

Table 21-6 shows there are significant variations in reliability with finer scales information generally less reliable given the need for a greater density of observations and/or for models to maintain accuracy at high resolutions. The reliability of information on past climate depends on the availability and quality of observations which is higher for temperature than precipitation as observations of temperature are easier to make and generally more representative of surrounding areas than is the case for precipitation. Future climate change reliability depends on the performance of the models used for the projections in simulating the processes that lead to these changes. Again, information on temperature is generally more reliable due to the models' demonstrated ability to simulate the relevant processes when reproducing past changes. The significant geographical variations, in the case of the observations, result from issues with availability and/or quality of data in many regions, especially for precipitation. For future climate change, data availability is less of an issue with the advent of large ensembles of climate model projections but quality is a significant problem in some regions where the models perform poorly and there is little confidence that processes driving the projected changes are accurately captured. A framework for summary information on model projections of future climate change placed this in the context of observed changes is presented in Box 21-2.

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Box 21-2. Summary Regional Climate Projection Information

Summary figures on observed and projected changes in temperature and precipitation are presented in the following regional chapters. These provide some context to the risks associated with climate change vulnerability and impacts and the decision-making on adaptations being planned and implemented in response to these risks. Figure 21-2 provides an example for Africa. The information is identical to that displayed in Box CC-RC.

[INSERT FIGURE 21-2 HERE
Figure 21-2: Observed and projected changes in annual average temperature and precipitation. (Top panel, left) Observed temperature trends from 1901-2012 determined by linear regression. [WGI AR5 Figures SPM.1 and 2.21] (Bottom panel, left) Observed precipitation change from 1951-2010 determined by linear regression. [WGI AR5 Figure SPM.2] For observed temperature and precipitation, trends have been calculated where sufficient data permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Solid colors indicate areas where change is significant at the 10% level. Diagonal lines indicate areas where change is not significant. (Top and bottom panel, right) CMIP5 multi-model mean projections of annual average temperature changes and average percent change in annual mean precipitation for 2046-2065 and 2081-2100 under RCP2.6 and 8.5. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability, and >90% of models agree on sign of change. Colors with white dots indicate areas with strong agreement, where >66% of models show change greater than the baseline variability and >66% of models agree on sign of change. Gray indicates areas with divergent changes, where >66% of models show change greater than the baseline variability, but <66% agree on sign of change. Colors with diagonal lines indicate areas with little or no change, less than the baseline variability in >66% of models. (There may be significant change at shorter timescales such as seasons, months, or days.). Analysis uses model data and methods building from WGI AR5 Figure SPM.8. See alsoAnnex I of WGI AR5. [Boxes 21-3 and CC-RC]]

These figures provide a very broad overview of the projected regional climate changes but in dealing with only annual averages they are not able to convey any information about projected changes on seasonal timescales or shorter, such as for extremes. In addition, they are derived solely from the CMIP5 general circulation models (GCMs) and do not display any information derived from CMIP3 data which are widely used in many of the studies assessed within the AR5 WG2 report. To provide additional context two additional sets of figures are presented here and in Box 21-4 that display temperature and precipitation changes at the seasonal and daily timescales respectively.

Figure 21-3 displays projected seasonal and annual changes averaged over the regions defined in the IPCC SREX report, "Managing the risks of extreme events and disasters to advance climate change adaptation" (IPCC 2012), for Central and South America for the four RCP scenarios and three of the SRES scenarios. The temperature and precipitation changes for the period 2071-2100 compared to a baseline of 1961-1990 are plotted for the four standard three months seasons with the changes from each CMIP3 or CMIP5 represented by a symbol. Symbols showing the CMIP3 model projections are all grey but differ in shape depending on the driving SRES concentrations scenario and those showing the CMIP5 projections differ in colour depending on the driving RCP emissions/concentrations scenario (see figure legend for details and Box 21-1 for more information on the SRES and RCP scenarios). The thirty year periods were chosen for consistency with the figures displayed in Box 21-4 (Figures 21-7 and 21-8) showing changes in daily temperatures and precipitation. Figures presenting similar information for the SREX regions contained in the other inhabited continents are presented in supplementary figures SM21-1 to SM21-7.

[INSERT FIGURE 21-3 HERE
Figure 21-3: Regional average change in seasonal and annual mean temperature and precipitation over five sub-regions covering South and Central America for the period 2071-2100 relative to 1961-90 in GCM projections from 35 CMIP5 ensemble under four RCP scenarios (van Vuuren et al., 2011) compared with GCM projections from 22 CMIP3 ensemble under three SRES scenarios (IPCC, 2000); see Table 21-1 for details of the relationship between the SRES and RCP scenarios. Regional averages are based on SREX region definitions (see Figure 21-3). Temperature changes are given in ºC and precipitation changes in mm/day with axes scaled relative to the maximum changes projected across the range of models. The models which generated the data displayed are listed in supplementary material Table SM21-3.]

_____ END BOX 21-2 HERE _____

21.3.1. Vulnerabilities and Impacts

21.3.1.1. Observed Impacts

The evidence linking observed impacts on biological, physical and (increasingly) human systems to recent and ongoing regional climate changes has become more compelling since the AR4 (see chapter 18). One reason for this is the improved reporting of published studies from hitherto under-represented regions of the world, especially in the tropics (Rosenzweig and Neofotis, 2013). That said, the disparity is still large between the copious evidence being presented from Europe and North America, as well as good quality data emerging from Australasia, polar regions, many ocean areas and some parts of Asia and South America, compared to the much sparser coverage of studies from Africa, large parts of Asia, central and South America and many small islands. On the other hand, as the time series of well-calibrated satellite observations become longer in duration, and hence statistically more robust, these are increasingly providing a near global coverage of changes in surface characteristics such as vegetation, hydrology, and snow and ice conditions that can usefully complement or substitute for surface observations (see Table 21-4 and chapter 18 for examples). Changes in climate variables other than temperature, such as precipitation. evapotranspiration and CO_2 concentration, are also being related to observed impacts in a growing number of studies (Rosenzweig and Neofotis, 2013; and see examples from Australia in chapter 25, Table 25-3 and south eastern South America in chapter 27, Figure 27-7).

Other regional differences in observed changes worth pointing out include trends in relative sea level, which is rising on average globally (Church *et al*., 2014), but displays large regional variations in magnitude, or even sign, due to a combination of influences ranging from El Niño/La Nina cycles to local tectonic activity (Nicholls et al., 2013), making general conclusions about ongoing and future risks of sea level change very difficult to draw across diverse regional groupings such as small islands (see chapter 29). There are also regional variations in another ongoing effect of rising CO_2 concentration – ocean acidification, with a greater pH decrease at high latitudes consistent with the generally lower buffer capacities of the high latitude oceans compared to lower latitudes (Rhein et al., 2014, section 3.8.2). Calcifying organisms are expected to show responses to these trends in future, but key uncertainties remain at organismal to ecosystem levels (chapter 30, Box CC-OA).

21.3.1.2. Future Impacts and Vulnerability

21.3.1.2.1. Impact models

The long-term monitoring of environmental variables, as well as serving a critical role in the detection and attribution of observed impacts, also provides basic calibration material used for the development and testing of impact models. These include process-based or statistical models used to simulate the biophysical impacts of climate on outcomes such as crop yield, forest productivity, river runoff, coastal inundation or human mortality and morbidity (see chapters 2-7; 11). They also encompass various types of economic models that can be applied to evaluate the costs incurred by biophysical impacts (see, for example, chapters 10 and 17). There are also integrated assessment models (IAMs), Earth System Models, and other more loosely linked integrated model frameworks that represent multiple systems and processes (e.g. energy, emissions, climate, land use change, biophysical impacts, economic effects, global trade) and the various interactions and feedbacks between them. For examples of these, see chapter 17, section 17.6.3 and Flato *et al*. (2014).

21.3.1.2.2. Vulnerability mapping

A second approach to projecting potential future impacts is to construct vulnerability maps. These usually combine information on three components: exposure to a hazard (commonly defined by the magnitude of climate change, sensitivity to that hazard), the magnitude of response for a given level of climate change, and adaptive capacity (describing the social and economic means to withstand the impacts of climate change (IPCC, 2001)). Key indicators are selected to represent each of the three components, which are sometimes combined into a single index of vulnerability. Indicators are usually measured quantities taken from statistical sources (e.g. income, population), or have been modelled separately (e.g. key climate variables). Vulnerability indices have received close scrutiny in several recent reviews (Füssel, 2010; Hinkel, 2011; Malone and Engle, 2011; Preston *et al*., 2011; Kienberger et al., 2012), and a number of global studies have been critiqued by Füssel (2010).

A variant of vulnerability mapping is risk mapping (e.g., Tran et al., 2009; Ogden et al., 2008). This commonly identifies a single indicator of hazard (e.g. a level of flood expected with a given return period), which can be mapped accurately to define those regions at risk from such an event (e.g. in a flood plain). Combined with information on changing return periods of such events under a changing climate would enable some estimate of altered risk to be determined.

21.3.1.2.3. Experiments

A final approach for gaining insights on potential future impacts, concerns physical experiments designed to simulate future altered environments of climate (e.g. temperature, humidity and moisture), and atmospheric composition (e.g. CO_2, surface ozone and sulphur dioxide concentrations). These are typically conducted to study responses of crop plants, trees and natural vegetation, using open top chambers, greenhouses or free air gas release systems (e.g., Craufurd *et al*., 2013), or responses of aquatic organisms such as plankton, macrophytes or fish, using experimental water enclosures known as mesocosms (e.g., Sommer et al., 2007; Lassen et al., 2010).

21.3.1.2.4. Scale issues

Impact models operate at a range of spatial and temporal resolutions, and while their outputs are sometimes presented as fine resolution maps, key model findings are rarely produced at the finest resolution of the simulations (i.e. they are commonly aggregated to political or topographic units of interest to the target audience, e.g. watershed, municipality, national or even global). Aggregation of data to coarse-scale units is also essential for allowing comparison of outputs from models operating at different resolutions, but it also means that sometimes quite useful detail may be overlooked when model outputs are presented at the scale of the coarsest common denominator. Conversely, if outputs from impact models are required as inputs to other models, the outputs may need to be harmonized to a finer grid than the original data. In such cases, downscaling methods are commonly applied. This was the case, for example, when providing spatially explicit projections of future land use from different IAMs (Hurtt et al., 2011) for climate modellers to apply in the CMIP5 process (Collins et al., 2014a). It is also a common procedure used in matching climate model outputs to impact models designed to be applied locally (e.g. over a river basin or an urban area – see section 21.3.3.2).

Even if the same metrics are being used to compare aggregate model results (e.g. developed versus developing country income under a given future scenario) estimates may have been obtained using completely different types of models operating at different resolutions. Moreover, many models that have a large-scale coverage (e.g. continental or global) may nonetheless simulate processes at a relatively fine spatial resolution, offering a potentially useful source of spatially explicit information that is unfamiliar to analysts working in specific regions, who may defer to models more commonly applied at the regional scale. Examples include comparison of hydrological models with a global and regional scope (Todd *et al*., 2011) and bioclimatic models of vascular plant distributions with a European and local scope (Trivedi *et al*., 2008). Vulnerability mapping exercises can also be undermined by the inappropriate merging of indicator datasets that resolve information to a different level of precision (e.g. Tzanopoulos *et al*., 2013). There is scope for considerably enhanced cross-scale model intercomparison work in the future, and projects such as AgMIP (Rosenzweig *et al*., 2013) and ISI-MIP (Schiermeier, 2012, – see section 21.5) have provision for just such exercises.

21.3.2. Adaptation

This section draws on material from the regional chapters (22-30) as well as the examples described in Table 21-4. Material from chapters 14-17 is also considered. See also Table 16.4 for a synthesis from the perspective of adaptation constrains and limits.

21.3.2.1. Similarities and Differences in Regions

As described in the regional chapters, a large portion of adaptation knowledge is based on conclusions drawn from case studies in specific locations, the conceptual findings are typically being applied globally (chapters 14-17).). It is this empirical knowledge on adaptation that guides understandings in the different regions. This is especially the case for developing regions. Thus, regional approaches to adaptation vary in their degree of generality. One of the most striking differences between regions in terms of adaptation is the extent to which it has been studied and implemented. Australia and Europe have invested heavily in research on adaptation since the AR4, and the result is a rich body of literature published by local scientists. The ability to advance in adaptation knowledge may be related to the amount and quality of reliable climate information, the lack of which has been identified as a constraint to developing adaptation measures in Africa (22.4.2). Many case studies, especially of community-based adaptation, stem from Asia, Africa, Central and South America and Small Islands but the majority of this work has been undertaken and authored by international non-governmental organisations, as well as by other non-local researchers. In Africa, most planned adaptation work is considered to be pilot, and seen as part of learning about adaptation, although there has been significant progress since the AR4 (22.4.4.2).

Most regional chapters report lags in policy work on adaptation (see also 16.5.2). While most European countries have adaptation strategies, few have been implemented (23.1.2). Lack of implementation of plans is also the case for Africa (22.4). In North (26.8.4.1.2*)* and Central and South America (27.5.3.2), adaptation plans are in place for some cities. In Australasia, there are few adaptation plans (25.4.2). In the Arctic, they are in their infancy (28.4). At the same time, civil society and local communities have the opportunity to play a role in decision making about adaptation in Europe and Asia (23.7.2, 24.4.6.5). In Africa, social learning and collective action are used to promote adaptation (22.4.5.3). Adaptation is observed as mostly autonomous (spontaneous) in Africa, although socio-ecological changes are creating constraints for autonomous adaptation (22.4.5.4). There is a disconnect in most parts of Africa between policy and planning levels, and the majority of work is still autonomous and unsupported (22.4.1). In the case of UNFCCC-supported activities, such as National Adaptation Programmes of Action, few projects from the African (22.4.4.2) least developed countries have been funded, thus limiting the effectiveness of these investments. Several chapters (Africa, Europe, North America, Central and South America and Small Islands) explicitly point out that climate change is only one of multiple factors that affect societies and ecosystems and drives vulnerability or challenges adaptation (22.4.2, 23.10.1, 26.8.3.1, 27.3.1.2, 29.6.3*)*. For example, North America reports that for water resources, most adaptation actions are 'no-regrets', meaning that they have benefits beyond just adaptation to climate change (26.3.4). In Australasia, the limited role of socio-economic information in vulnerability assessments restricts confidence regarding the conclusions about future vulnerability and adaptive capacity (25.3.2).

Some chapters (Polar Regions, North America, Australasia) emphasise the challenges faced by indigenous peoples and communities in dealing with climate change (28.4.1, 26.8.2.2, 25.8.2). Although they are described as having some degree of adaptive capacity to deal with climate variability, shifts in lifestyles combined with a loss of traditional knowledge leave many groups more vulnerable to climate change (28.2.4.2). Also, traditional responses have been found to be maladaptive because they are unable to adjust to the rate of change, or the broader context in which the change is taking place, as seen in the Arctic (28.4.1). In response to changing environmental conditions, people are taking on maladaptive behaviour – for instance, by going further to hunt because of changed fish-stocks and thus exposing themselves to greater risk, or changing to different species and depleting stocks (28.4.1). Limits to traditional approaches for responding to changing conditions have also been observed in several Small Island States (29.8).

Most populated regions have experience with adaptation strategies in agriculture, where exposure to the impacts of climate variability over centuries provides a starting point for making adjustments to new changes in climate. Water and land use management strategies stand out in the literature in common across all of the main continental regions.

The link between adaptation and development is explicit in Africa, where livelihood diversification has been key to reducing vulnerability (22.4.5.2). At the same time, there is evidence that many short-term development initiatives have been responsible for increasing vulnerability (22.4.4.2). Other chapters mention constraints or barriers to adaptation in their regions. For example, the low priority accorded to adaptation in parts of Asia, compared to more pressing issues of employment and education, is attributed in part to a lack of awareness of the potential impacts of climate change and the need to adapt, a feature common to many regions (22.5.4). All developing regions cite insufficient financial resources for implementing adaptation as a significant limitation.

21.3.2.2. Adaptation Examples in Multiple Regions

Across regions, similar responses to climate variability and change can be noted. Heat waves are an interesting example (Table 21-4), as early warning systems are gaining use for helping people reduce exposure to heat waves. At the global scale, the length and frequency of warm spells, including heat waves, has increased since 1950 (*medium confidence*), and over most land areas on a regional scale, more frequent and/or longer heat waves or warm spells are *likely* by 2016-2035 and *very likely* by 2081-2100 (IPCC, 2014d). Warning systems are now planned and implemented in Europe, the US, Canada, Asia and Australia.

Use of mangroves to reduce flood risks and protect coastal areas from storm surges is a measure promoted in Asia, Africa, the Pacific and South America (Table 21-4). Often, mangroves have been cut down to provide coastal access, so there is a need to restore and rehabilitate them. This is an example that is considered low-regrets because it brings multiple benefits to communities besides protecting them from storm surges, such as providing food security and enhancing ecosystem services. Mangrove forests also store carbon, offering synergies with mitigation.

In several African countries, as well as in India, index-based insurance for agriculture has been used to address food insecurity and loss of crops resulting from more hot and fewer cold nights, an increase in heavy precipitation events and longer warm spells (Table 21-4). A predetermined weather threshold typically associated with high loss triggers an insurance pay-out. The mechanism shares risk across communities and can help encourage adaptive responses and foster risk awareness and risk reduction. However, limited availability of accurate weather data mean that establishing which weather conditions causes losses can be challenging. Furthermore, if there are losses but not enough to trigger payout, farmers may lose trust in the mechanism.

21.3.2.3. Adaptation Examples in Single Regions

Although conditions are distinct in each region and location, practical lessons can often be drawn from looking at examples of adaptation in different locations. Experience with similar approaches in different regions offers additional lessons that can be useful when deciding whether an approach is appropriate.

Community-based adaptation is happening and being planned in many developing regions, especially in locations that are particularly poor. In small islands, where a significant increase in the occurrence of future sea-level extremes by 2050 and 2100 is anticipated, traditional technologies and skills may still be relevant for adapting (Table 21-4). In the Solomon Islands, relevant traditional practices include elevating concrete floors to keep them dry during heavy precipitation events and building low aerodynamic houses with palm leaves as roofing to avoid hazards from flying debris during cyclones, supported by perceptions that traditional construction methods are more resilient to extreme weather. In Fiji after cyclone Ami in 2003, mutual support and risk sharing formed a central pillar for community-based adaptation, with unaffected households fishing to support those with damaged homes. Participatory consultations across stakeholders and sectors within communities and capacity building taking into account traditional practices can be vital to the success of adaptation initiatives in island communities, such as in Fiji or Samoa. These actions provide more than just the immediate benefits; they empower people to feel in control of their situations.

In Europe, several governments have made ambitious efforts to address risks of inland and coastal flooding due to higher precipitation and sea level rise during the coming century (Table 21-4). Efforts include a multitude of options. One of the key ingredients is strong political leadership or government champions. In the Netherlands, government recommendations include ‘soft’ measures preserving land from development to accommodate increased river inundation; raising the level of lakes to ensure continuous freshwater supply; restoring natural estuary and tidal regimes; maintaining coastal protection through beach nourishment; and ensuring necessary political-administrative, legal, and financial resources. The British government has also developed extensive adaptation plans to adjust and improve flood defenses and restrict development in flood risk areas in order to protect London from future storm surges and river flooding. They undertook a multi-stage process, engaging stakeholders and using multi-criteria analysis. Pathways have been analyzed for different adaptation options and decisions, depending on eventual sea level rise, with ongoing monitoring of the drivers of risk informing decisions.

In Australia, farmers and industries are responding to experienced and expected changes in temperature, rainfall, and water availability by relocating parts of their operations, such as for rice, wine, or peanuts, or changing land use completely (Table 21-4). In South Australia, for instance, there has been some switching from grazing to cropping. The response is transformational adaptation, and can have positive or negative implications for communities in both origin and destination regions. This type of adaptation requires a greater level of commitment, access to more resources and greater integration across decision-making levels because it spans regions, livelihoods and economic sectors.

21.3.3. Climate System

This section places the regional chapters in a broader context of regional climate information, particularly regarding cross regional aspects, but does not provide a detailed region-by-region assessment. Boxes 21-2 and 21-4 introduce examples of regional information for continental/sub-continental regions but other regional definitions are often relevant (see Box 21-3). The focus in this section is on the summary of new and emerging knowledge since the AR4 relevant to vulnerability, impacts and adaptation research, with emphasis on material deriving from dynamical and statistical downscaling work which is often of greater relevance for VIA applications than the coarser resolution global climate model data. In a regional context, the AR5 WG1 Chapter 14 (Regional Phenomena) is particularly relevant for the projections and evaluation of confidence in models’ ability to simulate temperature, precipitation and phenomena, together with an assessed implication for the general level of confidence in projections for 2080-2099 of regional temperature and precipitation (See WG1, Ch 14, Table 14.2).

_____ START BOX 21-3 HERE _____

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

In many world regions, countries form political and/or economic groupings that coordinate activities to further the interests of the constituent nations and their peoples. For example, the Intergovernmental Authority on Development (IGAD) of the countries of the Greater Horn of Africa recognizes that the region is prone to extreme climate events such as droughts and floods that have severe negative impacts on key socio-economic sectors in all its countries. In response it has set up the IGAD Climate Prediction and Applications Centre (ICPAC). ICPAC provides and supports application of early warning and related climate information for the management of climate-related risks (for more details see http://www.icpac.net/). In addition it coordinates the development and dissemination of seasonal climate forecasts for the IGAD countries as part of a WMO-sponsored Regional Climate Outlook Forum process (Ogallo et al., 2008) which perform the same function in many regions. A more recent WMO initiative, the Global Framework for Climate Services (Hewitt et al., 2012), aims to build on these and other global, regional and national activities and institutions to develop climate information services for all nations.

As socio-economic factors are important contributors to both the vulnerability and adaptability of human and natural systems, it clearly makes sense to summarise and assess available climate and climate change information for these regions, as this will be relevant to policy decisions taken within these groupings on their responses to climate change. For example, Figure 22-2 in Chapter 22 illustrates the presentation of observed and projected climate changes of two summary statistics for 5 political/economic regions covering much of Africa. It conveys several important pieces of information: the models are able to reproduce the observed trends in temperature; they simulate significantly lower temperatures without the anthropogenic forcings and significantly higher future temperatures under typical emissions paths; for most regions the models project that future variations in the annual average will be similar to those simulated for the past. However, for a more comprehensive understanding additional information needs to be included on other important aspects of climate, e.g. extremes (see Box 21-4).

_____ END BOX 21-3 HERE _____

21.3.3.1. Global context

21.3.3.1.1. Observed changes

Temperature and precipitation

New estimates of global surface air temperatures give a warming of about 0.89 ºC (0.69 ºC – 1.08 ºC) for the period of 1901-2012 and about 0.72 ºC (0.49 ºC – 0.79 ºC) for the period 1951-2012 (WGI Chapter 2, Section 2.4.3). Positive annual temperature trends are found over most land areas, particularly since 1981. Over the period 1981-2012, relatively large trends have occurred over areas of Europe, the Sahara and middle East, central and northern Asia, north-eastern North America (WGI Chapter 2, Section 2.4.3).

For precipitation, the Northern Hemisphere mid to high latitudes show a *likely* increasing trend (*medium confidence* prior to 1950, *high confidence* afterwards) (WGI Chapter 2, Section 2.5.1). Observed precipitation trends show a high degree of spatial and temporal variability, with both positive and negative values (WGI Chapter 2, Section 2.5). The human influence on warming since the middle of the 20th century is *likely* over every continental region, except Antarctica (WGI Chapter 10, Section 10.3.1), while the attribution of changes in hydrological variables is *less confident* (WGI Chapter 10, Section 10.3.2).

Cryosphere

New data have become available since the AR4 to evaluate changes in the cryosphere (WGI Chapter 4, Section 4.1) showing that the retreat of annual Arctic sea ice extent has continued, at a *very likely* rate of 3.5-4.1% *per* decade during the period 1979-2012. The perennial sea ice extent (sea ice area at summer minimum) decreased at a rate of 11.5 ± 2.1% *per* decade (*very likely*) over the same period 1979-2012 (WGI Chapter 4, Section 4.2.2). The thickness, concentration and volume of arctic ice have also decreased. Conversely, the total annual extent of Antarctic ice has increased slightly (*very likely* 1.2-1.8% *per* decade between 1979 and 2011), with strong regional differences (WGI Chapter 4, Section 4.2.3).

Almost all glaciers worldwide have continued to shrink since the AR4, with varying rates across regions (WG1 Chapter 4, Sections 4.3.1, 4.3.3). In particular, during the last decade most ice loss has been observed from glaciers in Alaska, the Canadian Arctic, the Southern Andes, the Asian mountains and the periphery of the Greenland Ice Sheet. Several hundred glaciers globally have completely disappeared in the last 30 years (WG1 Chapter 4, 4.3.3).

Because of better techniques and more data, confidence has increased in the measurements of Greenland and Antarctica ice sheets. These indicate that parts of the Antarctic and Greenland ice sheets have been losing mass over the last two decades (*high confidence)*, mostly due to changes in ice flow in Antarctica, and a mix of changes in ice flow and increases in snow/ice melt in Greenland. Ice shelves in the Antarctic Peninsula are continuing a long-term trend of thinning and partial collapse started some decades ago (WGI Chapter 4, Sections 4.4.2, 4.4.3, 4.4.5).

21.3.3.1.2. Near-term and long-term climate projections

The uncertainty in near term CMIP5 projections is dominated by internal variability of the climate system (see Glossary entry on Climate Variability), initial ocean conditions and inter-model response, particularly at smaller spatial and temporal scales (Hawkins and Sutton 2009, 2011). In the medium and long term, emission profiles may affect the climate response. Global warming of 0.3-0.7ºC is *likely* for the period of 2016-2035 compared to 1986-2005 based on the CMIP5 multi model ensemble, and spatial patterns of near term warming are generally consistent with the AR4 (WGI Chapter 11, Section 11.3.6). For precipitation (2016-2035 vs. 1986-2005), zonal mean precipitation will *very likely* increase in high and some of the mid-latitudes, and will *more likely than not* decrease in the subtropics (WGI Chapter 11, Section 11.3.2). Results from multi-decadal near term prediction experiments (up to 2035) with initialized ocean state show that there is some evidence of predictability of yearly to decadal temperature averages both globally and for some geographical regions (WGI Chapter 11, Section 11.2.3).

Moving to long term projections (up to 2100), analyses of the CMIP5 ensemble have shown that, in general, the mean temperature and precipitation regional change patterns are similar to those found for CMIP3, with a pattern correlation between CMIP5 and CMIP3 ensemble mean late 21st century change greater than 0.9 for temperature and greater than 0.8 for precipitation (WGI Chapter 12, Section 12.4). Given the increased comprehensiveness and higher resolution of the CMIP5 models this adds an element of robustness to the projected regional change patterns.

Some of the main characteristics of the projected late 21st century regional temperature and precipitation changes derived from the CMIP5 ensemble can be broadly summarized as follows (from WGI Chapter 12 and the WGI Atlas) with further details provided in Box 21-2 and accompanying supplementary material.

Temperature

Regions that exhibit relatively high projected temperature changes (often greater than the global mean by 50% or more) are high latitude Northern Hemisphere land areas and the Arctic, especially in December-January-February, and Central North America, portions of the Amazon, the Mediterranean, and Central Asia in June-July-August (Figure 21-4).

[INSERT FIGURE 21-4 HERE
Figure 21-4: CMIP5 ensemble median ratio of local:global average temperature change in the period 2071-2100 relative to 1961-90 under the RCP8.5 emissions/concentrations scenario. The values are displayed on a common 2.5^{o}x3.75^{o} grid onto which each models' data were regridded and they were calculated as follows: 1) for each model the local change was calculated between 1961 and 1990 at each grid cell, and is divided by the global average change in that model projection over the same period; 2) the median ratio value across all models at each grid cell is identified and shown. Data used are from the 35 CMIP5 models for which monthly projections were available under RCP8.5 which are listed in supplementary Table 21-3. Overplotted polygons indicate the SREX regions (IPCC, 2012) used to define the sub-regions used to summarise information in Chapters 21 and some of the subsequent regional chapters.]

Precipitation

Changes in precipitation are regionally highly variable, with different areas projected to experience positive or negative changes (Box 21-2). By the end of the century in the RCP8.5 scenario, the high latitudes will *very likely* experience greater amounts of precipitation, some mid-latitude arid and semi-arid regions will *likely* experience drying, while some moist mid-latitude regions will *likely* experience increased precipitation (WG1 Chapter 12, Section 12.4.5).

Studies have also attempted to obtain regional information based on pattern scaling techniques in which regional temperature and precipitation changes are derived as a function of global temperature change (e.g. Giorgi 2008; Watterson 2008; Watterson and Whetton 2011; Watterson 2011 Ishizaki et al. 2012, 2013a, 2013b). Figure 21-5 from Harris et al. (2013) provides an example of Probability Density Functions (PDFs) of temperature and precipitation change over sub-continental scale regions obtained using a Bayesian method complemented by pattern scaling and performance-based model weighting.

[INSERT FIGURE 21-5 HERE
Figure 21-5: Evolution of the 5%, 17%, 33%, 50%, 66%, 83% and 95% percentiles of the distribution functions for annual surface air temperature changes (upper panel) and annual precipitation (lower panel) for the Giorgi-Francisco (2000) regions and the globe with the SRES A1B forcing scenario combining results from a perturbed physics ensemble and the CMIP3 ensemble. Twenty year means relative to the 1961-1990 baseline are plotted in decadal steps using a common y-axis scale. The 5%, 50% and 95% percentile values for the period 2080-2099 are displayed for each region. (From Harris et al. 2012).]

21.3.3.2. Dynamically and Statistically Downscaled Climate Projections

Dynamical and statistical downscaling techniques have been increasingly applied to produce regional climate change projections, often as part of multi-model intercomparison projects (Görgen et al, 2010). A large number of RCM-based climate projections for the European region were produced as part of the European projects PRUDENCE (Christensen et al. 2007; Deque et al. 2007) and ENSEMBLES (Hewitt 2005; Deque and Somot 2010). High resolution projections (grid interval of ~12 km) were also produced as part of Euro-CORDEX (Jacob et al 2013). All these studies 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)”. The ECO consists of a dipole pattern of precipitation change, with decreased precipitation to the south (Mediterranean) and increased to the north (Northern Europe) following a latitudinal/seasonal oscillation. As a result, the Mediterranean region is projected to be much drier and hotter than today in the warm seasons (Giorgi and Lionello 2008), and central/northern Europe much warmer and wetter in the cold seasons (Kjellstrom and Ruosteenoja, 2007). An increase of interannual variability of precipitation and summer temperature is also projected throughout Europe, with a decrease in winter temperature variability over Northern Europe (Schar et al. 2004; Giorgi and Coppola 2007; Lenderink et al. 2007). This leads to broader seasonal anomaly distributions and 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). 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; Zanis et al. 2009), however fine scale differences related to local topographical, land use and coastline features are produced (e.g. Gao et al. 2006; Coppola and Giorgi 2010; Tolika et al. 2012).

As part of the ENSEMBLES and AMMA projects, multiple 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 21-6). Although at least some of the response patterns may be within the natural variability, this result suggests 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, leading to a relatively high uncertainty (Engelbrecht et al. 2009; Haensler et al. 2011; Mariotti et al. 2011; Diallo et al. 2012). Statistical downscaling techniques have also been applied to the Africa region (Hewitson and Crane 2006; Lumsden et al. 2009; Paeth and Diederich 2010; Goergen et al., 2010; Benestad 2011). In this regard, methodological developments since the AR4 have been limited (see, for example reviews in Brown et al. 2008; Paeth et al. 2011) and activities have focused more on the applications (e.g. Mukheibir 2007; Gerbaux et al. 2009) for regional specific activities in the context of IAV work.

[INSERT FIGURE 21-6 HERE
Figure 21-6: Linear changes (i.e. changes obtained by fitting the time series at each grid point with straight lines) 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 Paeth et al. 2011 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 95% level are marked by black dots. From Paeth et al. (2011).]

Several RCM and time-slice high resolution GCM experiments have been conducted or analyzed for the South America continent (Nunez et al. 2009; Menendez et al. 2010; Sorensson et al. 2010; Marengo et al. 2009, 2010; Cabre et al. 2010; Kitoh et al. 2011). 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, particularly in June-July (Rauscher et al 2008, 2011). Regional model studies focusing specifically on Central America projections are however still too sparse to provide robust conclusions (e.g. Campbell et al. 2010).

Since the AR4 there has been considerable attention to producing higher resolution climate change projections over North America based on RCMs and high resolution global time slices (e.g. Salathe et al. 2008, 2010; Dominguez et al. 2010; Subin et al. 2011), in particular as part of the North American Regional Climate Change Assessment Program (NARCCAP – Mearns et al. 2009; 2012; 2013). Results indicate variations (and thus uncertainty) in future climate based on the different RCMs, even when driven by the same GCM in certain subdomains (De Elia and Cote 2010; Mearns et al., 2013; Bukovsky et al. 2013). However, in the NARCCAP suite of simulations there were also some important commonalities in the climate changes produced by the RCMs. For example, they produced larger and more consistent decreases in precipitation throughout the Great Plains in summer than did the driving GCMs or the full suite of CMIP3 GCM simulations as well as larger increases in precipitation in the northern part of the domain in winter. In the realm of statistical downscaling and spatial disaggregation, considerable efforts have been devoted to applying different statistical models for the entire US and parts of Canada (e.g., Maurer et al. 2007; Hayhoe et al. 2010; Schoof et al., 2010).

Numerous high resolution RCM projections have been carried out over the East Asia continent. While some of these find increases in monsoon precipitation over South Asia in agreement with the driving GCMs (Kumar et al. 2013) others also produce results that are not in line with those from GCMs. For example, both Ashfaq et al. (2009) and Gao et al. (2011) found in high resolution RCM experiments (20 and 25 km grid spacing, respectively) decreases in monsoon precipitation over areas of India and China in which the driving GCMs projected an increase in monsoon rain. Other high resolution (20 km grid spacing) projections include a series of double nested RCM scenario runs for the Korea peninsula (Im et al. 2007a; 2008a,b; 2010; 2011; Im and Ahn, 2011) indicating a complex fine scale structure of the climate change signal in response to local topographical forcing. Finally, very high resolution simulations were also performed. Using a 5-km mesh non-hydrostatic RCM nested within a 20-km mesh AGCM, Kitoh et al. (2009) and Kanada et al. (2012) projected a significant increase in intense daily precipitation around western Japan during the late Baiu season.

Finally, a range of RCM, variable resolution and statistical downscaling 21st century projections have been conducted over the Australian continent or some of its sub-regions (Nunez and Mc Gregor 2007; Watterson et al.

2008; Song et al. 2008, Timbal et al. 2008; Yin et al. 2010, Grose et al 2012a,b; Bennett et al 2012), showing that a local fine scale modulation of the large scale climate signal occurs in response to topographical and coastal forcings.

21.3.3.3. Projected Changes in Hydroclimatic Regimes, Major Modes of Variability, and Regional Circulations

By modifying the Earth's energy and water budgets, climate change may possibly lead to significant changes in hydroclimatic regimes and major modes of climate variability (Trenberth et al. 2003). For example, Giorgi et al. (2011) defined an index of hydroclimatic intensity (HY-INT) incorporating a combined measure of precipitation intensity and mean dry spell length. Based on an analysis of observations, global and regional climate model simulations, 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. This suggests that global warming may lead to a hydroclimatic regime shift towards more intense and less frequent precipitation events, which would increase the risk of both flood and drought associated with global warming.

ENSO is a regional mode of variability that substantially affects human and natural systems (Mc Phaden et al. 2006). Although model projections indicate that ENSO remains a major mode of tropical variability in the future, there is little evidence to indicate changes forced by GHG warming which are outside the natural modulation of ENSO occurrences (WGI Chapter 14, Sections 14.4, 14.8).

The North Atlantic Oscillation (NAO) is a major mode of variability for the northern Hemisphere mid-latitude climate. Model projections indicate that the NAO phase is *likely* to become slightly more positive (WGI Chapter 14 ES) due to GHG forcing, but the NAO will be dominated by its large natural fluctuations. Model projections indicate that the Southern Annular Mode (SAM), a major mode of variability for the southern hemisphere, is *likely* going to weaken as ozone concentrations recover through the mid-21st century (WGI Chapter 14, Sections 14.5, 14.8).

Regional circulations, such as the monsoon, are expected to change. The global monsoon precipitation, aggregated over all monsoon systems, is *likely* to strengthen in the 21st century with increases in its area and intensity, while the monsoon circulation weakens. Different regional monsoon systems, however, exhibit different responses to GHG forcing in the 21st century (WGI Chapter 14, Section 14.2.1).

21.3.3.4. Projected Changes in Extreme Climate Events

CMIP5 projections confirm results from the CMIP3; a decrease in the frequency of cold days and nights, an increase in the frequency of warm days and nights, an increase in the duration of heat waves and an increase in the frequency and intensity of high precipitation events, both in the near term and far future (IPCC (2012), 3.3.2, 3.4.4; WGI Chapter 12, 12.4.5). Increases in intensity of precipitation (and thus risk of flood) and summer drought occurrence over some mid-continental land areas is a robust signature of global warming, both in observations for recent decades and in model projections (Trenberth 2011; WG1 Chapter 12, 12.4.5). For tropical cyclones there is still little confidence in past trends and near term projections (Seneviratne et al 2012). Globally, tropical cyclone frequency is projected to either not change or decrease and, overall, wind speed and precipitation is *likely* to increase though basin scale specific conclusions are still unclear (Knutson et al. 2010). A summary of observed and projections extremes along with some statistics on CMIP5 projections of changes in daily temperature and precipitation extremes over the main continents and the SREX regions (Figure 21-4) are introduced in Box 21-4 and accompanying supplementary material.

_____ START BOX 21-4 HERE _____

Box 21-4. Synthesis of Projected Changes in Extremes Related to Temperature and Precipitation

The IPCC report, "Managing the risks of extreme events and disasters to advance climate change adaptation" (IPCC 2012), or SREX for short, provides an in depth assessment of observed and projected changes in climate extremes.

Due to the relevance of this material for assessing risks associated with climate change vulnerability and impacts and responses to these risks, summary information is presented here both drawing from and building on the material in the SREX report, including additional analyses of CMIP5 data (only CMIP3 data were used in SREX).

Summaries of SREX findings relevant to three continents Latin America (Cameron et al., 2012), Asia and Africa (available from http://cdkn.org/srex/) have been developed using material from SREX Chapter 3. A synthesis of this material for all SREX regions, along with additional material from WG1 AR5, is presented in Table 21-7. This demonstrates that in many areas of the world there is higher confidence in future changes in extreme events than there is in past trends, often due to a lack of evidence on observed changes.

[INSERT TABLE 21-7 HERE
Table 21-7: An assessment of observed and projected future changes in temperature and precipitation extremes over 26 sub-continental regions as defined in the SREX report (IPCC 2012; see also Figure 21-4 and Table SM21.2). Confidence levels are indicated by colour coding of the symbols. Likelihood terms are given only for high confidence statements and are specified in the text. Observed trends in temperature and precipitation extremes, including dryness, are generally calculated from 1950, using the period 1961-1990 as a baseline (see Box 3-1 of IPCC (2012a)). The future changes are derived from global and regional climate model projections of the climate of 2071-2100 compared with 1961-1990 or 2080-2100 compared with 1980-2000. Table entries are summaries of information in Tables 3-2 and 3-3 of IPCC (2012a) supplemented with or superseded by material from Chapters 2 (section 2.6 and Table 2-13) and 14 (section 14.4) of the IPCC AR5 WG1 report and Table 25-1 of the IPCC WG2 report. The source(s) of information for each entry are indicated by the superscripts a (Table 3-2 of IPCC, 2012a), b (Table 3-3 of IPCC, 2012a), c (Chapter 2 (section 2.6 and Table 2-13) IPCC AR5 WG1 report), d (Chapter 14 (section 14.4) of the IPCC AR5 WG1 report) and e (Table 25-1 of the IPCC WG2 report).]

In the SREX report, the only coordinated global multi-model ensemble information available was from the CMIP3. In order to provide information consistent with the projections assessed elsewhere in WG1 and 2, changes in daily temperature and precipitation projected by the CMIP5 models are presented here for two example indices, the 90th percentiles of the daily maximum temperature and daily precipitation amounts on wet days. Changes in these indices were calculated over 30 year periods (1961-1990 for the baseline and two future periods, 2041-2070 and 2071-2100) and the analysis was focused on the less extreme daily events to reduce problems with the number needed to be sampled to generate robust statistics (Kendon et. al, 2008). Projected changes were calculated for RCPs 4.5 and 8.5 and the results are displayed as a map for a given continental region and also regional averages over the SREX regions within that continent. Two examples are provided, for temperature changes over N America (Figure 21-7) and precipitation changes over Asia (Figure 21-8). A full set can be found in supplementary Figures SM21-8 to SM21-19.

[INSERT FIGURE 21-7 HERE
Figure 21-7: The frequency of 'warm days' (defined here as the 90th percentile daily maximum temperature during a baseline period of 1961-1990) projected for the 2071-2100 period by 26 CMIP5 GCMs for North America. Map: Ensemble median frequency of 'warm days' during 2071-2100 under RCP8.5. Graphs: Box-and-whisker plots indicate the range of regionally-averaged 'hot-day' frequency by 2041-2070 and 2071-2100 under RCPs 4.5 and 8.5 across the 26 CMIP5 models for each SREX sub-regions in North America. Boxes represent inter-quartile range and whiskers indicate full range of projections across the ensemble. The baseline frequency of ‘warm days’ of 10% is represented on the graphs by the dashed line. A full list of CMIP5 models for which data is shown here can be found in supplementary material Table SM21-4.]

[INSERT FIGURE 21-8 HERE
Figure 21-8: The frequency of 'very wet days' (defined here as the 90th percentile of daily precipitation on wet days during a baseline period of 1961-1990 with wet days defined as days with 1mm of precipitation or more) projected for the 2071-2100 period by 26 CMIP5 GCMs for Asia. Map: Ensemble median frequency of 'very wet days' during 2071-2100 under RCP8.5. Graphs: Box-and-whisker plots indicate the range of regionally-averaged 'very wet day' frequency by 2041-2070 and 2071-2100 under RCPs 4.5 and 8.5 across the 26 CMIP5 models for each SREX sub-regions in Asia Boxes represent inter-quartile range and whiskers indicate full range of projections across the ensemble. The baseline frequency of ‘Very wet days’ of 10% is represented on the graphs by the dashed line. A full

list of CMIP5 models for which data is shown here can be found in supplementary material Table SM21-4. (Note the WMO Expert Team on Climate Change Detection Indices defines "very wet days" threshold as the 95%-ile daily precipitation event.]

_____ END BOX 21-4 HERE _____

21.3.3.5. Projected Changes in Sea Level

Projections of regional sea level changes, both based on the CMIP3 and CMIP5 models, indicate a large regional variability of sea level rise (even more than 100% of the global mean sea level rise) in response to different regional processes (WGI Chapter 13, Section 13.6.5). However, by the end of the 21st century it is *very likely* that over about 95% of the oceans will undergo sea level rise, with about 70% of coastlines experiencing a sea level rise within 20% of the global value and most regions experiencing sea level fall being located near current and former glaciers and ice sheets (WGI Chapter 13, Section 13.6.5). Some preliminary analysis of the CMIP5 ensembles indicates areas of maximum steric sea level rise in the Northern Atlantic, the northwestern Pacific off the East Asia coasts, the eastern coastal oceanic regions of the Bay of Bengal and the western coastal regions of the Arabian Sea (WGI Chapter 13, Section 13.6.5).

21.3.3.6. Projected Changes in Air Quality

Since the AR4 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), Zhang et al. (2008), Weaver et al. (2009), 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, indicating 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. 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), Kruger et al (2008), Engardt et al. (2009), Carvalho et al. (2010), Andersson and Engardt (2010), Athanassiadou et al. (2010), Katragkou et al. (2010, 2011), Zanis et al. (2011), Huszar et al. (2011), Juda-Rezler et al. (2012). 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.

[INSERT FIGURE 21-9 HERE
Figure 21-9 Mean (top panels) and standard deviation (bottom panels) in future-minus-present (2050s minus 1990s) MDA8 summer ozone concentrations across (left-hand panels) all seven experiments (five regional and 2 global) and for comparison purposes (right hand panels), not including the WSU experiment (which simulated July only conditions). The different experiments use different pollutant emission and SRES GHG emission scenarios. The pollutant emissions are the same in the present and future simulations (from Weaver et al., 2009).]

21.4. Cross-Regional Phenomena

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

21.4.1. Trade and Financial Flows

Global trade and international financial transactions are the motors of modern global economic activity. Their role as key instruments for implementing mitigation and adaptation policies is explored in detail in chapters 14-17 and in the Working Group III report – Stavins et al., 2014; Gupta et al., 2014). They are also inextricably linked to climate change (WTO-UNEP, 2009) through a number of other interrelated pathways that are expanded here: (i) as a direct or indirect cause of anthropogenic emissions (e.g., Peters et al., 2011), (ii) as contributory factors for regional vulnerability to the impacts of climate change (e.g. Leichenko and O'Brien, 2008), and (iii) through their sensitivity to climate trends and extreme climate events (e.g., Nelson et al., 2009a; Headey, 2011).

21.4.1.1. 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. Bulk transport of these products, whether by air, sea or over land, is now a significant contributor to emissions of greenhouse gases and aerosols (Stavins et al., 2014). Furthermore, the relocation of manufacturing has transferred net emissions via international trade from developed to developing countries (see Figure 21-10), and most developed countries have increased their consumption-based emissions faster than their domestic (territorial) emissions (Peters *et al*., 2011). This regional transfer of emissions is commonly referred to in climate policy negotiations as "carbon leakage" (Barker *et al*., 2007), though only a very small portion of this can be attributed to climate policy ("strong carbon leakage"), a substantial majority being due to the effect of non-climate policies on international trade ("weak carbon leakage" – Peters, 2010). A particular example of strong carbon leakage concerns the conversion of land use from the production of food to bioenergy crops. These crops sequester carbon otherwise extracted from the ground as fossil fuels, but in the process displace demand for food production to land in other regions, often inducing land clearance and hence an increase in emissions (Searchinger *et al*., 2008), though the empirical basis for this latter assertion is disputed (see Kline and Dale, 2008).

[INSERT FIGURE 21-10 HERE
Figure 21-10: 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). Annex B and non-Annex B Parties to the UNFCCC are listed in the supplementary material.]

21.4.1.2. 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 (Leichenko and O'Brien, 2008). Examples of these risks, explored further in Chapters 7-9, 12, 13 and 19 of Part A, include:

- Severe impacts of food price spikes in many developing countries (including food riots and increased incidence of child malnutrition) such as occurred in 2008 following shortfalls in staple cereals, due to a coincidence of regional weather extremes (e.g. drought) in producer countries, the reallocation of food crops by some major exporters for use as biofuels (an outcome of climate policy – see previous section) and market speculation (Ziervogel and Ericksen, 2010). Prices subsequently fell back as the world economy went into recession, but spiked again in early 2011 for many of the same reasons (Trostle *et al*., 2011), with some commentators predicting a period of rising and volatile prices due to increasing demand and competition from biofuels (Godfray *et al*., 2010).

- A growing dependence of the rural poor on supplementary income from seasonal urban employment by family members and/or on international financial remittances from migrant workers (Davies *et al*., 2009). These workers are commonly the first to lose their jobs in times of economic recession, which automatically decreases the resilience of recipient communities in the event of adverse climate conditions.On the other hand, schemes to provide more effective communication with the diaspora in times of severe weather and other extreme events can provide rapid access to resources to aid recovery and reduce vulnerability (Downing, 2012).
- Some aspects of international disaster relief, especially the provision of emergency food aid over protracted periods, has been cited as an impediment to enhancing adaptive capacity to cope with climate-related hazards in many developing countries (Schipper and Pelling, 2006). Here, international intervention, while well-intentioned to relieve short-term stress, may actually be counter-productive in regard to the building of long-term resilience.

21.4.1.3. 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 an anticipated, potentially major 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/Denmark, Norway, Russia and the USA (Figure 21-11, and see chapter 28, section 28.3.4). For instance, the CCSM4 climate and sea ice model has been used to provide projections under RCP4.5, RCP6.0 and RCP8.5 forcing (see Box 21-1) of future accessibility for shipping to the sea ice hazard zone of the Arctic marine environment defined by the International Maritime Organization (Stephenson et al., 2013 – Figure 21-11 (central map). Results suggest that moderately ice-strengthened ships (Polar Class 6), which are estimated under baseline (1980-1999) conditions to be able to access annually about 36 % of the IMO zone, would increase this access to 45-48 % by 2011-2030, 58-69% by 2046-2065 and 68-93% by 2080-2099, with almost complete accessibility projected for summer (90-98% in July-October) by the end of the century (Stephenson *et al*., 2013). The robustness of those findings was confirmed using seven sea ice models in an analysis of optimal sea routes in peak season (September) for 2050-2069 under RCP 4.5 and RCP8.5 forcing (Smith and Stephenson, 2013). All studies imply increased access to the three major cross Arctic routes: the Northwest Passage, Northern Sea Route (which is part of the Northeast Passage), and Trans-Polar Route (Figure 21-11), which could represent significant distance savings for trans-continental shipping currently using routes via the Panama and Suez Canals (Stephenson *et al*., 2011). Indeed, in 2009 two ice-hardened cargo vessels – the Beluga Fraternity and Beluga Foresight – became the first to successfully traverse the Northeast Passage from South Korea to the Netherlands, a reduction of 5,500 km and 10 days compared to their traditional 20,000 km route via the Suez Canal, translating into an estimated saving of some $300,000 per ship, including the cost of standby icebreaker assistance (Smith, 2009; Det Norsk Veritas, 2010). A projection using an earlier version of the CCSM sea ice model under the SRES A1B scenario, but offering similar results (with forcing by mid-century lying just below RCP8.5 – chapter 1, Figure 1-5a), is presented in Figure 21-11 (peripheral maps), which also portrays winter transportation routes on frozen ground. These routes are heavily relied upon for supplying remote communities and for activities such as forestry and, in contrast to the shipping routes, are projected to decline in many regions.

[INSERT FIGURE 21-11 HERE
Figure 21-11: Central map: Marine exclusive environmental zones (EEZs – dashed lines) of Canada, Greenland/Denmark, Norway, Russia, and the USA, and location of the Northwest Passage, Northern Sea Route, Trans-Polar Route, and international high seas within the IMO Guidelines Boundary for Arctic shipping (thick black border). After Stephenson et al. (2013). Peripheral monthly maps: 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. Dark blue areas denote new maritime access to Polar Class 6 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, Latin America, Central Asia and Southeast Asia by countries in Europe, Africa, the Gulf and South and East Asia (De Schutter, 2009; Cotula *et al.*, 2011; Zoomers, 2011). While there is clearly a profit motive in many of these purchases (i.e., cheap and fertile land and the opportunity to cultivate high value food or biofuel crops), there is also a concern that domestic agricultural production in some countries will be unable to keep pace with rapid growth in domestic demand and changing dietary preferences, especially in agricultural regions affected by frequent shortfalls due to droughts, floods and cyclones (Cotula *et al*., 2011), or threatened by sea-level rise (Zoomers, 2011). Land acquisition on such a large scale raises a number of ethical issues relating to local access to food and the appropriate and sustainable management of the land (Deininger and Byerlee, 2012). These issues have led the UN Special Rapporteur on the right to food to recommend a list of eleven principles for ensuring informed participation of local communities, adequate benefit sharing and the respect of human rights (De Schutter, 2009). This issue is elaborated with respect to livelihoods and poverty in chapter 13, section 13.4.3.4, and land dispossession is categorised a key risk in chapter 19, section 19.6.2.

Extreme climate phenomena that may be harbingers of similar and more frequent events in a warmer world, already exact devastating consequences in some regions that extend well beyond country boundaries. A recent event that disrupted international trade and commodity flows was the severe 2010/2011 flooding in eastern Australia (Giles, 2011; Queensland Floods Commission of Inquiry, 2012; and see chapter 25, Box 25-8), which combined with damaging cyclones in Queensland and Western Australia curtailed numerous mining operations and damaged transportation networks, leading to declines in both thermal and metallurgical coal exports (by 31% and 19%, respectively, relative to the previous quarter – ABARES, 2011) with a sharp rise in their monthly price between November 2010 and January 2011 (Index Mundi, 2012). The severe weather was the primary factor contributing to a fall in Australian GDP of 1.2% during January-March 2011 compared with a rise of 0.7% in the preceding three-month period (Australian Bureau of Statistics, 2011). Other examples of how extreme climate events can affect international trade are reported by Oh and Reuveny (2010) and Handmer et al. (2012).

21.4.2. Human Migration

There has been considerable debate in recent years around the postulate that anthropogenic climate change and environmental degradation could lead to mass migration (Perch-Nielsen *et al*., 2008; Feng *et al*., 2010; Warner, 2010; Black *et al*., 2011; Government Office for Science, 2011; Assan and Rosenfeld, 2012). The issue is treated at length in Chapters 9, 12 and 19 of Part A, so only a few aspects are touched on here, to highlight the growing significance of migration in all regions of the world. Four possible pathways through which climate change could affect migration are suggested by Martin (2009):

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

Abundant historical evidence exists to suggest that changes in climatic conditions have been a contributory factor in migration, including large population displacements in the wake of severe events such as Hurricane Katrina in New Orleans, Louisiana in 2005 (Cutter *et al*., 2012), Hurricane Mitch in Central America in 1998 and the northern Ethiopian famines of the 1980s (McLeman and Smit, 2006). Other examples are provided in Chapter 12, Table 12-3. However, the evidence is not clear cut (Black, 2001), with counter examples also available of migration being limited due to economic hardship (e.g. during the Sahel drought of the mid-1980s in Mali – Findley, 1994).

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 it is also worth pointing out that internal migration for other (predominantly economic) reasons may actually expose populations to increased climate risk. For instance, there are large cities in developing countries in low elevation coastal zones that are vulnerable to sea-level rise. Increased migration to these cities could exacerbate the problems with the migrants themselves being especially vulnerable (Nordås and Gleditsch, 2007; UNFPA, 2007).

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

The causal chains and links between climate change and migration are complex and can be difficult to demonstrate (e.g., Perch-Nielsen et al., 2008; Piguet, 2010; Tänzler et al., 2010; ADB, 2012; Oliver-Smith, 2012; Chapter 12, section 12.4; Chapter 9, section 9.3.3.3.1; Chapter 19, section 19.4.2.1), though useful insights can be gained from studying past abandonment of settlements (McLeman, 2011). Thus projecting future climate-related migration remains a challenging research topic (Feng et al., 2010). There are also psychological, symbolic, cultural and emotional aspects to place attachment, which are well documented from other non-climate causes of forced migration, and are also applicable to cases of managed coastal retreat due to sea-level rise (e.g., Agyeman *et al.*, 2009).

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. 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). The Nansen Initiative, put forward jointly by Norway and Switzerland at a 2011 ministerial meeting, pledges "to cooperate with interested states and relevant actors, including UNHCR, to obtain a better understanding of cross-border movements provoked by new factors such as climate change, identify best practices and develop a consensus on how best to protect and assist those affected ", and may eventually result in a soft law or policy framework (Kolmannskog, 2012). However, migration should not always be regarded as a problem; in those circumstances where it contributes to adaptation (e.g. through remittances) it can be part of the solution (Laczko and Aghazarm, 2009).

21.4.3. Migration of Natural Ecosystems

One of the more obvious consequences of climate change is the displacement of biogeographical zones and the natural migration of species (see Chapters 4, 6 and 19). General warming of the climate can be expected to result in migration of ecosystems towards higher latitudes and upward into higher elevations (Chapter 4, section 4.3.2.5) or downward to cooler depths in marine environments (Chapter 6, section 6.3.2.1). 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 as well as combinations that may not survive global climate change (known respectively as novel and disappearing climates – Williams *et al.*, 2007; and see Chapter 19, section 19.5.1). 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 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; Burrows et al., 2011; Diffenbaugh and Field, 2013; Chapter 4, section 4.3.2.5). 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).

Conservation policy under a changing climate is largely a matter of promoting the natural adaptation of ecosystems, if this is even feasible for many species given the rapidity of projected climate change. Studies stress the risks of potential mismatching in responses of co-dependent species to climate change (e.g., Schweiger *et al*., 2012) as well as the importance of maintaining species diversity as insurance for the provision of basic ecosystem services (e.g., Traill et al., 2010; Isbell et al., 2011). Four priorities have been identified for conservation stakeholders to apply to climate change planning and adaptation (Heller and Zavaleta, 2009): (i) regional institutional coordination for reserve planning and management and to improve landscape connectivity; (ii) a broadening of spatial and temporal perspectives in management activities and practice, and actions to enhance system resilience; (iii) mainstreaming of climate change into all conservation planning and actions; and (iv) holistic treatment of multiple threats and global change drivers, also accounting for human communities and cultures. The regional aspects of conservation planning transcend political boundaries, again arguing for a regional (rather than exclusively national) approach to adaptation policy. This issue is elaborated in Chapters 4 (section 4.4.2) and 19 (section 19.4.2.3).

21.5. Analysis and Reliability of Approaches to Regional Impacts, Adaptation, and Vulnerability Studies

Assessing climate vulnerability or options for adapting to climate impacts in human and natural systems requires an understanding of all factors influencing the system and how change may be effected within the system or applied to one or more of the external influencing factors. This will require, in general, a wide range of climate and non-climate information and methods to apply this to enhance the adaptive capacity of the system. There are both areas of commonality across and differences between regions in the information and methods and these are explored in this section. It initially focuses on advances in methods to study vulnerability and adaptive capacity and to assess impacts (studies of practical adaptation and the processes of adaptation decision-making are treated in detail in Chapters 14-17 and so not addressed here). This is followed by assessments of new information on, and thinking related to: (a) baseline and recent trends in factors needed to assess vulnerability and define impacts baselines; and (b) future scenarios used to assess impacts, changes in vulnerability and adaptive capacity; and then assessment of the credibility of the various types of information presented.

21.5.1. Analyses of Vulnerability and Adaptive Capacity

Multiple approaches exist for assessing vulnerability and for exploring adaptive capacity (Schipper et al 2010, UNFCCC 2008). The choice of method is influenced by objectives and starting point (see Table 21-3) as well as the type of information available. Qualitative assessments usually draw on different methods and inputs from quantitative assessments. Qualitative information cannot always be translated to quantitative information, or *vice versa*, yet both approaches can sometimes be used to answer the same questions. Indicators, indices and mapping are the most common ways to aggregate the resulting vulnerability and adaptive capacity information to compare across regions (section 21.5.1.1) or to identify "hotspots" (section 21.5.1.2). .

21.5.1.1. Indicators and Indices

Several attempts have been made to develop vulnerability indicators and indices (Birkmann 2011; Chen et al. 2011; Barr et al 2010; Cardona, 2007; Luers et al 2003; Lawrence *et al.,* 2003, Villa and McLeod, 2002, Downing *et al.* 2001, Atkins *et al.,* 2000; Moss *et al.* 2001). Representation on a map or through an index is a common way to depict global vulnerability information and requires quantification of selected variables in order to measure them against a selected baseline, even though quantification of some qualitative information may not be possible (Hinkel, 2011; Edwards et al, 2007; Luers et al 2003). Vulnerability is differentiated according to factors such as gender, age, livelihood or access to social networks, among many other factors (Cardona et al 2012; Wisner et al 2005), which may not be represented accurately through some indicators. One approach used to create regional comparisons is to use indices, which are composites of several indicators thought to contribute to vulnerability, each normalised and sometimes weighted so they can be combined (Rygel et al 2006, Adger et al 2004). The approach has been critiqued extensively because the weights assigned the indicators depends on expert opinion which can result in different regions appearing more or less vulnerable, as Füssel (2010) found in reviewing global vulnerability maps based on different indices.

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

Indicator systems have also been developed to improve understanding of adaptive capacity. These are used both to measure adaptive capacity and identify entry points for enhancing it (Adaptation Sub-Committee, 2011; Lioubimtseva and Henebry, 2009; Swanson et al., 2007; Adger and Vincent, 2005; Eriksen and Kelly, 2007). For example, the Global Adaptation Index, developed by the Global Adaptation Alliance (GAIN, n.d.) uses a national approach to assess vulnerability to climate change and other global challenges and compare this with a country's "Readiness to improve resilience" (GAIN, n.d.) to assist public and private sectors to prioritise financial investments in adaptation activities.

21.5.1.2. Hotspots

A special case of the use of indicators concerns the identification of hotspots, a term original used in the context of biodiversity, where a "biodiversity hotspot" is a biologically diverse region typically under threat from human activity, climate change or other drivers (Myers, 1988). The term typically relates to a geographical location, which emerges as a concern when multiple layers of information are compiled to define it. In climate change analysis, hotspots are used to indicate locations that stand out in terms of impacts, vulnerability or adaptive capacity (or all three). Examples of hotspot mapping include how climate change can influence disease risk (de Wet et al., 2001), extinctions of endemic species (Malcolm et al., 2006), and disaster risk (Dilley, 2006). Hotspots analysis is used to serve various purposes, such as setting priorities for policy action, identifying focal regions for further research (de Sherbinin, 2013; Dilley, 2006, Ericksen et al., 2011, see www.climatehotmap.org), or, increasingly, helping distinguish priority locations for funding. Examples of the latter purpose include guiding the allocation of global resources to pre-empt, or combat, disease emergence (Jones et al 2008) or funding for disaster risk management (Arnold et al 2005). Because identifying hotspots raises important methodological issues about the limitation of using indicators to integrate quantitative impacts with qualitative dimensions of vulnerability, their use to compare regions leads to a subjective ranking of locations as having priority for climate change investment. This can be controversial and considered politically-motivated (Klein 2009).

Certain locations are considered hotspots because of their regional or global importance. These can be defined by population size and growth rate, contributions to regional or global economies, productive significance (e.g., food production) as well as by disaster frequency and magnitude, and projected climate change impacts. The choice of variables may result in different locations being identified as hotspots (Füssel, 2009). For example, the Consultative Group on International Agricultural Research (CGIAR) Research Program on Climate Change Agriculture and Food Security (CCAFS) mapped hotspots of food insecurity and climate change in the tropics (Ericksen et al, 2011) using stunted growth as a proxy for food security, but other variables could also have been selected. Scale matters in representing hotspots and they will look different on a global scale than on a finer scale (Arnold et al., 2006).

The rationale for identifying such hotspots is that they may gradually evolve into locations of conflict or disaster, where a combination of factors lead to the degradation of resources and social fabric. Climate change hotspots have been defined as locations where impacts of climate change are "well pronounced and well documented" (UCS 2011). A climate change hotspot can describe (a) a region for which potential climate change impacts on the environment or different activity sectors can be particularly pronounced or (b) a region whose climate is especially responsive to global change (Giorgi 2006). An example of the former is given by Fraser et al (2013), combining hydrological modelling with quantitatively modelled adaptive capacity (defined as the inverse of sensitivity to drought) to identify vulnerability hotspots for wheat and maize. Examples of the latter are given by Giorgi (2006), Diffenbaugh et al. (2008), Giorgi and Bi (2009), Xu et al. (2009), Diffenbaugh and Scherer (2011) and Diffenbaugh and Giorgi (2012) who used different regional climate change indices, including changes in mean and interannual variability of temperature and precipitation and metrics of seasonal extremes, to identify the Mediterranean Basin, Central America, Central and West Africa, the Northern high latitude regions, the Amazon, the southwestern United States, Southeast Asia and the Tibetan Plateau as prominent hot-spots.

21.5.2. Impacts Analyses

In recent years, there has been increased scrutiny of the methods and tools applied in impact assessment, especially quantitative models that are used to project the biophysical and socio-economic impacts of future climate change (see chapter 2, 2.3.2.1), but also encompassing qualitative methods, including studies of indigenous knowledge (Galloway McLean, 2010, and see chapter 12, 12.3.3). In an advance from previous assessments, different types of impact models are now being applied for the first time in many regions of the world. This is largely due to burgeoning international development support for climate change vulnerability and adaptation studies (Fankhauser, 2010). It is also related to a surge of interest in regional economic assessments in the wake of the Stern review (Stern, 2007) as well as to the evolution of climate models into Earth system models that incorporate a more realistic representation of land surface processes (Flato et al., 2014) and their increased application to study hydrological (chapter 3, 3.4.1), ecophysiological (chapter 4, 4.3.3) and cryospheric (Vaughan et al., 2014) impacts.

Potential impacts have been simulated for single as well as multiple sectors, at spatial scales ranging from site or household to global, and over a range of temporal scales and time horizons (Table 21-5). A majority of impact studies still follow the conventional approach where future impacts are modelled based on a set of assumptions (scenarios) about future climate and socioeconomic conditions (see 21.2.3, left hand side of Table 21-3),. However, an increasing number are being undertaken that follow a "socio-institutional" approach to adaptation planning (Downing, 2012), right hand side of Table 21-3, which emphasises the importance of adaptive flexibility and climate resilience given the often intractable, "deep" uncertainties implicit in many projections of future change (e.g., Donley *et al*., 2012; Garrett *et al*., 2013; Gersonius *et al*., 2013).

Impact modelling studies also commonly treat aspects of adaptation, either explicitly as modelled options or implicitly as built-in autonomous responses (Dickinson, 2007; White *et al*., 2011). Furthermore, as an anthropogenic signature is attributed to ongoing climate changes in many regions (Bindoff et al., 2014), and with growing evidence that these changes are having impacts on natural and human systems in many more regions than reported in the AR4 (chapter 18, Rosenzweig and Neofotis, 2013), it is now possible in some regions and sectors to test impact models' projections against observed impacts of recent climate change (e.g. Araújo *et al*., 2005; Barnett *et al*., 2008; Lobell *et al*., 2011). This is also an essential element in the attribution of observed impacts (Chapter 18, 18.3, 18.4, 18.5).

Uncertainties in and Reliability of Impacts Analyses

Literature on uncertainty in impacts analyses has focused mainly on the uncertainties in impacts that result from the uncertainties in future climate (Mearns et al., 2001; Carter et al., 2007), and this literature continues to grow since AR4, particularly in the realm of agriculture and water resources (e.g., Wetterhall et al., 20011; Ferrise et al., 2011; Ficklin et al., 2012; Littell et al., 2011, Osborne et al., 2013), but also in other areas such as flood risk (Ward et al., 2013). Furthermore, research has advanced to establish which future climate uncertainties are most important to the resultant uncertainties about crop yields (e.g., Lobell and Burke, 2008) and to apply future resource uncertainties to adaptation studies (Howden et al., 2007). Use of multiple global or regional model scenarios is now found in many more studies (e.g. Gosling et al., 2011; Bae et al., 2011; Arnell, 2011; Olsson et al., 2011) and the use of probabilistic quantification of climate uncertainties has produced estimates of probabilities of changes in future resources such as agriculture and water (e.g., Watterson and Whetton, 2011; Tebaldi and Lobell, 2008). Some studies have developed probability distributions of future impacts by combining results from multiple climate projections and, sometimes, different emissions scenarios, making different assumptions about the relative weight to give to each scenario (Brekke et al., 2009). Nobrega et al. (2011) apply 6 different GCMs and 4 different SRES emissions scenarios to study the impacts of climate change on water resources in the Rio Grande Basin in Brazil and found that choice of GCM was the major source of uncertainty in terms of river discharge.

With an ever-increasing number of impacts' projections appearing in the literature and the unprecedented rate and magnitude of climate change projected for many regions, some authors have begun to question both the robustness of the impacts models being applied (e.g., Heikkinen *et al*., 2006; Fitzpatrick and Hargrove, 2009; Watkiss, 2011a) as well as the methods used to represent key uncertainties in impacts' projections (e.g., Arnell, 2011; Rötter *et al*., 2011; White *et al*., 2011). This is being addressed through several prominent international research efforts, Agricultural Model Intercomparison and Improvement Project, involving crop and economic models at different scales (AgMIP – Rosenzweig *et al*., 2013), the Carbon Cycle Model Intercomparison Project (C^4MIP – Friedlingstein *et al*., 2006; Sitch *et al*., 2008; Arora *et al*., 2013) and the Water Model Intercomparison Project (WaterMIP – Haddeland *et al*., 2011). Modelling groups from these projects are also participating in the Inter-Sectoral Impact Model Intercomparison Project, initially focusing on intercomparing global impact models for agriculture, ecosystems, water resources, health and coasts under RCP- and SSP-based scenarios (see Box 21-1) with regional models being considered in a second phase of work (ISI-MIP – Schiermeier, 2012). AgMIP results for 27wheat models run at contrasting sites worldwide indicate that projections of yield to the mid-21st century are more sensitive to crop model differences than to global climate model scenario differences (Asseng et al., 2013; Carter, 2013). WaterMIP's analysis of runoff and evapotranspiration from five global hydrologic and six land surface models indicate substantial differences in the models' estimates in these key parameters (Haddelenad et al., 2011). Finally, as in climate modelling, researchers are now applying multiple impact model and perturbed parameter ensemble approaches to future projections (e.g., Araújo and New, 2007; Jiang *et al*., 2007; Palosuo *et al*., 2011), usually in combination with ensemble climate projections treated discretely (e.g., New *et al*., 2007; Graux *et al*., 2013; Tao and Zhang, 2013) or probabilistically (e.g., Luo *et al*., 2007; Fronzek *et al*., 2009, 2011; Børgesen and Olesen, 2011; Ferrise *et al*., 2011; Wetterhall *et al*., 2011).

These new impact MIPs, and similar initiatives, have the common purpose of mobilising the research community to address some long-recognised but pervasive problems encountered in impact modelling. A sample of recent papers illustrate the variety of issues being highlighted, e.g. forest model typology and comparison (Medlyn *et al*., 2011), crop pest and disease modelling and evaluation (Sutherst *et al*., 2011; Garrett *et al*., 2013), modelling responses to extreme weather events (Lobell *et al*., 2010; Asseng *et al*., 2013), field experimentation for model calibration and testing (Long *et al*., 2006; Craufurd *et al*., 2013) and data quality considerations for model input and calibration (Lobell, 2013). Greater attention is also being paid to methods of economic evaluation of the costs of impacts and adaptation at scales ranging from global (e.g., UNFCCC, 2007; Nelson *et al*., 2009b; Parry *et al*., 2009; Fankhauser, 2010; Füssel, 2010; Patt *et al*., 2010), through regional (e.g., EEA, 2007; World Bank, 2010; Ciscar *et al*., 2011; Watkiss, 2011b), to national (SEI, 2009; GCAP, 2011) and local level (e.g., Perrels *et al*., 2010).

21.5.3. Development and Application of Baseline and Scenario Information

21.5.3.1. Baseline Information: Context, Current Status, and Recent Advances

This section deals with defining baseline information for assessing climate change impacts, adaptation and vulnerability The baseline refers to a reference state or behaviour of a system, e.g. current biodiversity of an ecosystem, or a reference state of factors (e.g. agricultural activity, climate) which influence that system (see Glossary entry). For example, the UNFCCC defines the pre-industrial baseline climate, prior to atmospheric composition changes from its baseline pre-industrial state, as a reference for measuring global average temperature rises. A baseline may be used to characterise average conditions and/or variability during a reference period, or may allude to a single point in time, such as a reference year. It may provide information on physical factors such as climate, sea level or atmospheric composition, or on a range of non-climate factors, such as technological, land -use or socio-economic conditions. In many cases a baseline needs to capture much of system's variability to enable assessment of its vulnerability or to test whether significant changes have taken place. Thus the information used to establish this baseline must account for the variability of the factors influencing the system. In the case of climate factors often this requires 30 years of data (e.g. Jones et al., 1997) and sometimes substantially more (e.g. Kendon et al., 2008). Also temporal and spatial properties of systems will influence the information required. Many depend on high resolution information, for example urban drainage systems (high spatial scales) or temperature sensitive organisms (sub-daily time-scales). This section assesses methods to derive relevant climatic and non-climatic information and its reliability.

21.5.3.1.1. Climate baselines and their credibility

Observed weather data are generally used as climate baselines, e.g. with an impacts model to form a relevant impacts baseline, though downscaled climate model data are now being used as well. For example Bell et al. (2012) use dynamically and statistically downscaled hourly rainfall data with a 1km river flow model to generate realistic high resolution baseline river flows. These were then compared with future river flows derived used corresponding downscaled future climate projections to generate projected impacts representing realistic responses to the imposed climate perturbations. This use of high resolution data was important to ensure that changes in climate variability the system was sensitive to were taken into account (see also Hawkins et al., 2013). Underscoring the importance of including the full spectrum of climate variability when assessing climate impacts, Kay and Jones (2012) showed a greater range of projected changes in UK river flows resulted when using high time-resolution (daily rather than monthly) climate data.

Thus to develop the baseline of a climate-sensitive system it is important to have a good description of the baseline climate, thus including information on its variability on timescales of days to decades. This has motivated significant efforts to enhance the quality, length and homogeneity of, and make available, observed climate records (also important for monitoring, detecting and attributing observed climate change – Hartmann et al., 2014; Rhein et al., 2014; Vaughan et al., 2014; Masson-Delmotte et al., 2014; Bindoff et al., 2014). This has included generating new datasets such as APHRODITE (a gridded rain-gauge based dataset for Asia, Yatagai, et al., 2012), coordinated analyses of regional climate indices and extremes by CLIVAR’s ETCCDI (see e.g. Zhang et al., 2011) and data rescue work typified by the ACRE initiative (Allan et al., 2011) resulting in analysis and digitization of many daily or sub-daily weather records from all over the world. Also, estimates of uncertainty in the observations are either being directly calculated, e.g. for the HadCRUT4 near-surface temperature record (Morice et al., 2012), or can be generated from multiple datasets, e.g. for precipitation using datasets such as GPCC (Rudolf et al., 2011), TRMM (Huffman et al., 2010) and APHRODITE, Yatagi et al.; 2012.

Significant progress has also been made in developing improved and new global reanalyses. These use climate models constrained by long time-series of observations from across the globe to reconstruct the temporal evolution of weather patterns during the period of the observations. An important new development has been the use of digitized surface pressure data from ACRE by the 20th Century Reanalysis (20CR) project (Compo et al., 2011) covering 1871 to the present day. 20CR provides the basis for estimating historical climate variability from the sub-daily to the multi-decadal timescale (Figure 21-12) at any location. It can be used directly, or via downscaling, to develop estimates of the baseline sensitivity of a system to climate and addressing related issues such as establishing links between historical climate events and their impacts. Other advances in reanalyses (http://reanalyses.org) have focused on developing higher quality reconstructions for the recent past. They include a new European Centre for Medium Range Weather Forecasts Reanalyses (ERA) dataset, ERA-Interim (Dee et al., 2011) and the NASA Modern Era Reanalysis for Research and Applications (MERRA – Rienecker et al., 2011), 1979-present, the NCEP Climate Forecast System Reanalysis (CFSR), 1979-Jan 2010 (Saha et al., 2010) and regional reanalyses such as the North American Regional Reanalysis (NARR) (Mesinger et al., 2006) and EURO4M (http://www.euro4m.eu/).

[INSERT FIGURE 21-12 HERE
Figure 21-12: Time series of seasonally averaged climate indices representing three modes of large-scale climate variability: (a) the tropical September to January Pacific Walker Circulation (PWC); (b) the December to March North Atlantic Oscillation (NAO); (c) the December to March Pacific North America (PNA) pattern. Indices (as defined in Brönnimann etal. (2009) are calculated (with respect to the overlapping 1989–1999 period) from various observed, reanalysis and model sources: statistical reconstructions of the PWC, the PNA and the NAO, see Brönnimann et al. (2009) for details, (all cyan); 20CR (pink); NCEP–NCAR reanalyses (NNR; dark blue); ERA-40 (green); ERA-Interim (orange). The black line and grey shading represent the ensemble mean and spread from a climate model ensemble with a lower boundary condition of observed seas-surface temperatures and sea-ice from the HadISST dataset (Rayner et al. 2003), see Brönnimann etal. (2009) for details. The model results provide a measure of the predictability of these modes of variability from sea-surface temperature and sea-ice alone and demonstrate that the reanalyses have significantly higher skill in reproduces these modes of variability.]

In many regions high temporal and spatial resolution baseline climate information is not available (e.g. Washington et al. 2006, World Weather Watch 2005). Recent reanalyses may provide globally complete and temporally detailed reconstructions of the climate of the recent past but generally lack the spatial resolution or have significant biases (Thorne and Vose, 2010; Dee et al., 2011; Cerezo-Mota et al., 2011). Downscaling the reanalyses can be used with available observations to estimate the error in the resulting reconstructions which can often be significant (Duryan et al., 2010; Mearns et al., 2012). Advances in this area are expected through the WCRP-sponsored Coordinated Regional Downscaling Experiment (CORDEX) project (http://wcrp.ipsl.jussieu.fr/SF_RCD_CORDEX.html; Giorgi et al., 2009) which includes downscaling ERA-Interim over all land and enclosed sea areas (e.g. Nikulin et al. 2012).

21.5.3.1.2. Non-climatic baselines and their credibility

Climate-sensitive systems can be influenced by many non-climatic factors, so information on the baseline state of these factors is also commonly required (Carter et al., 2001; Carter et al., 2007). Examples of physical non-climatic factors include availability of irrigation systems, effectiveness of disease prevention or flood protection. Examples of socio-economic factors include levels of social, educational and economic development, political/governance background and available technology. Significant work has been undertaken to collect and make this information available. Local and national governments and international agencies (e.g. UN agencies, World Bank) have been collecting data (http://data.worldbank.org/data-catalog) on the human-related factors for many decades and similarly information on technological developments is widely available. Often these factors are evolving quickly and the baseline is taken as the reference state at a particular point in time rather than aggregated over a longer period. In the case of the physical factors, information on many of these have been refined and updated as they are critical inputs to deriving the climate forcings in the Representative Concentration Pathways (RCPs, van Vuuren et al., 2011) used in CMIP5 (Taylor et al., 2012). This includes updated information on land-use change (Hurtt et al., 2011), atmospheric composition (Meinshausen et al., 2011) and aerosols (Grainer et al., 2011, Lamarque et al., 2011).

The importance of establishing an appropriate physical baseline is illustrated in a study of potential climate change impacts on flow in the River Thames in the UK over a 126 year period. No long-term trend is seen in annual maximum flows despite increases in temperature and a major change in the seasonal partitioning of rainfall, winter rainfall becoming larger than summer (Marsh 2004). An investigation of the physical environment found that it had been significantly modified as part of river management activities with increases in channel capacity of 30% over 70 years leading to fewer floods. Thus establishing a baseline for river channel capacity explained the current reduced vulnerability of the Thames to flooding. In a study of the potential for crop adaptation (Challinor et al., 2009), the relevant non-climatic factor identified was technological. Detailed field studies demonstrated that the current germplasm included varieties with a wide range of tolerance to higher temperatures (Badigannavar et al., 2002). This established an agricultural technology baseline, current crop properties, which demonstrated the potential to reduce vulnerability in the system to compensate for the projected climate change impact.

21.5.3.2. Development of Projections and Scenarios

Since the AR4 there have been several new developments in the realm of scenarios and projections: 1) a new approach to the construction of global scenarios for use in climate change analysis, initiated with the development of representative concentration pathways (RCPs) (see Box 21.1 for a full description); 2) the development and application of a greater number of higher resolution climate scenarios (21.3.3.2); and 3) further use of multiple scenario elements as opposed to use of climate change scenarios only and greater focus on multiple stressors.

21.5.3.2.1. Application of high-resolution future climate information

There are now many examples of the generation and application of high resolution climate scenarios for assessing impacts and adaptation planning. These provide information at resolutions relevant for many impacts and adaptation studies but also, particularly with regard to dynamical downscaling, account for higher resolution forcings, such as complex topography (e.g., Salathé et al., 2010) or more detailed land-atmosphere feedbacks such as in West Africa (Taylor et al. 2011). In an analysis of climate impacts including possible adaptations in the Pacific North West of North America (Miles et al., 2010) application of two dynamically downscaled scenarios was particularly useful for the assessment of effects of climate change on storm water infrastructure (Rosenberg et al., 2010). More widely in North America results from NARCCAP have been used to assess impacts of climate change on available wind energy (Pryor and Barthelmie, 2011), road safety (Hambly et al., 2012), hydrology (Burger et al., 2011; Shrestha et al., 2011), forest drought (Williams et al., 2012), and human health (Li et al., 2012).

Several European-led projects have generated and applied high resolution climate scenarios to investigate the impacts of climate change over Europe for agriculture, river flooding, human health, and tourism (Christensen et al. 2012) and on energy demand, forest fire risk, wind storms damage, crop yields and water resources (Morse et al., 2009). The UK developed new UK Climate Projections in 2009 (UKCP09) combining the CMIP3, a perturbed physics GCM and a regional climate model ensemble to develop probabilities of changes in temperature and precipitation at a 25 km resolution (Murphy et al., 2009) to determine probabilities of different impacts of climate change and possible adaptations. In general, with all of this work a range of different techniques have been used with little assessment or guidance on the relative merits of each.

21.5.3.2.2. Use of multiple scenario elements and focus on multiple stressors

Many more impacts and adaptation studies now use multiple scenario elements, and focus on multiple stressors as opposed to climate change scenarios and effects alone (e.g., 3.3.2, 4.2.4, and 7.1.2). Good examples of use of multiple scenario elements involve studies of climate change and human health considering additional factors such as urban heat island (e.g., Knowlton et al., 2008; Rosenzweig et al., 2009), population increase and expanded urban areas (McCarthy et al., 2010) and population and socio-economic conditions (Watkiss and Hunt, 2012). As these studies are often undertaken at small scales, local scale information on relevant factors may be inconsistent with larger scale scenario elements used in quantifying other stressors. In recognition of this, efforts have been or are being made to downscale the large-scale scenario elements, e.g. the SRES scenarios were downscaled for Europe (van Vuuren and O'Neill, 2006) and economic activity information has been downscaled to 0.5 degree grids in some regions (Gaffin et al., 2004; Grübler et al., 2007; van Vuuren et al., 2010) However, this information is far from comprehensive and has not yet been examined carefully in the impacts and vulnerability literature (van Ruijven et al., 2013).

Typical non-climate stressors include changes in population, migration, land use, economic factors, technological development, social capital, air pollution, and governance structures. They can have independent, synergistic, or antagonistic effects and their importance varies regionally. Land-use and socio-economic changes are stressors of equal importance to climate change for some studies in Latin America (27.2.2.1), numerous changes in addition to climate strongly affect ocean ecosystem health (6.6.1) and in Asia rapid urbanization, industrialization and economic development are identified as major stressors expected to be compounded by climate change in (24.4-7). Most multiple stressor studies are regional or local in scope. For example Ziervogel and Taylor (2008) examined two different villages in South Africa and found that a suite of stressors are present such as high unemployment, health status (e.g., increased concern about AIDs), and access to education with climate change concerns present only in the context of other impacts such as 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). Mawdesly et al. (2009) considered wildlife management and biodiversity conservation and noted that reducing pressure from other stressors can maximize flexibility for adaptation to climate change. 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.

21.5.3.3. Credibility of Projections and Scenarios

21.5.3.3.1. Credibility of regional climate projections

Obtaining robust regional projections of climate change (i.e. at least a clear indication of the direction of change), requires combining 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 (Flato et al., 2014, section 10.3). The ability of GCMs 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 confidence that models capture correctly the physical processes driving the changes. This can also provide confidence in projections of precipitation when physically linked to changes in temperature (Rowell and Jones, 2006; Kendon et al. 2010). It is important, especially with precipitation where regional change may appear to differ in direction from one model to another, to distinguish when changes are significant (Tebaldi et al. 2011, Collins et al., 2014b, Box 12.1). Significant future projections of opposite direction are found with neither possibility able to be excluded on the basis of our physical understanding of the drivers of these changes. For example, McSweeney et al. (2012) found that in an ensemble of GCM projections over south-east Asia, all models simulated the important monsoon processes and rainfall well but projected both positive and negative changes in monsoon precipitation and significantly different patterns of change.

Model trends or projections may also be inconsistent with trends in available observations and in these cases, their projections are less credible. For example, the magnitude of the significant drying trend seen in the Sahel from the 1960s to the 1990s is not captured by models driven by observed sea-surface temperatures (SSTs) (e.g. Held et al. 2005) despite statistical analysis demonstrating the role of SSTs in driving Sahel rainfall variability. Thus our understanding of the system and its drivers, and their representation in the models, is incomplete, which complicates the interpretation of future projected changes in this region (e.g. Biasutti et al., 2008, Druyan, 2010). It implies that other processes are important and so research is required to identify these and ensure they are correctly represented in the models, without which projections of rainfall changes over this region cannot be considered reliable.

21.5.3.3.1. Credibility regarding socioeconomic scenario elements

Cash et al. (2003) distinguish three criteria for linking scientific knowledge to policy action; credibility (scientific adequacy of a policy-relevant study), salience (relevance of a study's findings to the needs of decision-makers), and legitimacy (the perception that the study is respectful of divergent values and beliefs). Studies examining the performance of scenarios in climate change research across all three of these criteria are rare, but a general conclusion has been that much less attention is paid to salience and legitimacy (Hulme and Dessai 2008, Garb et al.

2008, Girod et al. 2009). Recognising this a new framework for global scenarios has been developed (Box 21-1), providing researchers greater freedom than hitherto for customizing information provided by global scenarios. These innovations may pose challenges for scientific credibility, and it is unclear how difficult it will be to bring independently developed climate and socioeconomic projections together as scenarios in an internally consistent manner, especially when some of these may include fine-scale regional detail (O'Neill and Schweizer, 2011; O'Neill et al., 2013).

Due to the common practice for scenario development of using narrative descriptions of alternative futures as the inspiration for socioeconomic simulations (the Story and Simulation approach – Alcamo 2008) it has been suggested that the exclusion of some details in socioeconomic scenario studies can affect the internal consistency and therefore the overall credibility of a study (e.g. Lloyd and Schweizer, 2013; Schweizer and Kriegler, 2012). Storylines can offer a point of entry for multi-scalar scenario analyses (Rounsevell and Metzger, 2010), and such sub-global scenario studies have been on the rise (Kok et al. 2011, Preston et al. 2011, Sietz et al. 2011, van Ruijven et al., 2013).

Environmental scenario exercises crossing geographical scales suggests that linkages between scenarios at different scales can be hard or soft (Zurek and Henrichs 2007), where downscaling (van Vuuren et al. 2010) would be an example of a hard linkage while other similarities between scenarios would be soft linkages. How to apply flexible interpretations of scientific adequacy and maintain scenario credibility is relatively unexplored, and there is thus a need for studies to document best practices in this respect.

21.6. Knowledge Gaps and Research Needs

Understanding of the regional nature of climate change, its impacts, regional and cross-regional vulnerabilities, and options for adaptation is still at a rudimentary level. There are both fundamental and methodological research issues in the physical sciences concerned with the projection of regional changes in the climate system and the potential impacts of those changes on various resource sectors and natural systems. Of equal importance, there are also fundamental gaps in our understanding of the determinants of vulnerability and adaptive capacity, thus presenting methodological challenges for projecting how societal vulnerability might evolve as the climate system changes. While development of new scenarios is a part of the underlying research agenda, they will inevitably be limited without further progress in our knowledge of the determinants of vulnerability.

Table 21-8 summarizes major research gaps in the physical, ecological, and social sciences that impede the scientific communities' progress in understanding the regional context of climate changes, their consequences, and societies' responses.

[INSERT TABLE 21-8 HERE]
Table 21-8: Leading knowledge gaps and related research needs.]

Frequently Asked Questions

FAQ 21.1: How does this report stand alongside previous assessments for informing regional adaptation?
[to be inserted in Section 21.3]
The five major Working Group II Assessment Reports produced since 1990 all share a common focus that addresses the environmental and socioeconomic implications of climate change. In a general sense, the earlier assessments are still valid, but the assessments have become much more complete over time, evolving from making very simple, general statements about sectoral impacts, through greater concern with regions regarding observed and projected impacts and associated vulnerabilities, through to an enhanced emphasis on sustainability and equity, with a deeper examination of adaptation options. Finally, in the current report there is a much improved appreciation of the context for regional adaptation and a more explicit treatment of the challenges of decision-making within a risk management framework.

Obviously one can learn about the latest understanding of regional impacts, vulnerability and adaptation in the context of climate change by looking at the most recent report. This builds on the information presented in previous reports by reporting developments in key topics. New and emergent findings are given prominence, as these may present fresh challenges for decision-makers. Differences with the previous reports are also highlighted – whether reinforcing, contradicting or offering new perspectives on earlier findings – as these too may have a bearing on past and present decisions. Following its introduction in the Third Assessment Report (TAR), uncertainty language has been available to convey the level of confidence in key conclusions, thus offering an opportunity for calibrated comparison across successive reports. Regional aspects have been addressed in dedicated chapters for major world regions, first defined following the Second Assessment and used with minor variations in the three subsequent assessments. These comprise the continental regions of Africa, Europe, Asia, Australasia, North America, Central and South America, Polar Regions and Small Islands , with a new chapter on The Oceans added for the present assessment.

FAQ 21.2: Do local and regional impacts of climate change affect other parts of the world?
[to be inserted in Section 21.3.1]
Local and regional impacts of climate change, both adverse and beneficial, may indeed have significant ramifications in other parts of the world. Climate change is a global phenomenon, but often expresses itself in local and regional shocks and trends impacting vulnerable systems and communities. These impacts often materialize in the same place as the shock or trend, but also much farther afield, sometimes in completely different parts of the world. Regional interdependencies include both the global physical climate system as well as economic, social and political systems that are becoming increasingly globalised.

In the physical climate system, some geophysical impacts can have large-scale repercussions well beyond the regions in which they occur. A well-known example of this is the melting of land-based ice, which is contributing to sea-level rise (and adding to the effects of thermal expansion of the oceans), with implications for low-lying areas far beyond the polar and mountain regions where the melting is taking place.

Other local impacts can have wider socio-economic and geopolitical consequences. For instance, extreme weather events in one region may impact production of commodities that are traded internationally, contributing to shortages of supply and hence increased prices to consumers, influencing financial markets and disrupting food security worldwide, with social unrest a possible outcome of food shortages. Another example, in response to longer-term trends is the potential prospect of large-scale migration due to climate change. While hotly contested, this link is already seen in the context of natural disasters, and could become an issue of increasing importance to national and international policy makers. A third example is the shrinkage of Arctic sea ice, opening Arctic shipping routes as well as providing access to valuable mineral resources in the exclusive economic zones of countries bordering the Arctic, with all the associated risks and opportunities. Other examples involving both risks and opportunities include changes of investment flows to regions where future climate change impacts may be beneficial for productivity

Finally, some impacts that are entirely local and may have little or no direct effect outside the regions in which they occur still threaten values of global significance, and thus trigger international concern. Examples include humanitarian relief in response to local disasters or conservation of locally threatened and globally valued biodiversity.

FAQ 21.3: What regional information should I take into account for climate risk management for the 20 year time horizon? *[to be inserted in Section 21.3.2]*
The fundamental information required for climate risk management is to understand the climate events that put the system being studied at risk and what is the likelihood of these arising. The starting point for assembling this information is a good knowledge of the climate of the recent past including any trends in aspects of these events (e.g. their frequency or intensity). It is also be important to consider that many aspects of the climate are changing, to understand how the future projected changes may influence the characteristics of these events and that these changes will, in general, be regionally variable. However, it should be noted that over the coming 20 years the magnitude of projected changes may not be sufficient to have a large influence the frequency and intensity of these events. Finally, it is also essential to understand which other factors influence the vulnerability of the system. These may be important determinants in managing the risks and also if they are changing at faster rates than the climate then changes in the latter become a secondary issue.

For managing climate risks over a 20-year time horizon it is essential to identify the climate variables which the system at risk is vulnerable to. It could be a simple event such as extreme precipitation or a tropical cyclone or a more complex sequence of a late onset of the monsoon coupled with prolonged dry spells within the rainy season.

The current vulnerability of the system can then be estimated from historical climate data on these variables including any information on trends in the variables. These historical data would give a good estimate of the vulnerability assuming the record was long enough to provide a large sample of the relevant climate variables and that the reasons for any trends, e.g. clearly resulting from climate change, were understood. It should be noted that in many regions sufficiently long historical records of the relevant climate variables are often not available.

It is also important to recognize that many aspect of the climate of the next 20 years will be different from the past. Temperatures are continuing to rise with consequent increases in evaporation and atmospheric humidity and reductions in snow amount and snow season length in many regions. Average precipitation is changing in many regions with both increases and decreases and there is a general tendency for increases in extreme precipitation observed over land areas. There is a general consensus amongst climate projections that further increases in heavy precipitation will be seen as the climate continues to warm and more regions will see significant increases or decreases in average precipitation. In all cases the models project a range of changes for all these variables which are generally different for different regions.

Many of these changes may often be relatively small compared to their natural variations but it is the influence of these changes on the specific climate variables which the system is at risk from that is important. Thus information needs to be derived from the projected climate changes on how the characteristics of these variables, e.g. the likelihood of their occurrence or magnitude, will change over the coming 20 years. These projected future characteristics in some cases may be indistinguishable from those historically observed but in other cases some or all models will project significant changes. In the latter situation, the effect of the projected climate changes will then result in a range of changes in either the frequency or magnitude of the climate event, or both. The climate risk management strategy would then need to adapt to accounting for either a greater range or changed magnitude of risk. This implies that in these cases a careful analysis of the implications of projected changes for the specific temporal and spatial characteristic of the climate variables relevant to the system at risk is required.

FAQ 21.4: Is the highest resolution climate projection the best to use for performing impacts assessments?
[to be inserted in Section 21.5.3.3]
A common perception is that higher resolution (i.e., more spatial detail) equates to more useable and robust information. Unfortunately data does not equal information, and more high resolution data does not necessarily translate to more or better information. Hence, while high resolution global climate models (GCMs) and many downscaling methods can provide high resolution data, and add value in, for example, regions of complex topography, it is not a given that there will be more value in the final climate change message. This partially depends upon how the higher resolution data were obtained. For example, simple approaches such as spatial interpolation or adding climate changes from GCMs to observed data fields do increase the spatial resolution but add no new information on high resolution climate change. Nonetheless, these data sets are useful for running impacts models. Many impacts settings are somewhat tuned to a certain resolution, such as the nested size categorizations of hydrologic basins down to watershed size, commonly used in hydrologic modeling. Using dynamical or statistical downscaling methods will add a new high resolution component, providing extra confidence that sub-GCM scale processes are being represented more accurately. However, , there are new errors associated with the additional method applied which need to be considered. More importantly, if downscaling is applied to only one or two GCMs then the resulting high resolution scenarios will not span the full range of projected changes that a large GCM ensemble would indicate are plausible futures. Spanning that full range is important in being able to properly sample the uncertainty of the climate as it applies in an impacts context. Thus for many applications, such as understanding the full envelope of possible impacts resulting from our current best estimates of regional climate change, lower resolution data may be more informative. At the end of the day, no one data set is best, and it is through the integration of multiple sources of information that robust understanding of change is developed. What is important in many climate change impacts contexts is appropriately sampling the full range of known uncertainties, regardless of spatial resolution. It is through the integration of multiple sources of information that robust understanding of change is developed.

Cross-Chapter Box

Box CC-RC. Regional Climate Summary Figures

[Noah Diffenbaugh (USA), Dáithí Stone (Canada / South Africa / USA), Peter Thorne (USA / Norway / UK), Filippo Giorgi (Italy), Bruce Hewitson (South Africa), Richard Jones (UK), Geert Jan van Oldenborgh (Netherlands)]

Information about the likelihood of regional climate change, assessed by WGI, is foundational for the Working Group II assessment of climate-related risks. To help communicate this assessment, the regional chapters of WGII present a coordinated set of regional climate figures, which summarize observed and projected change in annual average temperature and precipitation during the near-term and the longer-term for RCP2.6 and RCP8.5. These WGII regional climate summary figures use the same temperature and precipitation fields that are assessed in WGI Chapter 2 and WGI Chapter 12, with spatial boundaries, uncertainty metrics, and data classes tuned to support the WGII assessment of climate-related risks and options for risk management. Additional details on regional climate and regional climate processes can be found in WGI Chapter 14 and WGI Annex 1.

The WGII maps of observed annual temperature and precipitation use the same source data, calculations of data sufficiency, and calculations of trend significance as WGI Chapter 2 and WGI Figures SPM.1 and SPM.2. (A full description of the observational data selection and significance testing can be found in WGI Box 2.2.) Observed trends are determined by linear regression over the 1901-2012 period of MLOST for annual temperature, and over the 1951-2010 period of GPCC for annual precipitation. Data points on the maps are classified into three categories, reflecting the categories used in WGI Figures SPM.1 and SPM.2:

1) Solid colors indicate areas where (i) sufficient data exist to permit a robust estimate of the trend (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period), and (ii) the trend is significant at the 10% level (after accounting for autocorrelation effects on significance testing).
2) Diagonal lines indicate areas where sufficient data exist to permit a robust estimate of the trend, but the trend is not significant at the 10% level.
3) White indicates areas where there are not sufficient data to permit a robust estimate of the trend.

The WGII maps of projected annual temperature and precipitation are based on the climate model simulations from Phase 5 of the Coupled Model Intercomparison Project (CMIP5) (Taylor et al., 2012), which also form the basis for the figures presented in WGI (including WGI Chapter 12, Chapter 14, and Annex I). The CMIP5 archive includes output from atmosphere-ocean general circulation models (AOGCMs), AOGCMs with coupled vegetation and/or carbon cycle components, and AOGCMs with coupled atmospheric chemistry components. The number of models from which output is available, and the number of realizations of each model, varies between the different CMIP5 experiments.

The WGII regional climate maps use the same source data as WGI Chapter 12 (e.g., Box 12.1 Figure 1), including the WGI multi-model mean values; the WGI individual model values; the WGI measure of baseline (“internal”) variability; and the WGI time periods for the reference (1986-2005), mid-21st-century (2046-2065), and late-21st-century (2081-2100) periods. The full description of the selection of models, the selection of realizations, the definition of internal variability, and the interpolation to a common grid can be found in WGI Chapter 12 and Annex 1.

In contrast to Phase 3 of the Coupled Model Intercomparison Project (CMIP3) (Meehl et al., 2007), which used the IPCC SRES emission scenarios (IPCC, 2000), CMIP5 uses the Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011) to characterize possible trajectories of climate forcing over the 21st century. The WGII regional climate projection maps include RCP2.6 and RCP8.5, which represent the high and low end of the RCP range at the end of the 21st century. Projected changes in global mean temperature are similar across the RCPs over the next few decades (Figure RC-1; WGI Fig. 12.5). During this near-term era of committed climate change, risks will evolve as socioeconomic trends interact with the changing climate. In addition, societal responses, particularly adaptations, will influence near-term outcomes. In the second half of the 21st century and beyond, the magnitude of global temperature increase diverges across the RCPs (Figure RC-1; WGI Fig. 12.5). For this longer-term era of climate options, near-term and ongoing mitigation and adaptation, as well as development pathways, will determine the risks of climate change. The benefits of mitigation and adaptation thereby occur over different timeframes, and present-day choices thus affect the risks of climate change throughout the 21st century.

[INSERT FIGURE RC-1 HERE
Figure RC-1: Observed and projected changes in global annual average temperature. Values are expressed relative to 1986-2005. Black lines show the GISTEMP, NCDC-MLOST, and HadCRUT4.2 estimates from observational measurements. Colored shading denotes the ±1.64 standard deviation range based on simulations from 32 models for RCP2.6 (blue) and 39 models for RCP8.5 (red). Blue and red lines denote the scenario mean for RCP2.6 and RCP8.5, respectively.]

The projection maps plot differences in annual average temperature and precipitation between the future and reference periods (Figure RC-2 and Figure RC-3), categorized into four classes. The classes are constructed based on the IPCC uncertainty guidance, providing a quantitative basis for assigning likelihood (Mastrandrea et al., 2010), with "likely" defined as 66-100% and "very likely" defined as 90-100%.

The classifications in the WGII regional climate projection figures are based on two aspects of likelihood (e.g., WGI Box 12.1 and Knutti et al. (2010)). The first is the likelihood that projected changes exceed differences arising from internal climate variability (e.g., Tebaldi et al. (2011)). The second is agreement among models on the sign of change (e.g., Christensen et al. (2007) and IPCC (2012)).

The four classifications of projected change depicted in the WGII regional climate maps are:

1) Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability, and >90% of models agree on sign of change. These criteria (and the areas that fall into this category) are identical to the highest-confidence category in WGI Box 12.1. This category supersedes other categories in the WGII regional climate maps.
2) Colors with white dots indicate areas with strong agreement, where >66% of models show change greater than the baseline variability, and >66% of models agree on sign of change.
3) Gray indicates areas with divergent changes, where >66% of models show change greater than the baseline variability, but <66% agree on sign of change.
4) Colors with diagonal lines indicate areas with little or no change, where >66% of models show change less than the baseline variability. It should be noted that areas that fall in this category for the annual average could still exhibit significant change at seasonal, monthly and/or daily timescales.

[INSERT FIGURE RC-2 HERE
Figure RC-2: Observed and projected changes in annual average temperature. (A) Observed temperature trends from 1901-2012 are determined by linear regression. Trends have been calculated where sufficient data permit a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Solid colors indicate areas where change is significant at the 10% level (after accounting for autocorrelation effects on significance testing). Diagonal lines indicate areas where change is not significant. Observed data are from WGI AR5 Figures SPM.1 and 2.21. The range of grid-point values is -0.53 to +2.50°C over period. (B) CMIP5 multi-model mean projections of annual average temperature changes for 2046-2065 and 2081-2100 under RCP2.6 and RCP8.5, relative to 1986-2005. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability and >90% of models agree on the sign of change. Colors with white dots indicate areas with strong agreement, where >66% of models show change greater than the baseline variability and >66% of models agree on the sign of change. Gray indicates areas with divergent changes, where >66% of models show change greater than the baseline variability, but <66% agree on the sign of change. Colors with diagonal lines indicate areas with little or no change, where >66% of models show change less than the baseline variability (although there may be significant change at shorter timescales such as seasons, months, or days). Analysis uses model data from WGI AR5 Figure SPM.8, Box 12.1, and Annex I. The range of grid-point values for the multi-model mean is: +0.19 to +4.08˚C for mid-21st century of RCP2.6; +0.06 to +3.85˚C for late-21st century of RCP2.6; +0.70 to +7.04˚C for mid-21st century of RCP8.5; and +1.38 to +11.71°C for late-21st century of RCP8.5.]

[INSERT FIGURE RC-3 HERE
Figure RC-3: Observed and projected changes in annual average precipitation. (A) Observed precipitation trends from 1951-2010 are determined by linear regression. Trends have been calculated where sufficient data permit a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Solid colors indicate areas where change is significant at the 10% level (after accounting for autocorrelation effects on significance testing). Diagonal lines indicate areas where change is not significant. Observed data are from WGI AR5 Figures SPM.2. The range of grid-point values is -185 to +111 mm/year/decade. (B) CMIP5 multi-model mean projections of annual average precipitation changes for 2046-2065 and 2081-2100 under RCP2.6 and RCP8.5, relative to 1986-2005. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability and >90% of models agree on the sign of change. Colors with white dots indicate areas with strong agreement, where >66% of models show change greater than the baseline variability and >66% of models agree on the sign of change. Gray indicates areas with divergent changes, where >66% of models show change greater than the baseline variability, but <66% agree on the sign of change. Colors with diagonal lines indicate areas with little or no change, where >66% of models show change less than the baseline variability (although there may be significant change at shorter timescales such as seasons, months, or days). Analysis uses model data from WGI AR5 Figure SPM.8, Box 12.1, and Annex I. The range of grid-point values for the multi-model mean is: -10 to +24% for mid-21st century of RCP2.6; -9 to +22% for late-21st century of RCP2.6; -19 to +57% for mid-21st century of RCP8.5; and -34 to +112% for late-21st century of RCP8.5.]

Box CC-RC References

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Table 21-1: Dimensions of the institutions and actors involved in climate change decision-making, including example entries referred to in chapters of this volume. Vertical integration can occur within as well as between levels. Decison-making domains are illustrative. Modified and extended from Mickwitz (2009).

Coherent policies and decision-making

Multi-level organisation and governance

Level: / Domain:	Economy	Energy	Food/fibre	Technology	Environment	...
Global	IMF/WB WTO MDGs NGOs	IEA NGOs	FAO WTO CLOS (fisheries) NGOs	WIPO NGOs	UNFCCC CBD Montreal Protocol NGOs	
Trans-national	MFIs/MDBs BFIs OECD/EU CLOS (transport)	OPEC Electric grid operators Oil/gas distributor	AFTA COMESA MERCOSUR EU CAP/CFP	Multi-nationals R&D EU Innovation Union	CLRTAP MRC LVBC EU Directives	
National	Ministry/Gov. Dept./Agency Banks Taxation	Ministry/Gov. Dept./Agency Energy provider Energy regulator	Ministry/Gov. Dept./Agency Tariffs, Quotas, Regulations	Ministry/Gov. Dept./Agency Education/R&D/ Innovation	Ministry/Gov. Dept./Agency Environmental law	
Sub-national	State/Province/ County/City Taxation	State/Province/ County/City Public/private energy provider	State/Province/ County/City Extension service Land use planning	State/Province/ County/City Incentives, Science parks	State/Province/ County/City Protected areas Regional offices	
Local	Micro-finance, Co-operative, Employer, Voter, Consumer	Renewables Producer, Voter, Consumer	Farmer, Forester, Fisher, Landowner, Voter, Consumer	Entrepreneur, Invester, Voter, Consumer	Environmentalist, Landowner, Voter, Consumer	

Acronyms: IMF – International Monetary Fund; WB – World Bank; WTO – World Trade Organization; MDGs – Millennium Development Goals, NGO – Non-governmental Organization; MDBs – Multilateral Development Banks; MFIs Multilateral Financial Institutions; BFIs – Bilateral Finance Institutions; ECD – Organisation for Economic Co-operation and Development; EU – European Union; CLOS – United Nations Convention on the Law of the Sea; IEA – International Energy Agency; OPEC – Organization of the Petroleum Exporting Countries; FAO – Food and Agriculture Organization of the United Nations; AFTA – Association of Southeast Asian Nations (ASEAN) Free Trade Area; COMESA – Common Market for Eastern and Southern Africa; MERCOSUR – Mercado Común del Sur (Southern Common Market); CAP/CFP – Common Agricultural Policy/Common Fisheries Policy; WIPO – World Intellectual Property Organization, UNFCCC – United Nations Framework Convention on Climate Change; CBD – Convention on Biological Diversity; CLRTAP – Convention on Long-range Transboundary Air Pollution (Europe, N. America, C. Asia); MRC – Mekong River Commission For Sustainable Development; Lake Victoria Basin Commission.

Table 21-2: 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 x 60° longitude grid boxes
		Impacts: Agriculture by continent (7 regions); Ecosystem impacts for 4 biomes; water resources for case study regions; Oceans and Coastal Zones treated separately
		Responses: Emissions scenarios by 5 economic groupings; Energy and Industry by 9 regions; Coastal Zone and Wetlands by 20 world regions
Supplements to FAR [4, 5]	1992	*Climate*: IS92 emissions scenarios by 7 world regions
		Impacts: Agriculture by continent (6 regions); Ocean Ecology by 3 latitude zones; Questionnaire to governments on current activities on impacts by 6 WMO regions
***SR**: Climate Change 1994* [6]	1994	Evaluation of IS92 emissions scenarios by 4 world regions: OECD, USSR/E. Europe, China/Centrally Planned Asia and Other.
Second Assessment Report (SAR) [7, 8, 9]	1995	*Climate*: Gridded proportional circle maps for observed climate trends (5° latitude/ longitude); climate projections for 7 sub-continental regions
		Impacts, Adaptations, Mitigation: Energy production statistics by 10 world regions; Forests, Wood Production and Management by three zones: Tropical, Temperate, Boreal; separate chapters by physiographic types: Deserts, Mountain Regions, Wetlands, Cryosphere, Oceans, and Coastal Zones and small islands; country case studies, Agriculture by 8 continental-scale regions; Energy supply by 8 world regions
		Economic and Social Dimensions: Social Costs and Response Options by 6 economic regions
***SR**: Regional Impacts* [10]	1998	10 continental-scale regions: Africa, Arctic and Antarctic, Australasia, Europe, Latin America, Middle East and Arid Asia, North America, Small Island States, Temperate Asia, Tropical Asia. Subdivisions applied in some regions; Vegetation shifts mapped by 9 biomes; Baseline (1990) Socio-Economic data provided by country and for all regions except polar.
***SR**: Land-Use Change and Forestry* [11]	1998	9 Biomes; 15 land-use categories; National and Regional case studies.
***SR**: Aviation* [12]	1999	Observed and projected emissions by 22 regional air routes; Inventories by 5 economic regions
***SR**: Technology Transfer* [13]	2000	Country case studies; Indicators of technology transfer by 6-7 economic regions
***SR**: Emissions Scenarios* [14]	2000	4 SRES world regions defined in common across integrated assessment models; 11 sub-regions; Driving Factors by 6 continental regions
Third Assessment Report (TAR) [15, 16, 17]	2001	*Climate*: gridded observations of Climate trends; 20 example Glaciers; 9 Biomes for Carbon Cycle; Circulation Regimes for model evaluation; 23 "Giorgi" regions for regional climate projections
		Impacts, adaptation and vulnerability: Example projections from 32 "modified-Giorgi" regions; Basins by continent; 5 Coastal types; Urban/Rural Settlements; Insurance by economic regions; 8 continental-scale regions equivalent to 1998 Special report but with single chapter for Asia; Subdivisions used for each region (Africa, Asia and Latin America by climate zones; North America by 6 core regions and 3 border regions)
		Mitigation: Country examples; Developed (Annex I) and Developing (non-Annex I); Various economic regions; Policies, Measures and Instruments by 4 blocs: OECD, Economies in Transition, China and Centrally Planned Asia, and Rest of the World.
***SR**: Ozone Layer* [18]	2005	Various economic regions/countries depending on sources and uses of chemicals;
***SR**: Carbon Capture and Storage* [19]	2005	CO_2 sources by 9 economic regions; potential storage facilities: by geological formation, by oil/gas wells, by ocean depth,; costs, by 4 economic groupings

Fourth Assessment Report (AR4) [20, 21, 22]	2007	*Climate*: Land-use types for surface forcing of climate; Observations by 19 "Giorgi" regions; Modes of variability for Model Evaluation; Attribution of climate change by 22 "Giorgi-type" regions and by 6 ocean regions; Climate statistics for 30 "Giorgi-type" regions; PDFs of projections for 26 regions; summary graphs for 8 continental regions
		Impacts, adaptation and vulnerability: Studies reporting observed impacts by 7 IPCC regions; comparison of TAR and AR4 climate projections for 32 Giorgi regions; Ecosystems by 11 biomes; Agriculture by latitudinal zone; Examples of Coastal mega-Deltas; Industry and settlement by continetal region; 8 continental regions, as in TAR, but Small Islands not Small Island States; Sub-regional summary maps for each region, using physiographic, biogeographic or geographic definitions; Example vulnerability maps at sub-national scale and globally by country.
		Mitigation: 17 global economic regions for GDP; Energy supply by continent, by economic regions, by 3 UNFCCC groupings; Trends in CO_2 emissions (and projections) , waste and carbon balance by economic regions.
SR*: Renewable Energy Sources and Climate Change Mitigation* [23]	2012	Global maps showing potential resources for renewable energy: land suitability for bioenergy production, global irradiance for solar, geoethermal, hydropower, ocean waves/tidal range, wind); Various economic/continental regions: installed capacity (realised vs. potential), types of technologies, investment cost, cost effectiveness, various scenario-based projections; Country comparisons of deployment and uptake of technologies, share of energy market.
SR*: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [24]	2012	Trends in observed (tables) and projected (maps and tables) climate extremes (Tmax, Tmin, heat waves, heavy precipitation and dryness) by 26 sub-continental regions covering most land areas of the globe; Attribution studies of return periods of extreme temperatures for 15 "Giorgi-type" regions; Gridded global maps of projected extremes of temperature, precipitation, windspeed, dry spells and soil moisture anomalies; Continental-scale estimates of projected changes in impacts of extremes (floods, cyclones, coastal inundation) as well as frequencies of observed climate extremes and their estimated costs); Distinctions drawn between local, country and international/global actors with respect to risk management and its financing.
Fifth Assessment Report (AR5) [25, 26, 27]	2014	*Climate*: Gridded global maps of observed changes in climate; Cryosphere observations from 19 glacierized regions and 3 Arctic permafrost zones; Paleoclimatic reconstructions for 7 continental regions; CO_2 fluxes for 11 land and 10 ocean regions; Observed aerosol concentrations for 6 continental regions and projections for 9 regions; Detection and attribution of changes in mean and extreme climate for 7 continental and 8 ocean regions; Climate model evaluation and multi-model projections of extremes for 26 sub-continental regions; Maps and time series of seasonal and annual multi-model simulated climate changes for 19 sub-continental regions and global over 1900-2100.
		Impacts, adaptation and vulnerability – Part A Global and sectoral aspects: Gridded global maps of water resources, species distributions, ocean productivity; Global map of 51 ocean biomes; Detection and attribution of observed impacts, key risks and vulnerabilities and adaptation synthesis by IPCC regions. *Part B Regional aspects:* Nine continental-scale regions, eight as in AR4 plus the ocean; Sub-regions in Africa (5), Europe (5), Asia (6), Central and South America (5 or 7); Polar (2); Small Islands (4), Oceans (7); Other disaggregation by gridded maps or countries.
		Mitigation: Economic statistics by development (3 or 5 categories) or by income; 5 country groupings (plus international transport) for emission-related scenario analysis (RCP5: OECD 1990 countries, Reforming Economies, Latin America and Caribbean, Middle East and Africa, Asia) with further disaggregation to 10 regions (RCP10) for regional development; Land use regions for forest (13) and agriculture (11); Most other analyses by example countries.

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 (2012b); 24. IPCC (2012a); 25. IPCC (2014b); 26. This assessment; 27. IPCC (2014a).

Table 21-3: Two possible entry points for thinking about vulnerability to climate change (illustrative and adapted from Füssel 2007).

Context	**Climate change impacts perspective**	**Vulnerability perspective**
Root problem	Climate change	Social vulnerability
Policy context	Climate change mitigation, compensation, technical adaptation	Social adaptation, sustainable development
Illustrative policy question	What are the benefits of climate change mitigation?	How can the vulnerability of societies to climatic hazards be reduced?
Illustrative research question	What are the expected net impacts of climate change in different regions?	Why are some groups more affected by climatic hazards than others?
Vulnerability and adaptive capacity	Adaptive capacity determines vulnerability	Vulnerability determines adaptive capacity
Reference for adaptive capacity	Adaptation to future climate change	Adaptation to current climate variability
Starting point of analysis	Scenarios of future climate change	Current vulnerability to climatic variabilty
Analytical function	Descriptive, positivist	Explanatory, normative
Main discipline	Natural science	Social science
Meaning of 'vulnerability'	Expected net damage for a given level of global climate change	Susceptibility to climate change and variability as determined by socioeconomic factors
Vulnerability approach	Integrated, risk-hazard	Political economy
Reference	IPCC (2001a)	Adger (1999)

Table 21-4: Illustrative examples of adaptation experience, as well as approaches to reduce vulnerability and enhance resilience. Adaptation actions can be influenced by climate variability, extremes, and change, and by exposure and vulnerability at the scale of risk management. Many examples and case studies demonstrate complexity at the level of communities or specific regions within a country. It is at this spatial scale that complex interactions between vulnerabilities, inequalities, and climate change come to the fore. At the same time, place-based examples illustrate how larger-level drivers and stressors shape differential risks and livelihood trajectories, often mediated by institutions.

Early warning systems for heat
EXPOSURE AND VULNERABILITY: Factors affecting exposure and vulnerability include age, pre-existing health status, level of outdoor activity, socioeconomic factors including poverty and social isolation, access to and use of cooling, physiological and behavioral adaptation of the population, urban heat island effects, and urban infrastructure. [8.2.3-4, 11.3.3-4, 11.4.1, 11.7, 13.2.1, 19.3.2, 23.5.1, 25.3, 25.8.1, SREX Table SPM.1]
CLIMATE INFORMATION AT THE GLOBAL SCALE: **Observed:** *Very likely* decrease in the number of cold days and nights and increase in the number of warm days and nights, on the global scale between 1951 and 2010. [WGI AR5 2.6.1] *Medium confidence* that the length and frequency of warm spells, including heat waves, has increased globally since 1950. [WGI AR5 2.6.1] **Projected:** *Virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global mean temperatures increase, for events defined as extremes on both daily and seasonal timescales. [WGI AR5 12.4.3]
CLIMATE INFORMATION AT THE REGIONAL SCALE: **Observed:** *Likely* that heat wave frequency has increased since 1950 in large parts of Europe, Asia, and Australia. [WGI AR5 2.6.1] *Medium confidence* in overall increase in heat waves and warm spells in North America since 1960. Insufficient evidence for assessment or spatially varying trends in heat waves or warm spells for South America and most of Africa. [SREX Table 3-2; WGI AR5 2.6.1] **Projected:** *Likely* that, by the end of the 21st century under RCP8.5 in most land regions, a current 20-year high temperature event will at least double its frequency and in many regions occur every two years or annually, while a current 20-year low temperature event will become exceedingly rare. [WGI AR5 12.4.3] *Very likely* more frequent and/or longer heat waves or warm spells over most land areas. [WGI AR5 12.4.3]
DESCRIPTION: Heat-health early warning systems are instruments to prevent negative health impacts during heat waves. Weather forecasts are used to predict situations associated with increased mortality or morbidity. Components of effective heatwave and health warning systems include identifying weather situations that adversely affect human health, monitoring weather forecasts, communicating heatwave and prevention responses, targeting notifications to vulnerable populations, and evaluating and revising the system to increase effectiveness in a changing climate. Warning systems for heat waves have been planned and implemented broadly, for example in Europe, the United States, Asia, and Australia. [11.7.3, 24.4.6, 25.8.1, 26.6, Box 25-6]
BROADER CONTEXT: •Heat health warning systems can be combined with other elements of a health protection plan, for example building capacity to support communities most at risk, supporting and funding health services, and distributing public health information. •In Africa, Asia, and elsewhere, early warning systems have been used to provide warning of and reduce a variety of risks, related to famine and food insecurity; flooding and other weather-related hazards; exposure to air pollution from fire; and vector-borne and food-borne disease outbreaks. [7.5.1, 11.7,15.4.2, 22.4.5, 24.4.6, 25.8.1, 26.6.3, Box 25-6]
Mangrove restoration to reduce flood risks and protect shorelines from storm surge
EXPOSURE AND VULNERABILITY : Loss of mangroves increases exposure of coastlines to storm surge, coastal erosion, saline intrusion, and tropical cyclones. Exposed infrastructure, livelihoods, and people are vulnerable to associated damage. Areas with development in the coastal zone, such as on small islands, can be particularly vulnerable. [5.4.3, 5.5.6, 29.7.2, Box CC-EA]
CLIMATE INFORMATION AT THE GLOBAL SCALE: **Observed:** *Likely* increase in the magnitude of extreme high sea level events since 1970, mostly explained by rising mean sea

level. [WGI AR5 3.7.5] *Low confidence* in long-term (centennial) changes in tropical cyclone activity, after accounting for past changes in observing capabilities. [WGI AR5 2.6.3] **Projected:** *Very likely* significant increase in the occurrence of future sea level extremes by 2050 and 2100. [WGI AR5 13.7.2] In the 21st century, *likely* that the global frequency of tropical cyclones will either decrease or remain essentially unchanged. *Likely* increase in both global mean tropical cyclone maximum wind speed and rainfall rates. [WGI AR5 14.6]
CLIMATE INFORMATION AT THE REGIONAL SCALE: **Observed:** Change in sea level relative to the land (relative sea level) can be significantly different from the global mean sea level change because of changes in the distribution of water in the ocean and vertical movement of the land. [WGI AR5 3.7.3] **Projected:** *Low confidence* in region-specific projections of storminess and associated storm surges. [WGI AR5 13.7.2] Projections of regional changes in sea level reach values of up to 30% above the global mean value in the Southern Ocean and around North America, and between 10% to 20% above the global mean value in equatorial regions. [WGI AR5 13.6.5] *More likely than not* substantial increase in the frequency of the most intense tropical cyclones in the western North Pacific and North Atlantic. [WGI AR5 14.6]
DESCRIPTION: Mangrove restoration and rehabilitation has occurred in a number of locations (e.g., Vietnam, Djibouti, and Brazil) to reduce coastal flooding risks and protect shorelines from storm surge. Restored mangroves have been shown to attenuate wave height and thus reduce wave damage and erosion. They protect aquaculture industry from storm damage and reduce saltwater intrusion. [2.4.3, 5.5.4, 8.3.3, 22.4.5, 27.3.3]
BROADER CONTEXT: •Considered a low-regrets option benefiting sustainable development, livelihood improvement, and human well-being through improvements for food security and reduced risks from flooding, saline intrusion, wave damage, and erosion. Restoration and rehabilitation of mangroves, as well as of wetlands or deltas, is ecosystem-based adaptation that enhances ecosystem services. •Synergies with mitigation given that mangrove forests represent large stores of carbon. •Well-integrated ecosystem-based adaptation can be more cost effective and sustainable than non-integrated physical engineering approaches. [5.5, 8.4.2, 14.3.1, 24.6, 29.3.1, 29.7.2, 30.6.1-2, Table 5-4, Box CC-EA]
Community-based adaptation and traditional practices in small island contexts
EXPOSURE AND VULNERABILITY: With small land area, often low elevation coasts, and concentration of human communities and infrastructure in coastal zones, small islands are particularly vulnerable to rising sea levels and impacts such as inundation, saltwater intrusion, and shoreline change. [29.3.1, 29.3.3, 29.6.1-2, 29.7.2]
CLIMATE INFORMATION AT THE GLOBAL SCALE: **Observed:** *Likely* increase in the magnitude of extreme high sea level events since 1970, mostly explained by rising mean sea level. [WGI AR5 3.7.5] *Low confidence* in long-term (centennial) changes in tropical cyclone activity, after accounting for past changes in observing capabilities. [WGI AR5 2.6.3] Since 1950 the number of heavy precipitation events over land has *likely* increased in more regions than it has decreased. [WGI AR5 2.6.2] **Projected:** *Very likely* significant increase in the occurrence of future sea level extremes by 2050 and 2100. [WGI AR5 13.7.2] In the 21st century, *likely* that the global frequency of tropical cyclones will either decrease or remain essentially unchanged. *Likely* increase in both global mean tropical cyclone maximum wind speed and rainfall rates. [WGI AR5 14.6] Globally, for short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms. [WGI AR5 12.4.5]
CLIMATE INFORMATION AT THE REGIONAL SCALE: **Observed:** Change in sea level relative to the land (relative sea level) can be significantly different from the global mean sea level change because of changes in the distribution of water in the ocean and vertical movement of the land. [WGI AR5 3.7.3] **Projected:** *Low confidence* in region-specific projections of storminess and associated storm surges. [WGI AR5 13.7.2] Projections of regional changes in sea level reach values of up to 30% above the global mean value in the Southern Ocean and around North America, and between 10% to 20% above the global mean value in equatorial regions. [WGI AR5 13.6.5] *More likely than not* substantial increase in the frequency of the most intense tropical cyclones in the western North Pacific and North Atlantic. [WGI AR5 14.6]
DESCRIPTION:

Traditional technologies and skills can be relevant for climate adaptation in small island contexts. In the Solomon Islands, relevant traditional practices include elevating concrete floors to keep them dry during heavy precipitation events and building low aerodynamic houses with palm leaves as roofing to avoid hazards from flying debris during cyclones, supported by perceptions that traditional construction methods are more resilient to extreme weather. In Fiji after cyclone Ami in 2003, mutual support and risk sharing formed a central pillar for community-based adaptation, with unaffected households fishing to support those with damaged homes. Participatory consultations across stakeholders and sectors within communities and capacity building taking into account traditional practices can be vital to the success of adaptation initiatives in island communities, such as in Fiji or Samoa. [29.6.2]

BROADER CONTEXT:

• Perceptions of self-efficacy and adaptive capacity in addressing climate stress can be important in determining resilience and identifying useful solutions.

•The relevance of community-based adaptation principles to island communities, as a facilitating factor in adaptation planning and implementation, has been highlighted, for example with focus on empowerment and learning-by-doing, while addressing local priorities and building on local knowledge and capacity. Community-based adaptation can include measures that cut across sectors and technological, social, and institutional processes, recognizing that technology by itself is only one component of successful adaptation.
[5.5.4, 29.6.2]

Adaptive approaches to flood defense in Europe

EXPOSURE AND VULNERABILITY :

Increased exposure of persons and property in flood risk areas has contributed to increased damages from flood events over recent decades.
[5.4.3-4, 5.5.5, 23.3.1, Box 5-1]

CLIMATE INFORMATION AT THE GLOBAL SCALE:

Observed: *Likely* increase in the magnitude of extreme high sea level events since 1970, mostly explained by rising mean sea level. [WGI AR5 3.7.5]

Since 1950 the number of heavy precipitation events over land has *likely* increased in more regions than it has decreased. [WGI AR5 2.6.2]

Projected: *Very likely* that the time-mean rate of global mean sea level rise during the 21st century will exceed the rate observed during 1971-2010 for all RCP scenarios. [WGI AR5 13.5.1]

Globally, for short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms. [WGI AR5 12.4.5]

CLIMATE INFORMATION AT THE REGIONAL SCALE:

Observed: *Likely* increase in the frequency or intensity of heavy precipitation in Europe, with some seasonal and/or regional variations. [WGI AR5 2.6.2] Increase in heavy precipitation in winter since the 1950s in some areas of northern Europe (*medium confidence*). Increase in heavy precipitation since the 1950s in some parts of west-central Europe and European Russia, especially in winter (*medium confidence*). [SREX Table 3-2]

Increasing mean sea level with regional variations, except in the Baltic sea where the relative sea level is decreasing due to vertical crustal motion. [5.3.2, 23.2.2]

Projected: Over most of the mid-latitude land-masses, extreme precipitation events will *very likely* be more intense and more frequent in a warmer world. [WGI AR5 12.4.5]

Overall precipitation increase in northern Europe and decrease in southern Europe (*medium confidence*). [23.2.2]

Increased extreme precipitation in northern Europe during all seasons, particularly winter, and in central Europe except in summer (*high confidence*). [23.2.2; SREX Table 3-3]

DESCRIPTION:

Several governments have made ambitious efforts to address flood risk and sea level rise over the coming century. In the Netherlands, government recommendations include “soft” measures preserving land from development to accommodate increased river inundation, maintaining coastal protection through beach nourishment, and ensuring necessary political-administrative, legal, and financial resources. Through a multi-stage process, the British government has also developed extensive adaptation plans to adjust and improve flood defenses in order to protect London from future storm surges and river flooding. Pathways have been analyzed for different adaptation options and decisions, depending on eventual sea level rise, with ongoing monitoring of the drivers of risk informing decisions. [5.5.4, 23.7.1, Box 5-1]

BROADER CONTEXT:

•The Dutch plan is considered a paradigm shift, addressing coastal protection by “working with nature” and providing “room for

river."
•The British plan incorporates iterative, adaptive decisions depending on the eventual sea level rise with numerous and diverse measures possible over the next 50-100 years to reduce risk to acceptable levels.
• In cities in Europe and elsewhere, the importance of strong political leadership or government champions in driving successful adaptation action has been noted.
[5.5.3-4, 8.4.3, 23.7.1-2, 23.7.4, Boxes 5-1 and 26-3]

Index-based insurance for agriculture in Africa

EXPOSURE AND VULNERABILITY:
Susceptibility to food insecurity and depletion of farmers' productive assets following crop failure. Low prevalence of insurance due to absent or poorly developed insurance markets or to amount of premium payments. The most marginalized and resource-poor especially may have limited ability to afford insurance premiums. [10.7.6, 13.3.2, Box 22-1]

CLIMATE INFORMATION AT THE GLOBAL SCALE:
Observed: *Very likely* decrease in the number of cold days and nights and increase in the number of warm days and nights, on the global scale between 1951 and 2010. [WGI AR5 2.6.1]
Medium confidence that the length and frequency of warm spells, including heat waves, has increased globally since 1950. [WGI AR5 2.6.1]
Since 1950 the number of heavy precipitation events over land has *likely* increased in more regions than it has decreased. [WGI AR5 2.6.2]
Low confidence in a global-scale observed trend in drought or dryness (lack of rainfall). [WGI AR5 2.6.2]
Projected: *Virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global mean temperatures increase, for events defined as extremes on both daily and seasonal timescales. [WGI AR5 12.4.3]
Regional to global-scale projected decreases in soil moisture and increased risk of agricultural drought are *likely* in presently dry regions, and are projected with *medium confidence* by the end of this century under the RCP8.5 scenario. [WGI AR5 12.4.5]
Globally, for short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms. [WGI AR5 12.4.5]

CLIMATE INFORMATION AT THE REGIONAL SCALE:
Observed: *Medium confidence* in increase in frequency of warm days and decrease in frequency of cold days and nights in southern Africa. [SREX Table 3-2]
Medium confidence in increase in frequency of warm nights in northern and southern Africa. [SREX Table 3-2]
Projected: *Likely* surface drying in southern Africa by the end of this century under RCP8.5 (*high confidence*). [WGI AR5 12.4.5]
Likely increase in warm days and nights and decrease in cold days and nights in all regions of Africa (*high confidence*). Increase in warm days largest in summer and fall (*medium confidence*). [Table SREX 3-3]
Likely more frequent and/or longer heat waves and warm spells in Africa (*high confidence*). [Table SREX 3-3]

DESCRIPTION:
A recently introduced mechanism that has been piloted in a number of rural locations, including in Malawi, Sudan, and Ethiopia, as well as in India. When physical conditions reach a particular predetermined threshold where significant losses are expected to occur--weather conditions such as excessively high or low cumulative rainfall or temperature peaks--the insurance pays out.
[9.4.2, 13.3.2, 15.4.4, Box 22-1]

BROADER CONTEXT:
•Index-based weather insurance is considered well-suited to the agricultural sector in developing countries.
•The mechanism allows risk to be shared across communities, with costs spread over time, while overcoming obstacles to traditional agricultural and disaster insurance markets. It can be integrated with other strategies such as micro-finance and social protection programs.
•Risk-based premiums can help encourage adaptive responses and foster risk awareness and risk reduction by providing financial incentives to policyholders to reduce their risk profile.
•Challenges can be associated with limited availability of accurate weather data and difficulties in establishing which weather conditions cause losses. Basis risk (i.e., farmers suffer losses but no payout is triggered based on weather data) can promote distrust. There can also be difficulty in scaling up pilot schemes.
•Insurance for work programs can enable cash-poor farmers to work for insurance premiums by engaging in community-identified disaster risk reduction projects.
[10.7.4-6, 13.3.2, 15.4.4, Table 10-7, Box 22-1, Box 25-7]

Relocation of agricultural industries in Australia
EXPOSURE AND VULNERABILITY : Crops sensitive to changing patterns of temperature, rainfall, and water availability. [7.3, 7.5.2]
CLIMATE INFORMATION AT THE GLOBAL SCALE: **Observed:** *Very likely* decrease in the number of cold days and nights and increase in the number of warm days and nights, on the global scale between 1951 and 2010. [WGI AR5 2.6.1] *Medium confidence* that the length and frequency of warm spells, including heat waves, has increased globally since 1950. [WGI AR5 2.6.1] *Medium confidence* in precipitation change over global land areas since 1950. [WGI AR5 2.5.1] Since 1950 the number of heavy precipitation events over land has *likely* increased in more regions than it has decreased. [WGI AR5 2.6.2] *Low confidence* in a global-scale observed trend in drought or dryness (lack of rainfall). [WGI AR5 2.6.2] **Projected:** *Virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global mean temperatures increase, for events defined as extremes on both daily and seasonal timescales. [WGI AR5 12.4.3] *Virtually certain* increase in global precipitation as global mean surface temperature increases. [WGI AR5 12.4.1] Regional to global-scale projected decreases in soil moisture and increased risk of agricultural drought are *likely* in presently dry regions, and are projected with *medium confidence* by the end of this century under the RCP8.5 scenario. [WGI AR5 12.4.5] Globally, for short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms. [WGI AR5 12.4.5]
CLIMATE INFORMATION AT THE REGIONAL SCALE: **Observed:** Cool extremes rarer and hot extremes more frequent and intense over Australia and New Zealand, since 1950 (*high confidence*). [Table 25-1] *Likely* increase in heat wave frequency since 1950 in large parts of Australia. [WGI AR5 2.6.1] Late autumn/winter decreases in precipitation in Southwestern Australia since the 1970s and Southeastern Australia since the mid-1990s, and annual increases in precipitation in Northwestern Australia since the 1950s (*very high confidence*). [Table 25-1] Mixed or insignificant trends in annual daily precipitation extremes, but a tendency to significant increase in annual intensity of heavy precipitation in recent decades for sub-daily events in Australia (*high confidence*). [Table 25-1] **Projected:** Hot days and nights more frequent and cold days and nights less frequent during the 21st century in Australia and New Zealand (*high confidence*). [Table 25-1] Annual decline in precipitation over southwestern Australia (*high confidence*) and elsewhere in southern Australia (*medium confidence*). Reductions strongest in the winter half-year (*high confidence*). [Table 25-1] Increase in most regions in the intensity of rare daily rainfall extremes and in sub-daily extremes (*medium confidence*) in Australia and New Zealand. [Table 25-1] Drought occurrence to increase in Southern Australia (*medium confidence*). [Table 25-1] Snow depth and snow area to decline in Australia (*very high confidence*). [Table 25-1] Freshwater resources projected to decline in far southeastern and far southwest Australia (*high confidence*). [25.5.2]
DESCRIPTION: Industries and individual farmers are relocating parts of their operations, for example for rice, wine, or peanuts in Australia, or are changing land use in situ in response to recent climate change or expectations of future change. For example, there has been some switching from grazing to cropping in South Australia. Adaptive movement of crops has also occurred elsewhere. [7.5.1, 25.7.2, Table 9-7, Box 25-5]
BROADER CONTEXT: •Considered transformational adaptation in response to impacts of climate change. •Positive or negative implications for the wider communities in origin and destination regions. [25.7.2, Box 25-5]

Table 21-5: Dimensions of assessments of impacts and vulnerability and of adaptation drawn upon to serve different target fields (cf. Table 21-1). Scales refer to the level of aggregation at which study results are presented. Entries are illustrations of different types of study approaches reported and evaluated in this volume, with references given both to the original studies and to the chapters in which they are cited. Aspects of some of the studies in this table are also alluded to in Section 21.5.

Approach/field: **Scale:**	**Impacts/vulnerability**	**Adaptation**	**Target field**
Global	Resource availability[1,2,3] Impact costs[4,5,6,7] Vulnerability/risk mapping[8,9,10] Hotspots analysis[11]	Adaptation costs[4,5,6,7,12]	- Policy negotiations - Development aid - Disaster planning - Capacity building
Continental/ biome	Observed impacts[13,14,15] Future biophysical impacts[16,17] Impact costs[5,16] Vulnerability/risk mapping[18]	Adaptation costs[5] Modelled adaptation[19]	- Capacity building - International law - Policy negotiations - Regional development
National/ state/province	Observed impacts[20,21,22] Future impacts/risks[23,24] Vulnerability assessment[24] Impact costs[25]	Observed adaptation[26] Adaptation assessment[24,27]	- National adaptation plan/strategy - Nat. Communication - Legal requirement - Regulation
Municipality/ basin/patch/ delta/farm	Hazard/risk mapping[28] Pest/disease risk mapping[29] Urban risks/vulnerabilities[30]	Adaptation cost[28] Urban adaptation[30,31]	- Spatial planning - Extension services - Water utilities - Private sector
Site/field/tree/ floodplain/ household	Field experiments[32]	Coping studies[33,34] Economic modelling[35] Agent-based modelling[36]	- Individual actors - Local planners

Notes for Table 21-5

[1] Global terrestrial water balance, in the Water Model Intercomparison Project (Haddeland *et al*., 2011), see chapter 3
[2] Global dynamic vegetation model intercomparison (Sitch *et al*., 2008), see chapter 4
[3] Impacts on agriculture, coasts, water resources, ecosystems and health in the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP – Schiermeier, 2012), see chapter 19
[4] UNFCCC study to estimate the aggregate cost of adaptation (UNFCCC, 2007), which is critiqued by Parry (2009) and Fankhauser (2010)
[5] The Economics of Adaptation to Climate Change study (World Bank, 2010)
[6] Chapter 17 provides a thorough evaluation of global modelling studies (see also chapters 14 and 16)
[7] Impacts on agriculture and costs of adaptation (e.g. Nelson *et al*., 2009), see chapter 7
[8] Can we avoid dangerous climate change? (AVOID) programme and Quantifying and Understanding the Earth System (QUEST) Global-scale impacts of climate change (GSI) project (Arnell *et al*., 2013), see chapter 19
[9] OECD project on Cities and Climate Change (Hanson *et al*., 2011), see chapters 5, 23, 24 and 26
[10] For critical reviews of global vulnerability studies, see Füssel (2010) and Preston et al.(2011)
[11] A discussion of hotspots can be found in section 21.5.1.2
[12] Adaptation costs for climate change-related human health impacts (Ebi, 2008), see chapter 17
[13] Satellite monitoring of sea ice over polar regions (Comiso and Nishio, 2008), see also Vaughan *et al*. (2014) and chapters 18 and 28
[14] Satellite monitoring of vegetation growth (e.g., Piao *et al*., 2011) and phenology (e.g., Heumann *et al*., 2007), see chapters 4 and 18
[15] Meta-analysis of range shifts in terrestrial organisms (e.g., Chen *et al*., 2011), see chapters 4 and 18
[16] Physical and economic impacts of future climate change in Europe (Ciscar *et al*., 2011), see chapter 23
[17] Impacts on crop yields in West Africa (Roudier *et al*., 2011), see chapter 22
[18] Climate change integrated methodology for cross-sectoral adaptation and vulnerability in Europe (CLIMSAVE) project (Harrison *et al*., 2012), see chapter 23
[19] Modelling agricultural management under climate change in sub-Saharan Africa (Waha *et al*., 2013)
[20] Satellite monitoring of lake levels in China (Wang *et al*., 2013)

[21] Satellite monitoring of rice phenology in India (Singh *et al*., 2006), see chapter 18
[22] UK Climate Change Risk Assessment (CCRA, 2012), see chapter 23
[23] United States Global Change Research Program second (Karl *et al*., 2009) and third (in review) national climate change impact assessments, see chapter 26
[24] The Global Environment Facility (GEF)-funded Assessments of Impacts and Adaptations to Climate Change (AIACC) program addressed impacts and vulnerability (Leary *et al*., 2008b) and adaptation (Leary *et al*., 2008a) in developing countries, see chapter 27
[25] Economics of Climate Change national studies in Kenya and Tanzania (SEI, 2009; GCAP, 2011), see chapter 22
[26] Sowing dates of various crops in Finland (Kaukoranta and Hakala, 2008), and see chapter 18
[27] Finnish Climate Change Adaptation Research Programme (ISTO) Synthesis Report (Ruuhela, 2012)
[28] Urban flood risk and adaptation cost, Finland (Perrels *et al*., 2010)
[29] See Garrett (2013) for a specific example of a risk analysis, or Sutherst (2011) for a review – and see chapter 25
[30] New York City coastal adaptation (Rosenzweig *et al*., 2011), see chapters 8 and 26
[31] Bangkok Assessment Report of Climate Change (BMA/GLF/UNEP, 2009), see chapters 8 and 24
[32] Field, chamber and laboratory plant response experiments (e.g., Long *et al*., 2006; Hyvönen *et al*., 2007; Wittig *et al*., 2009; Craufurd *et al*., 2013), see chapters 4 and 7
[33] Farming response to irrigation water scarcity in China (Liu *et al*., 2008) and see chapter 13
[34] Farmers' mechanisms for coping with hurricanes in Jamaica (Campbell and Beckford, 2009) and see chapter 29
[35] Modelling micro-insurance of subsistence farmers for drought losses in Ethiopia (Meze-Hausken *et al*., 2009), see chapter 14
[36] Simulating adaptive behaviour of farming communities in the Philippines (Acosta-Michlik and Espaldon, 2008), see chapter 24

Table 21-6: Reliability of climate information on temperature and precipitation over a range of spatial and temporal scales. Reliability is assigned to one of seven broad categories from Very High (VH) to Medium (M) through to Very Low (VL).

Scale	**Temporal**	**Annual**		**Seasonal-Monthly**		**Daily**	
Spatial	**Variable** / **Era**	**Temp**	**Precip**	**Temp**	**Precip**	**Temp**	**Precip**
Global	Past	VH	H	VH	H	N/A	N/A
	Future change	VH – direction H – amount	H – direction MH – amount	VH – direction H – amount	H – direction MH – amount	N/A	N/A
Regional, Large river basin	Past	VH-H depends on observation availability	H-L depends on observation availability	VH-H depends on observation availability	H-L depends on observation availability	VH-H depends on observation availability	H-L depends on observation availability
	Future change	VH – direction H – amount	H-L depends on capture of processes	VH – direction MH – amount	H-L depends on capture of processes	VH – direction MH – amount	H-L depends on capture of processes
National, State	Past	VH-H depends on observation availability	H-L depends on observation availability	VH-H depends on observation availability	H-L depends on observation availability	VH-H depends on observation availability	H-VL depends on observation availability
	Future change	VH – direction MH – amount	H-L depends on capture of processes	VH – direction MH – amount	H-L depends on capture of processes	H – direction MH – amount	H-VL depends on capture of processes
City, County	Past	VH-M depends on observation availability	H-VL depends on observation availability	VH-M depends on observation availability	H-VL depends on observation availability	H-ML depends on observation availability	H-VL depends on observation availability
	Future change	H – direction MH – amount	H-VL depends on capture of processes	H – direction MH – amount	H-VL depends on capture of processes	H – direction M – amount	M-VL depends on capture of processes
Village, Site/field	Past	VH-ML depends on observation availability	H-VL depends on observation availability	VH-ML depends on observation availability	H-VL depends on observation availability	H-ML depends on observation availability	H-VL depends on observation availability
	Future change	H – direction MH – amount	H-VL depends on capture of processes	H – direction MH – amount	H-VL depends on capture of processes	H – direction M – amount	M-VL depends on capture of processes

Table 21-7: An assessment of observed and projected future changes in temperature and precipitation extremes over 26 sub-continental regions as defined in the SREX report (IPCC 2012; see also Figure 21.4 and Table SM21.2). Confidence levels are indicated by colour coding of the symbols. Likelihood terms are given only for high confidence statements and are specified in the text. Observed trends in temperature and precipitation extremes, including dryness, are generally calculated from 1950, using the period 1961-1990 as a baseline (see Box 3.1 chapter 3 of IPCC (2012a)). The future changes are derived from global and regional climate model projections of the climate of 2071-2100 compared with 1961-1990 or 2080-2100 compared with 1980-2000. Table entries are summaries of information in Tables 3.2 and 3.3 of IPCC (2012a) supplemented with or superseded by material from Chapters 2 (section 2.6 and Table 2.13) and 14 (section 14.4) of the IPCC AR5 WG1 report and Table 25-1 of the IPCC WG2 report. The source(s) of information for each entry are indicated by the superscripts a (Table 3.2 of IPCC, 2012a), b (Table 3.3 of IPCC, 2012a), c (Chapter 2 (section 2.6 and Table 2.13) IPCC AR5 WG1 report), d (Chapter 14 (section 14.4) of the IPCC AR5 WG1 report) and e (Table 25-1 of the IPCC WG2 report).

Region/ region code	Trends in daytime temperature extremes (frequency of hot and cool days)		Trends in nighttime temperature extremes (frequency of warm and cold nights)		Trends in heat waves/warm spells		Trends in heavy precipitation (rain, snow)		Trends in dryness and drought	
	Observed	Projected	Observed	Projected	Observed	Projected	Observed	Projected	Observed	Projected
West North America WNA, 3	*Very likely* large increases in hot days (large decreases in cool days)[a]	*Very likely* increase in hot days (decrease in cool days)[b]	*Very likely* large decreases in cold nights (large increases in warm nights)[a]	*Very likely* increase in warm nights (decrease in cold nights)[b]	Increase in warm spell duration[a]	*Likely* more frequent, longer and/or more intense heat waves and warm spells[b]	Spatially varying trends. General increase, decrease in some areas[a]	Increase in 20-year return value of annual maximum daily precipitation and other metrics over northern part of the region (Canada)[b] Less confidence in Southern part of the region, due to inconsistent signal in these other metrics[b]	No or overall slight decrease in dryness[a]	Inconsistent signal[b]
Central North America CNA, 4	Spatially varying trends: small increases in hot days in the north, decreases in the south[a]	*Very likely* increase in hot days (decrease in cool days)[b]	Spatially varying trends: Small increase in cold nights (and decreases in warm nights) in south and vice versa in the north[a]	*Very likely* increase in warm nights (decrease in cold nights)[b]	Spatially varying trends[a]	*Likely* more frequent, longer and/or more intense heat waves and warm spells[b]	*Very likely* increase since 1950[a]	Increase in 20-year return value of annual maximum daily precipitation[b] Inconsistent signal in other heavy precipitation days metrics[b]	*Likely* decrease[a, c]	Increase in consecutive dry days and soil moisture in southern part of Central North America[b] Inconsistent signal in the rest of the region[b]
East North America ENA, 5	Spatially varying trends. Overall increases in hot days (decreases in cool days), opposite or insignificant signal in a few areas[a]	*Very likely* increase in hot days (decrease in cool days)[b]	Weak and spatially varying trends[a]	*Very likely* increase in warm nights (decrease in cold nights)[b]	Spatially varying trends, many areas with increase in duration, some areas with decrease[a]	*Likely* more frequent, longer and/or more intense heat waves and warm spells[b]	*Very likely* increase since 1950[a]	Increase in 20-year return value of annual maximum daily precipitation. Additional metrics support an increase in heavy precipitation over northern part of the region[b] No signal or inconsistent signal in these other metrics in the southern part of the region[b]	Slight decrease in dryness since 1950[a]	Inconsistent signal in consecutive dry days, some consistent decrease in soil moisture[b]
Alaska/ Northwest Canada ALA, 1	*Very likely* large increases in warm days (decreases in cold days)[a]	*Very likely* increase in hot days (decrease in cool days)[b]	*Very likely* large decreases in cold nights, increases in warm nights[a]	*Very likely* increase in warm nights (decrease in cold nights)[b]	Insufficient evidence[a]	*Likely* more frequent, and/or longer heat waves and warm spells[b]	Slight tendency for increase[a] No significant trend in southern Alaska[a]	*Likely* increase in heavy precipitation[b]	Inconsistent trends[a] Increases in dryness in part of the region[a]	Inconsistent signal[b]

Key

Symbols

- Increasing trend or signal
- Decreasing trend or signal
- Both increasing and decreasing trends or signals
- Inconsistent trend or signal or insufficient evidence
- No or only slight change

Level of confidence in findings

- Low confidence
- Medium confidence
- High confidence

Region/ region code	Trends in daytime temperature extremes (frequency of hot and cool days)		Trends in nighttime temperature extremes (frequency of warm and cold nights)		Trends in heat waves/warm spells		Trends in heavy precipitation (rain, snow)		Trends in dryness and drought	
	Observed	Projected	Observed	Projected	Observed	Projected	Observed	Projected	Observed	Projected
East Canada, Greenland, Iceland CGI, 2	*Likely* increases in hot days (decreases in cool days) in some areas, decrease in hot days (increase in cool days) in others[a]	*Very likely* increase in warm days (decrease in cold days)[b]	Small increases in unusually cold nights and decreases in warm nights in northeastern Canada[a] Small decrease in cold nights and increase in warm nights in south-eastern/central Canada[a]	*Very likely* increase in warm nights (decrease in cold nights)[b]	Some areas with warm spell duration increase, some with decrease[a]	*Likely* more frequent, and/or longer heat waves and warm spells[b]	Increase in a few areas[a]	*Likely* increase in heavy precipitation[b]	Insuffcient evidence[a]	Inconsistent signal[b]
Northern Europe NEU, 11	Increase in hot days (decrease in cool days), but generally not significant at the local scale[a]	*Very likely* increase in hot days (decrease in cool days) [but smaller trends than in central and southern Europe][b]	Increase in warm nights (decrease in cold nights) over the whole region, but generally not significant at the local scale[a]	*Very likely* increase in warm nights (decrease in cold nights)[b]	Increase in heat waves. Consistent tendency for increase in heat wave duration and intensity, but no significant trend[a]	*Likely* more frequent, longer and/or more intense heat waves/ warm spells, but summer increases smaller than in southern Europe[b] Little change over Scandinavia[b]	Increase in winter in some areas, but often insignificant or inconsistent trends at subregional scale, particularly in summer[a]	*Likely* increase in 20-year return value of annual maximum daily precipitation. *Very likely* increases in heavy preciptation intensity and frequency in winter in the north[b]	Spatially varying trends. Overall only slight or no increase in dryness, slight decrease in dryness in part of the region[a]	No major changes in dryness[b]
Central Europe CEU, 12	*Likely* overall increase in hot days (decrease in cool days) since 1950 in most regions. *Very likely* increase in hot days (likely decrease in cool days) in west Central Europe[a] Lower confidence in trends in east Central Europe (due to lack of literature, partial lack of access to observations, overall weaker signals, and change point in trends)[a]	*Very likely* increase in hot days (decrease in cool days)[b]	*Likely* overall increase in warm nights (decrease in cold nights) at the yearly timescale. Some regional and seasonal variations in significance and in a few cases sign of trends. *Very likely* increase in warm nights (decrease in cold nights) in west Central Europe[a] Lower confidence in trends in east Central Europe (due to lack of literature, partial lack of access to observations, overall weaker signals, and change point in trends)[a]	*Very likely* increase in warm nights (decrease in cold nights)[b]	Increase in heat waves. Consistent increase in heat wave duration and intensity, but no significant trend. Significant increase in maximum heatwave duration in west Central Europe in summer[a]	*Likely* more frequent, longer and/or more intense heat waves/ warm spells[b]	Increase in part of the region, in particular central Western Europe and European Russia, especially in winter[a] Insignificant or inconsistent trends elsewhere, in particular in summer[a]	*Likely* increase in 20-year return value of annual maximum daily precipitation. Additional metrics support an increase in heavy precipitation in large part of the region over winter[b] Less confidence in summer, due to inconsistent evidence[b]	Spatially varying trends. Increase in dryness in part of the region but some regional variation in dryness trends and dependence of trends on studies considered (index, time period)[a]	Increase in dryness in central Europe and increase in short-term droughts[b]
Southern Europe and Mediterra-nean MED, 13	*Likely* increase in hot days (decrease in cool days) in most of the region. Some regional and temporal variations in the significance of the trends. Likely strongest and most significant trends in Iberian peninsula and southern France[a] Smaller or less significant trends in southeastern Europe and Italy due to change point in trends, strongest increase in hot days since 1976[a]	*Very likely* increase in hot days (decrease in cool days)[b]	*Likely* increase in warm nights (decrease in cold nights) in most of the region. Some regional variations in the significance of the trends.Very likely overall increase in warm nights (decrease in cold nights in S.W. Europe/W. Mediterranean[a]	*Very likely* increase in warm nights (decrease in cold nights)[b]	*Likely* increase in most regions[a]	*Likely* more frequent, longer and/or more intense heat waves and warm spells (*likely* largest increases in SW, S and E of the region)[b]	Inconsistent trends across the region and across studies[a]	Inconsistent changes and/or regional variations[b]	Overall increase in dryness, *likely* increase in the Mediterranean[a, c]	Increase in dryness. Consistent increase in area of drought[b, d]

Region/ region code	Trends in daytime temperature extremes (frequency of hot and cool days)		Trends in nighttime temperature extremes (frequency of warm and cold nights)		Trends in heat waves/warm spells		Trends in heavy precipitation (rain, snow)		Trends in dryness and drought	
	Observed	Projected	Observed	Projected	Observed	Projected	Observed	Projected	Observed	Projected
West Africa WAF, 15	Significant increase in temperature of hottest day and coolest day in some parts[a] Insufficient evidence in other parts[a]	*Likely* increase in hot days (decrease in cool days)[b]	Increasing frequency of warm nights. Decrease in cold nights in western central Africa, Nigeria, and Gambia[a] Insufficient evidence on trends in cold nights in other parts[a]	*Likely* increase in warm nights (decrease in cold nights)[b]	Insufficient evidence for most of the region[a]	*Likely* more frequent and/or longer heat waves and warm spells[b]	Rainfall intensity increased[a]	Slight or no change in heavy precipitation indicators in most areas[b] Low model agreement in northern areas[b]	*Likely* increase but 1970s Sahel drought dominates the trend; greater inter- annual variation in recent years[a, c]	Inconsistent signal[b]
East Africa EAF, 16	Lack of evidence due to lack of literature and spatially non-uniform trends[a] Increases in hot days in Southern tip (decrease in cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	Spatially varying trends in most areas[a] Increases in warm nights in Southern tip (decrease in cold nights)[a]	*Likely* increase in warm nights (decrease in cold nights)[b]	Insufficient evidence[a] Increase in warm spell duration in Southern tip of the region[a]	*Likely* Likely more frequent and/or longer heat waves and warm spells[b]	Insufficient evidence[a]	*Likely* increase in heavy precipitation[b]	Spatially varying trends in dryness[a]	Decreasing dryness in large areas[b]
Southern Africa SAF, 17	*Likely* increase in hot days (decrease in cool days)[a, c]	*Likely* increase in hot days (decrease in cool days)[b]	*Likely* increase in warm nights (decrease in cold nights)[a, c]	*Likely* increase in warm nights (decrease in cold nights)[b]	Increase in warm spell duration[a]	*Likely* more frequent and/or longer heat waves and warm spells[b]	Increases in more regions than decreases but spatially varying trends[a]	Lack of agreement in signal for region as a whole[b] Some evidence of increase in heavy precipitation in southeast regions[b]	General increase in dryness[a]	Increase in dryness, except eastern part[b, d] Consistent increase in area of drought[b]
Sahara SAH, 14	Lack of literature[a]	*Likely* increase in hot days (decrease in cool days)[b]	Increase in warm nights[a] Lack of literature on trends in cold nights[a]	*Likely* increase in warm nights (decrease in cold nights)[b]	Insufficient evidence[a]	*Likely* more frequent and/or longer heat waves and warm spells[b]	Insufficient evidence[a]	Low agreement[b]	Limited data, spatial variation of the trends[a]	Inconsistent signal of change[b]
Central America and Mexico CAM, 6	Increases in the number of hot days, decreases in the number of cool days[a]	*Likely* increase in hot days (decrease in cool days)[b]	Increases in number of warm nights (decrease in number of cold nights)[a]	*Likely* increase in warm nights (*likely* decrease in cold nights)[b]	Spatially varying trends (increases in some areas, decreases in others)[a]	*Likely* more frequent, longer and/or more intense heat waves/ warm spells in most of the region[b]	Spatially varying trends. Increase in many areas, decrease in a few others[a]	Inconsistent trends[b]	Varying and inconsistent trends[a]	Increase in dryness in Central America and Mexico, with less confidence in trend in extreme South of region[b]
Amazon AMZ, 7	Insufficient evidence to identify trends[a]	Hot days *likely* to increase (cool days *likely* to decrease)[b]	Insufficient evidence to identify trends[a]	*Very likely* increase in warm nights (*likely* decrease in cold nights)[b]	Insufficient evidence[a]	*Likely* more frequent and longer heat waves and warm spells[b]	Increases in many areas, decreases in a few[a]	Tendency for increases in heavy precipitation events in some metrics[b]	Decrease in dryness for much of the region. Some opposite trends and inconsistencies[a]	Inconsistent signals[b]
Northeastern Brazil NEB, 8	Increases in the number of hot days[a]	Hot days *likely* to increase (cool days *likely* to decrease)[b]	Increases in the number of warm nights[a]	*Likely* increase in warm nights (*likely* decrease in cold nights)[b]	Insufficient evidence[a]	*Likely* more frequent and longer heat waves and warm spells in some studies[b]	Increases in many areas, decreases in a few[a]	Slight or no change[b]	Varying and inconsistent trends[a]	Increase in dryness[b]
Southeast-ern South America SSA, 10	Spatially varying trends (increases in some areas decreases in others)[a]	Hot days *likely* to increase (cool days *likely* decrease)[b]	Increases in number of warm nights (decreases in number of cold nights)[a]	*Very likely* increase in warm nights (*likely* decrease in cold nights)[b]	Spatially varying trends (increases in some areas, decreases in others)[a]	Tendency for more frequent and longer heat waves and warm spells[b]	Increases in northern areas[a] Insufficient evidence in southern areas[a]	Increases in northern areas[b] Insufficient evidence in southern areas[b]	Varying and inconsistent trends[a]	Inconsistent signals[b]
West Coast South America WSA, 9	Spatially varying trends (increases in some areas decreases in others)[a]	Hot days *likely* to increase (cool days *likely* decrease)[b]	Increases in number of warm nights (decreases in number of cold nights)[a]	*Likely* increase in warm nights (*likely* decrease in cold nights)[b]	Insufficient evidence[a]	*Likely* more frequent and longer heat waves and warm spells[b]	Increases in many areas, decrease in a few areas[a]	Increases in tropics[b] Low confidence in extratropics[b]	Varying and inconsistent trends[a]	Decrease in consecutive dry days in the tropics, and increase in the extratropics[b] Increase in consecutive dry days and soil moisture in southwest South America[b]

Region/ region code	Trends in daytime temperature extremes (frequency of hot and cool days)		Trends in nighttime temperature extremes (frequency of warm and cold nights)		Trends in heat waves/warm spells		Trends in heavy precipitation (rain, snow)		Trends in dryness and drought	
	Observed	Projected	Observed	Projected	Observed	Projected	Observed	Projected	Observed	Projected
North Asia NAS, 18	*Likely* increase in hot days (decrease cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	*Likely* increase in warm nights (decrease cold nights)[a]	*Likely* increase in warm nights (decrease in cold nights)[b]	Spatially varying trends[a]	*Likely* more frequent and/or longer heat waves and warm spells[a]	Increase in some regions, but spatial variation[a]	*Likely* increase in heavy precipitation for most regions[b]	Spatially varying trends[a]	Inconsistent signal of change[b]
Central Asia CAS, 20	*Likely* increase in hot days (decrease cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	*Likely* increase in warm nights (decrease cold nights)[a]	*Likely* increase in warm nights (decrease in cold nights)[b]	Increase in warm spell duration in a few areas[a] Insufficient evidence in others[a]	*Likely* more frequent and/or longer heat waves and warm spells[b]	Spatially varying trends[a]	Inconsistent signal in models[b]	Spatially varying trends[a]	Inconsistent signal of change[b]
East Asia EAS, 22	*Likely* increase in hot days (decrease cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	Increase in warm nights (decrease cold nights)[a]	*Likely* increase in warm nights (decrease in cold nights)[b]	Increase heat wave in China[a] Increase in warm spell duration in northern China, decrease in southern China[a]	*Likely* more frequent and/or longer heat waves and warm spells[b]	Spatially varying trends[a]	Increase in heavy precipitation across the region[b]	Tendency for increased dryness[a]	Inconsistent signal of change[b]
Southeast Asia SEA, 24	Increase in hot days (decrease cool days) for northern areas[a] Insufficient evidence for Malay Archipelago[a]	*Likely* increase in hot days (decrease in cool days)[b]	Increase in warm nights (decrease cold nights) for northern areas[a] Insufficient evidence for Malay Archipelago[a]	*Likely* increase in warm nights (decrease in cold nights)[b]	Insufficient evidence[a]	*Likely* more frequent and/or longer heat waves and warm spells over continental areas[b] Low confidence in changes for some areas[b]	Spatially varying trends, partial lack of evidence[a]	Increases in most metrics over most (especially non-continental) regions. One metric shows inconsistent signals of change[b]	Spatially varying trends[a]	Inconsistent signal of change[b]
South Asia SAS, 23	Increase in hot days (decrease cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	Increase in warm nights (decrease in cold nights)[a]	*Likely* increase in warm nights (decrease in cold nights)[b]	Insufficient evidence[a]	*Likely* more frequent and/or longer heat waves and warm spells[b]	Mixed signal in India[a]	More frequent and intense heavy precipitation days over parts of S. Asia. Either no change or some consistent increases in other metrics[b]	Inconsistent signal for different studies and indices[a]	Inconsistent signal of change[b]
West Asia WAS, 19	*Very likely* increase in hot days (decrease in cool days *more likely than not*)[a]	*Likely* increase in hot days (decrease in cool days)[b]	*Likely* increase in warm nights (decrease in cold nights)[a]	*Likely* increase in warm nights (decrease in cold nights)[b]	Increase in warm spell duration[a]	*Likely* more frequent and/or longer heat waves and warm spells[b]	Decrease in heavy precipitation events[a]	Inconsistent signal of change[b]	Lack of studies, mixed results[a]	Inconsistent signal of change[b]
Tibetan Plateau TIB, 21	*Likely* increase in hot days (decrease cool days)[a]	*Likely* increase in hot days (decrease in cool days)[b]	*Likely* increase in warm nights (decrease cold nights)[a]	*Likely* increase in warm nights (decrease in cold nights)[b]	Spatially varying trends[a]	*Likely* more frequent and/or longer heat waves and warm spells[b]	Insufficient evidence[a]	Increase in heavy precipitation[b]	Insufficient evidence. Tendency to decreased dryness[a]	Inconsistent signal of change[b]
North Australia NAU, 25	*Likely* increase in hot days (decrease in cool days). Weaker trends in northwest[e]	*Very likely* increase in hot days (decrease in cool days)[b]	*Likely* increase in warm nights (decrease in cold nights)[a]	*Very likely* increase in warm nights (decrease of cold nights)[b]	Insufficient literature[a]	*Likely* more frequent and/or longer heat waves and warm spells[b]	Spatially varying trends, which mostly reflect changes in mean rainfall[e]	Increase in most regions in the intensity of extreme (i.e. current 20 year return period) heavy rainfall events[e]	No significant change in drought occurrence over Australia (defined using rainfall anomalies)[e]	Inconsistent signal[b]
South Aus- tralia/ New Zealand SAU, 26	*Very likely* increase in hot days (decrease in cool days)[a]	*Very likely* increase in hot days (decrease in cool days)[b]	*Very likely* increase in warm nights (decrease in cold nights)[a]	*Very likely* increase in warm nights (decrease in cold nights)[b]	Increase in warm spells across southern Australia[a]	*Likely* more frequent and/or longer heat waves and warm spells[b]	Spatially varying trends in S Australia, which mostly reflect changes in mean rainfall[e] Spatially varying trends in NZ, which mostly reflect changes in mean rainfall[e]	Increase in most regions in the intensity of extreme (i.e. current 20 year return period) heavy rainfall events[e]	No significant change in drought occurrence over Australia (defined using rainfall anomalies)[e] No trend in drought occurrence over New Zealand (defined using a soil water balance model) since 1972[e]	Increase in drought frequency in southern Australia, and in many regions of New Zealand[e]

Table 21-8: Leading knowledge gaps and related research needs.

	Knowledge Gap	**Research need**
1	There is no clear understanding of how to integrate the diversity of climate change projections data. The full associated uncertainty is weakly characterized and quantifying how much of an observed or simulated climate change is due to internal variability or external forcings is difficult in many situations. Collectively this results in data products with differing time and space resolution, differing dependencies and assumptions and that can have conflicting messages. At present individual products are plausible and mostly defensible in-so-far as they have physical basis within the assumptions of the method. However, at decision-relevant scales understanding where (or whether) the true outcome will lie within the range of the products collectively is often not possible and thus the products are often not strongly actionable.	Research is needed to distinguish the relative stochastic and deterministic sources of variability and change as a function of scale, variable, and application. The need is to develop further and build on physical understanding of the drivers of climate variability and change and how to represent these realistically within models to understand the source of the spread and any contradictions in the regional projections at scales relevant to users –and then to provide guidance on a likely range of outcomes within which the true response would be expected to lie. Similarly, there is a need is to articulate the real inherent uncertainty within climate projection data and to understand when climate information is useful at the scales of need. This also requires stronger dialogues with users of climate information to inform choices of variables and ways to characterize envelopes of risk and uncertainties.
2.	The growth of multi-model, multi-method, and multi-generational data for climate projections creates confusion for the IAV community. The lack of a clear approach to handling this diversity leads to choosing one or other subset, and where one choice may substantially alter the IAV conclusion compared to a different subset.	Methodological and conceptual advances are needed to facilitate the synthesis of diverse data sets on different scales from methods with different assumptions, and to integrate these into cohesive and defensible understanding of projected regional change.
3	The attributes of regional climate change through which impacts are manifest, such as the intensity, persistence, distribution, recurrence, and frequency of weather events is poorly understood. The information conveyed to the adaptation community is dominated by aggregates in time and space (e.g. SREX regional averages, or time averages), which hide the important attributes underlying these aggregated changes. In part this is a consequence of (1) above.	The research need is to be able to demonstrate how to unpack the regional projections into terms relevant for impacts and adaptation. For example, how is the shape of the distribution of weather events changing (not just the extremes), or how stable are the critical global teleconnection patterns that contribute to the variability of a region?
4	The historical record for many regions, especially those regions most vulnerable to climate change, is poor to the extent that the historical record is at best an estimate with unknown uncertainty. This severely undermines the development of regional change analysis, limits the evaluation of model skill, and presents a weak baseline against which to assess change signals or to develop impacts, adaptation or vulnerability baselines.	The research need is to integrate the multiplicity of historical data as represented by the raw observations processed gridded products (e.g. CRU and GPCP), satellite data, and reanalysis data sets. Involving national scientists with their inherent local knowledge and rescue and digitization of the many national archives still inaccessible to the wider research community would significantly enhance this research activity.
5	Impact model sensitivity studies and inter-comparison exercises are beginning to reveal fundamental flaws and omissions in some impact models in the representation of key processes that are expected to be important under projected climate changes. For example, high temperature constraints, and CO2 and drought effects on agricultural yields are poorly represented in many crop models.	Intensified efforts are needed to refine, test and inter-compare impact models over a wider range of sectors and environments than hitherto. These should be supported, where applicable, by targeted field, chamber and laboratory experiments under controlled atmospheric composition and climate conditions, to improve understanding of key physical, biological and chemical processes operating in changed environments. Such experiments are needed across a range of terrestrial and aquatic biogeographical zones in different regions of the world

6	New global scenarios are under development, based on climate projections for different representative concentration pathways (RCPs) and socio-economic scenarios based on shared socio-economic pathways (SSPs). However, there is currently little or no guidance on how these projections are to be accessed or applied in IAV studies. Moreover, as yet, quantitative SSPs are available only for large regions (basic SSPs), and regional SSPs that are consistent with the global SSPs (extended SSPs) along with scenarios that include mitigation and adaptation policies (shared policy assumptions – SPAs) have not yet been developed.,	Extended SSPs for major sub-continental regions of the world, including variables that define aspects of adaptive capacity and guidance on how to combine RCP-based regional climate projections with regional SSPs and SPAs to form plausible regional scenarios for application in IAV analysis.
7	The determinants and regional variability of vulnerability, exposure and adaptive capacity are not well understood, and methods for projecting changes in them are under-developed. Furthermore, given these lacks of understanding uncertainties of these three elements are poorly characterized and quantified	Case studies and underlying theory of these features of societies, and documentation of the effectiveness of actions taken are needed in conjunction with methods development for projections. More attention placed on determining their uncertainties, in national and regional assessments.

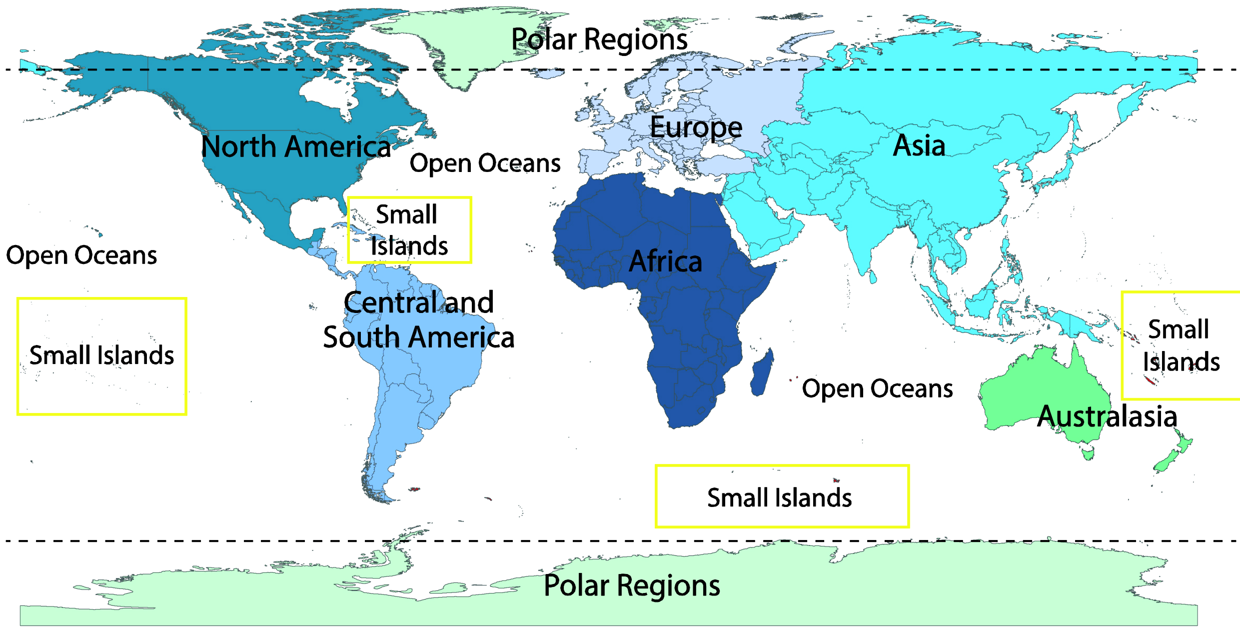

Figure 21-1: Specification of the world regions described in chapters 22-30 of this volume.
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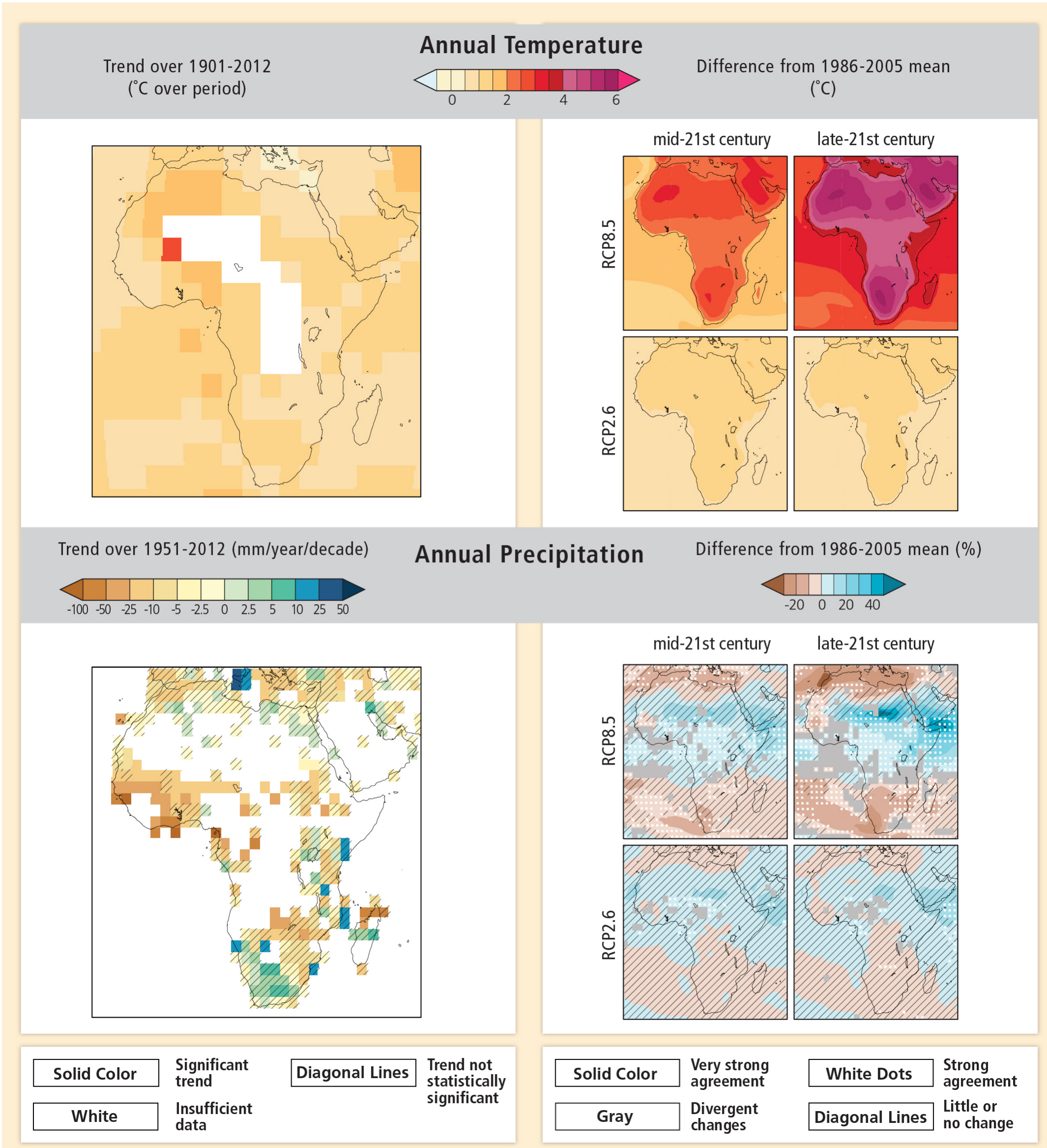

Figure 21-2: Observed and projected changes in annual average temperature and precipitation. (Top panel, left) Observed temperature trends from 1901-2012 determined by linear regression. [WGI AR5 Figures SPM.1 and 2.21] (Bottom panel, left) Observed precipitation change from 1951-2010 determined by linear regression. [WGI AR5 Figure SPM.2] For observed temperature and precipitation, trends have been calculated where sufficient data permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Solid colors indicate areas where change is significant at the 10% level. Diagonal lines indicate areas where change is not significant. (Top and bottom panel, right) CMIP5 multi-model mean projections of annual average temperature changes and average percent change in annual mean precipitation for 2046-2065 and 2081-2100 under RCP2.6 and 8.5. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability, and >90% of models agree on sign of change. Colors with white dots indicate areas with strong agreement, where >66% of models show change greater than the baseline variability and >66% of models agree on sign of change. Gray indicates areas with divergent changes, where >66% of models show change greater than the baseline variability, but <66% agree on sign of change. Colors with diagonal lines indicate areas with little or no change, less than the baseline variability in >66% of models. (There may be significant change at shorter timescales such as seasons, months, or days.). Analysis uses model data and methods building from WGI AR5 Figure SPM.8. See alsoAnnex I of WGI AR5. [Boxes 21-3 and CC-RC]

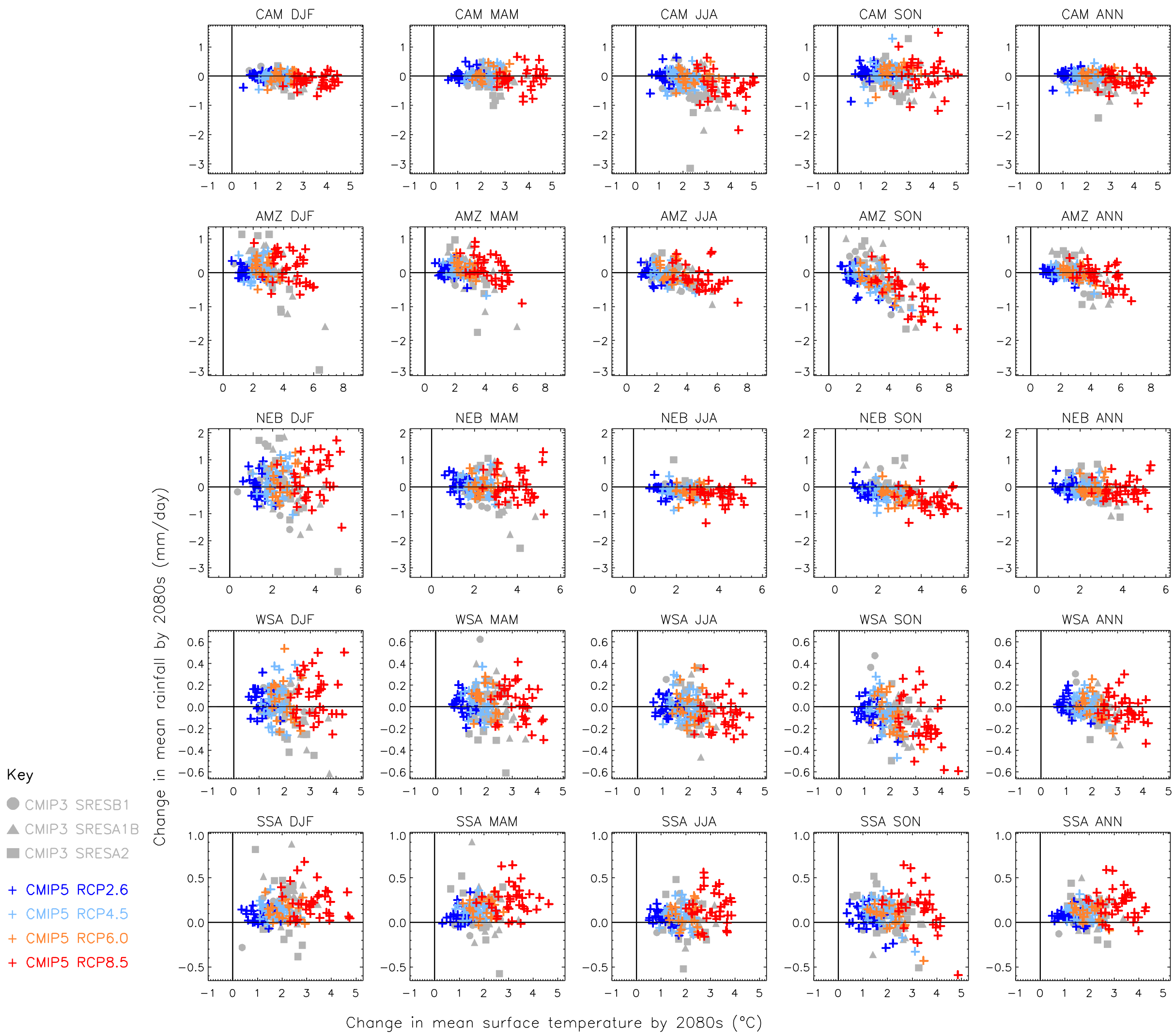

Figure 21-3: Regional average change in seasonal and annual mean temperature and precipitation over five sub-regions covering South and Central America for the period 2071-2100 relative to 1961-90 in GCM projections from 35 CMIP5 ensemble under four RCP scenarios (van Vuuren et al., 2011) compared with GCM projections from 22 CMIP3 ensemble under three SRES scenarios (IPCC, 2000); see Table 21-1 for details of the relationship between the SRES and RCP scenarios. Regional averages are based on SREX region definitions (see Figure 21-3). Temperature changes are given in ºC and precipitation changes in mm/day with axes scaled relative to the maximum changes projected across the range of models. The models which generated the data displayed are listed in supplementary material Table SM21-3.

[Illustration to be redrawn to conform to IPCC publication specifications.]

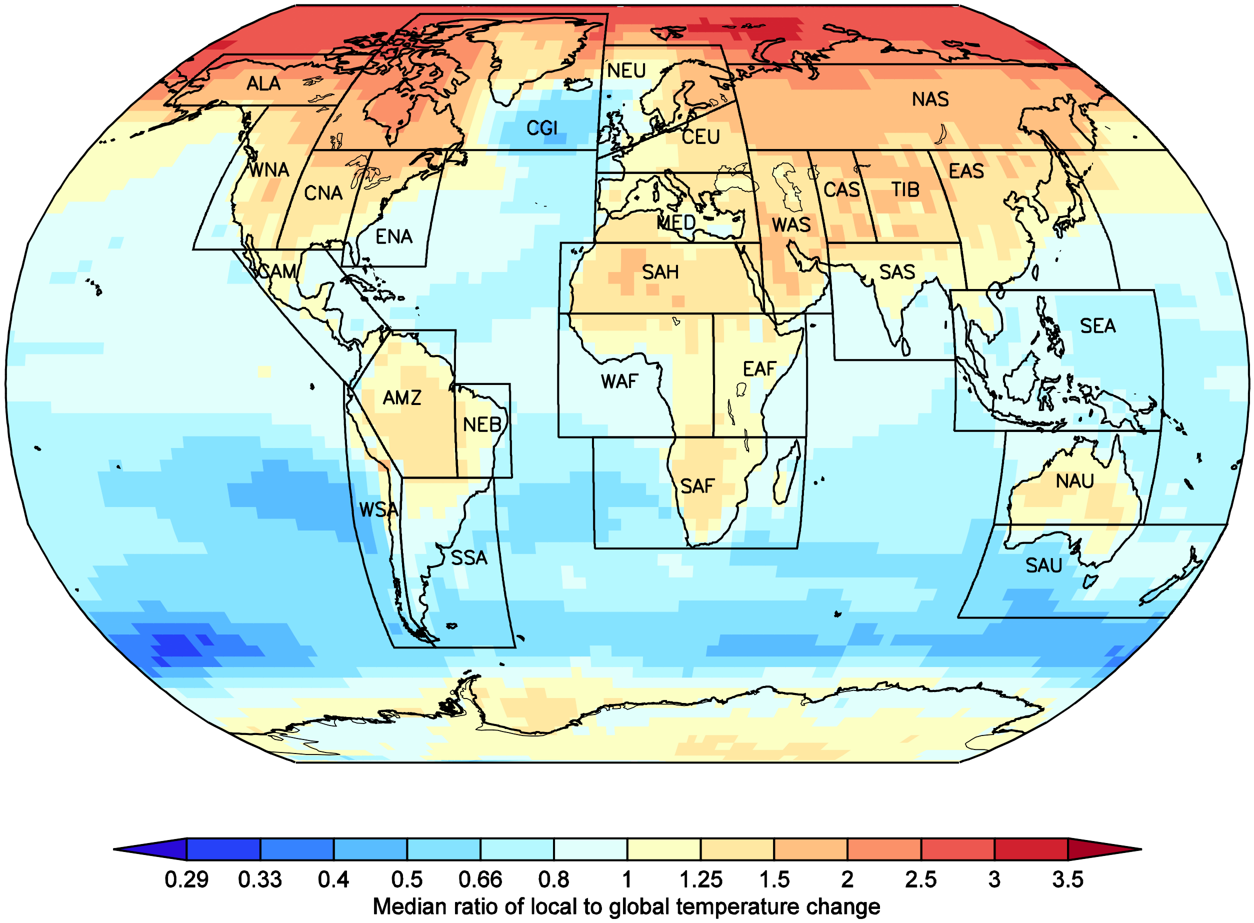

Figure 21-4: CMIP5 ensemble median ratio of local:global average temperature change in the period 2071-2100 relative to 1961-90 under the RCP8.5 emissions/concentrations scenario. The values are displayed on a common 2.5ºx3.75º grid onto which each models' data were regridded and they were calculated as follows: 1) for each model the local change was calculated between 1961 and 1990 at each grid cell, and is divided by the global average change in that model projection over the same period; 2) the median ratio value across all models at each grid cell is identified and shown. Data used are from the 35 CMIP5 models for which monthly projections were available under RCP8.5 which are listed in supplementary Table 21-3. Overplotted polygons indicate the SREX regions (IPCC, 2012) used to define the sub-regions used to summarise information in Chapters 21 and some of the subsequent regional chapters**. [Illustration to be redrawn to conform to IPCC publication specifications.]**

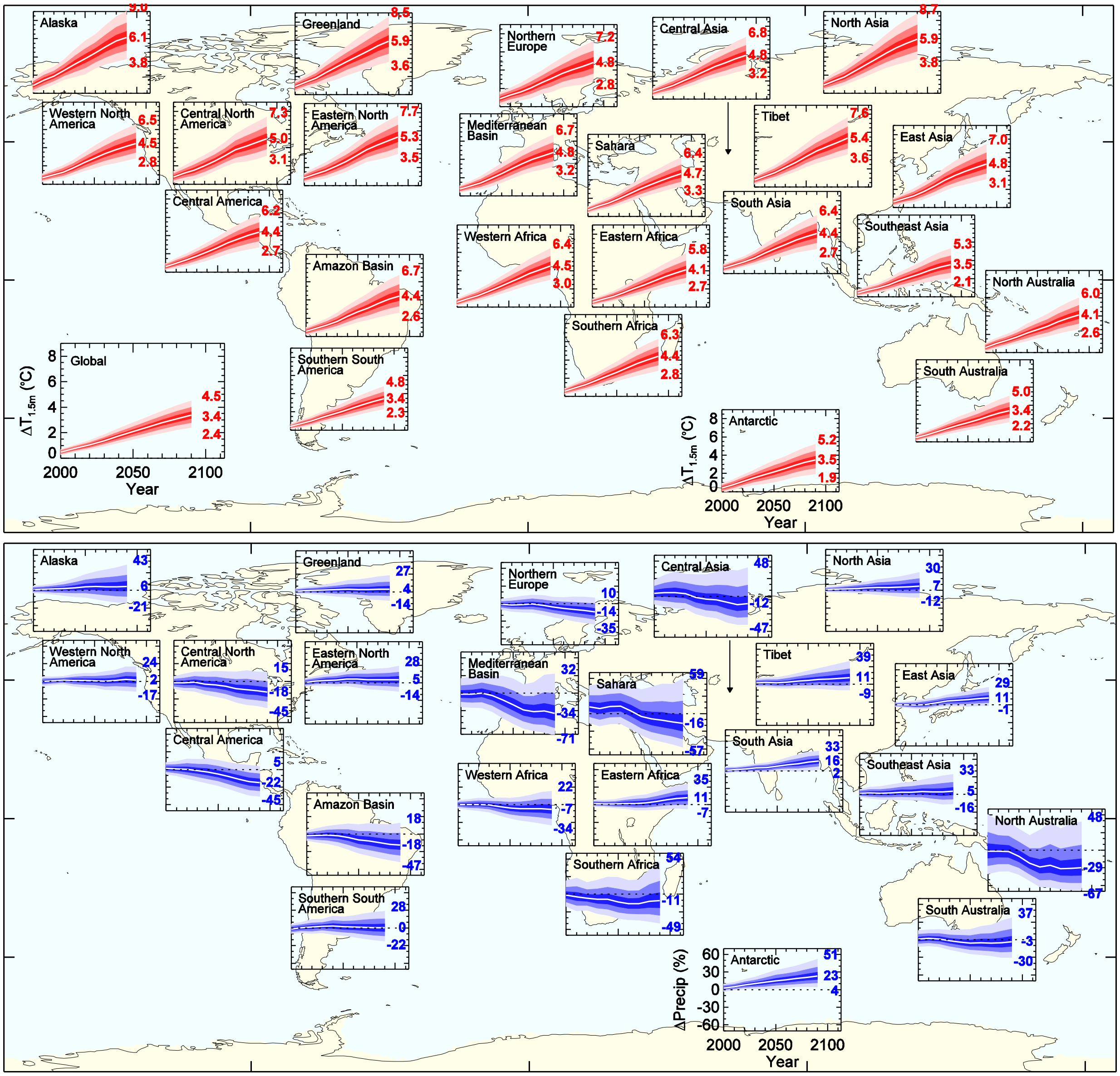

Figure 21-5: Evolution of the 5%, 17%, 33%, 50%, 66%, 83% and 95% percentiles of the distribution functions for annual surface air temperature changes (upper panel) and annual precipitation (lower panel) for the Giorgi-Francisco (2000) regions and the globe with the SRES A1B forcing scenario combining results from a perturbed physics ensemble and the CMIP3 ensemble. Twenty year means relative to the 1961-1990 baseline are plotted in decadal steps using a common y-axis scale. The 5%, 50% and 95% percentile values for the period 2080-2099 are displayed for each region. (From Harris et al. 2012).

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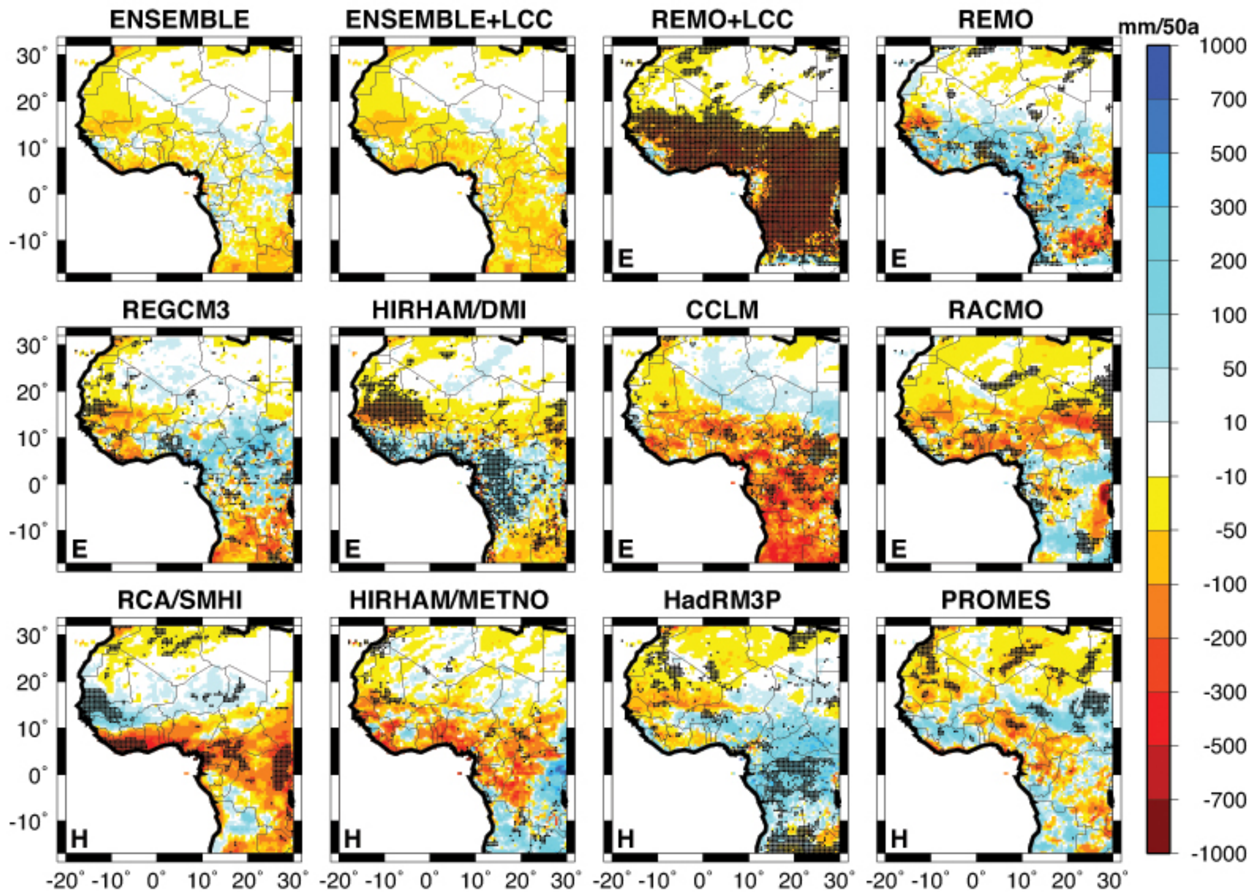

Figure 21-6: Linear changes (i.e. changes obtained by fitting the time series at each grid point with straight lines) of annual precipitation during the 2001-2050 period from 10 individual RCM experiments and the MME mean under the A1B emission scenario. The top middle panels also account for projected land cover changes (see Paeth et al. 2011 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 95% level are marked by black dots. From Paeth et al. (2011).

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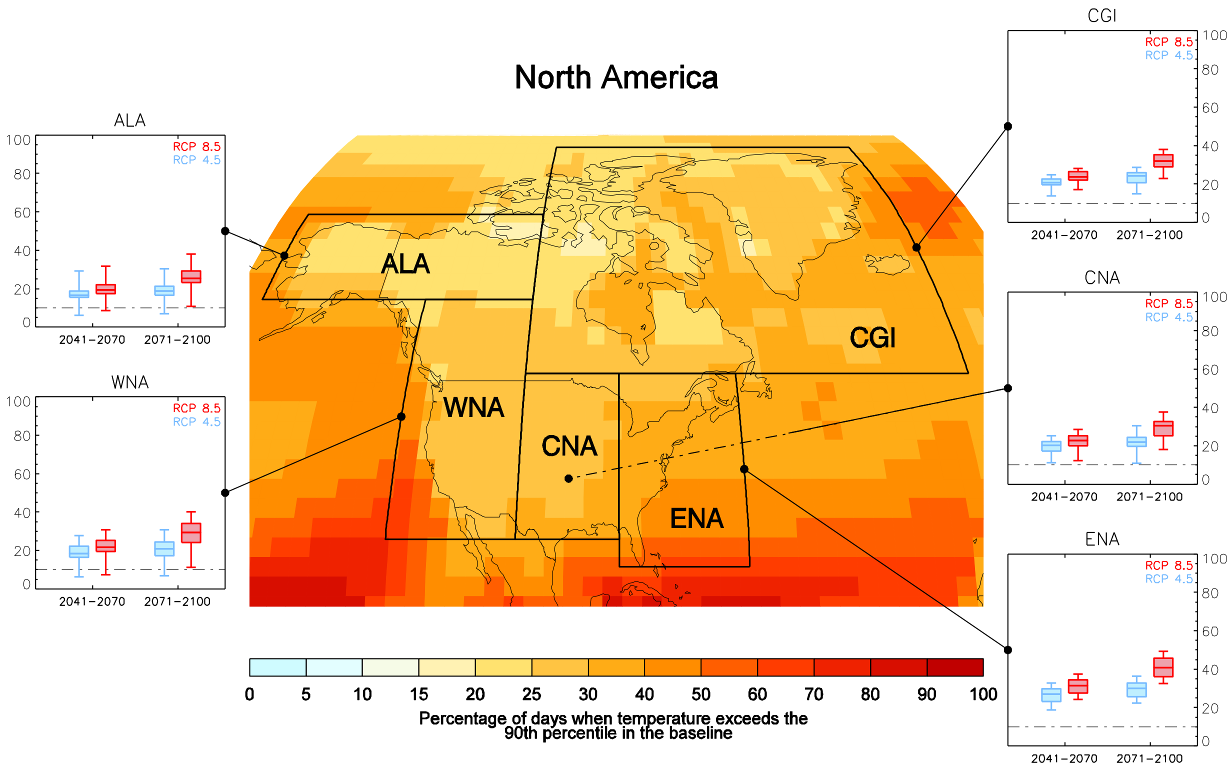

Figure 21-7: The frequency of 'warm days' (defined here as the 90th percentile daily maximum temperature during a baseline period of 1961-1990) projected for the 2071-2100 period by 26 CMIP5 GCMs for North America. Map: Ensemble median frequency of 'warm days' during 2071-2100 under RCP8.5. Graphs: Box-and-whisker plots indicate the range of regionally-averaged 'hot-day' frequency by 2041-2070 and 2071-2100 under RCPs 4.5 and 8.5 across the 26 CMIP5 models for each SREX sub-regions in North America. Boxes represent inter-quartile range and whiskers indicate full range of projections across the ensemble. The baseline frequency of 'warm days' of 10% is represented on the graphs by the dashed line. A full list of CMIP5 models for which data is shown here can be found in supplementary material Table SM21-4.

[Illustration to be redrawn to conform to IPCC publication specifications.]

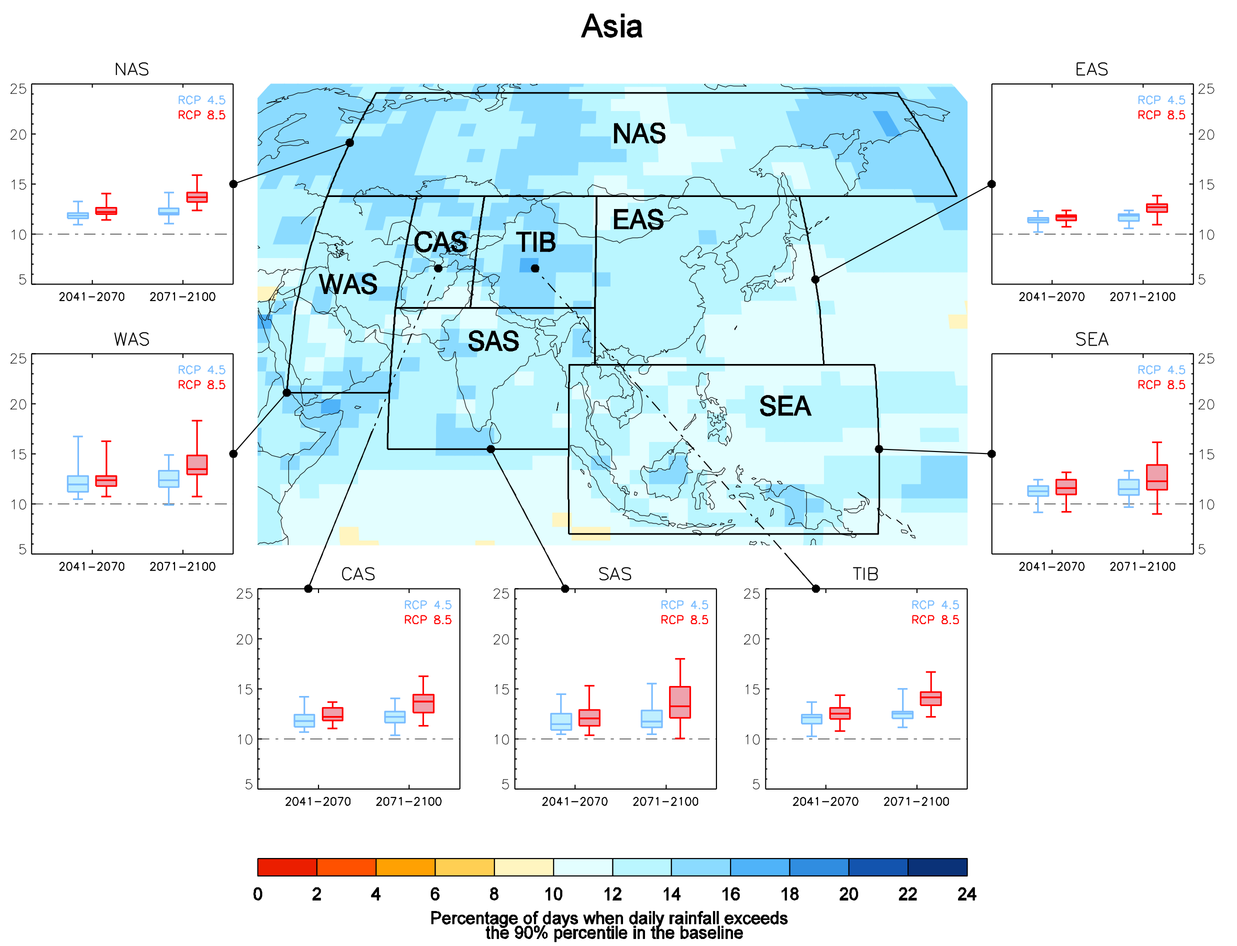

Figure 21-8: The frequency of 'very wet days' (defined here as the 90th percentile of daily precipitation on wet days during a baseline period of 1961-1990 with wet days defined as days with 1mm of precipitation or more) projected for the 2071-2100 period by 26 CMIP5 GCMs for Asia. Map: Ensemble median frequency of 'very wet days' during 2071-2100 under RCP8.5. Graphs: Box-and-whisker plots indicate the range of regionally-averaged 'very wet day' frequency by 2041-2070 and 2071-2100 under RCPs 4.5 and 8.5 across the 26 CMIP5 models for each SREX sub-regions in Asia Boxes represent inter-quartile range and whiskers indicate full range of projections across the ensemble. The baseline frequency of 'Very wet days' of 10% is represented on the graphs by the dashed line. A full list of CMIP5 models for which data is shown here can be found in supplementary material Table SM21-4. (Note the WMO Expert Team on Climate Change Detection Indices defines "very wet days" threshold as the 95%-ile daily precipitation event. **[Illustration to be redrawn to conform to IPCC publication specifications.]**

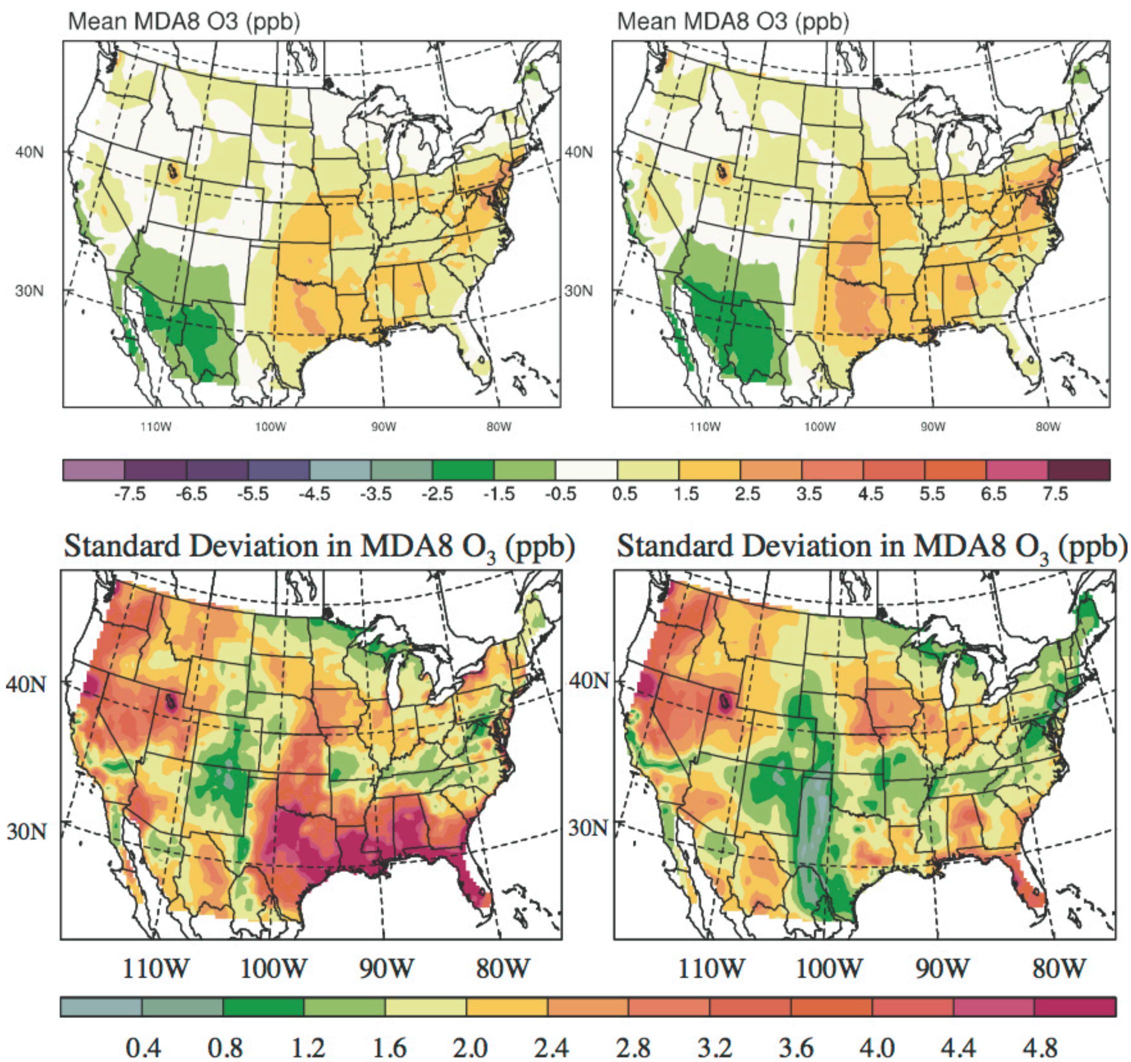

Figure 21-9: Mean (top panels) and standard deviation (bottom panels) in future-minus-present (2050s minus 1990s) MDA8 summer ozone concentrations across (left-hand panels) all seven experiments (five regional and 2 global) and for comparison purposes (right hand panels), not including the WSU experiment (which simulated July only conditions). The different experiments use different pollutant emission and SRES GHG emission scenarios. The pollutant emissions are the same in the present and future simulations (from Weaver et al., 2009).
[Illustration to be redrawn to conform to IPCC publication specifications.]

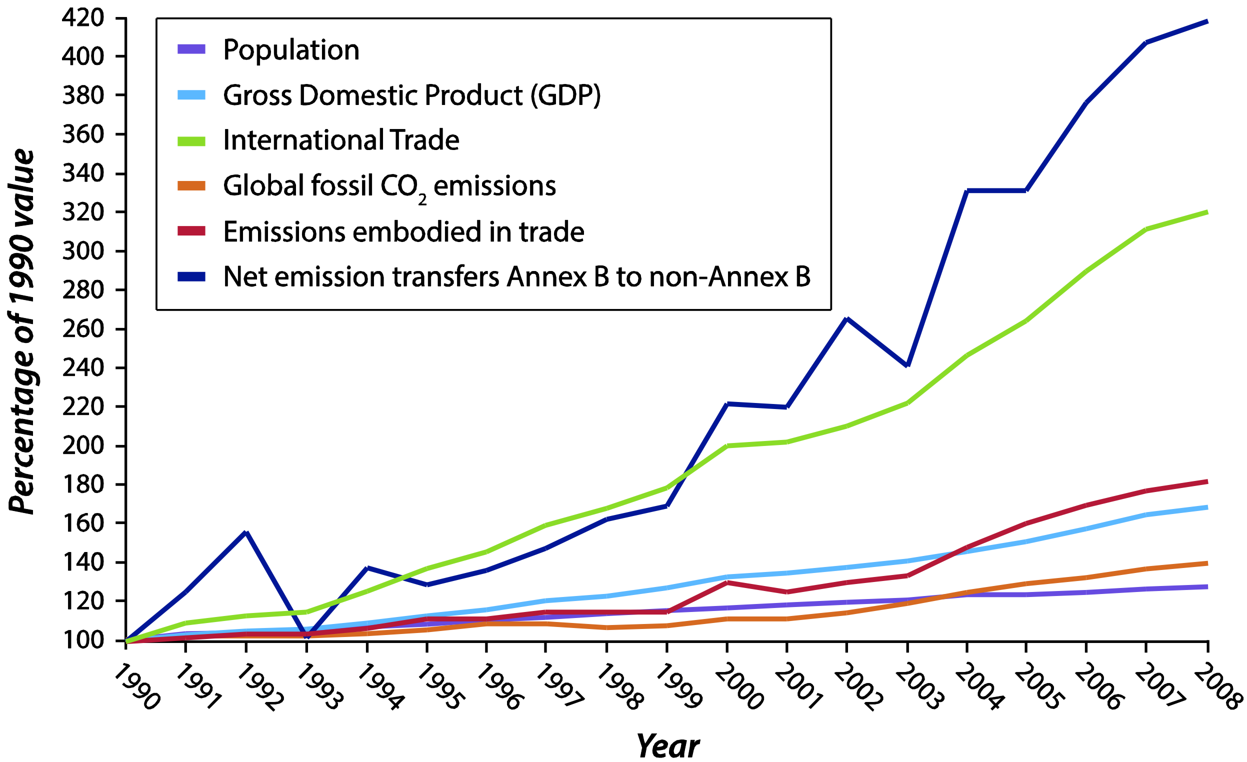

Figure 21-10: Growth rates from 1990-2008 of international trade, its embodied CO_2 emissions and net emissions transfers from Annex B and non-Annex B countries compared to other global macrovariables, all indexed to 1990 (Peters et al., 2011). Annex B and non-Annex B Parties to the UNFCCC are listed in the supplementary material. **[Illustration to be redrawn to conform to IPCC publication specifications.]**

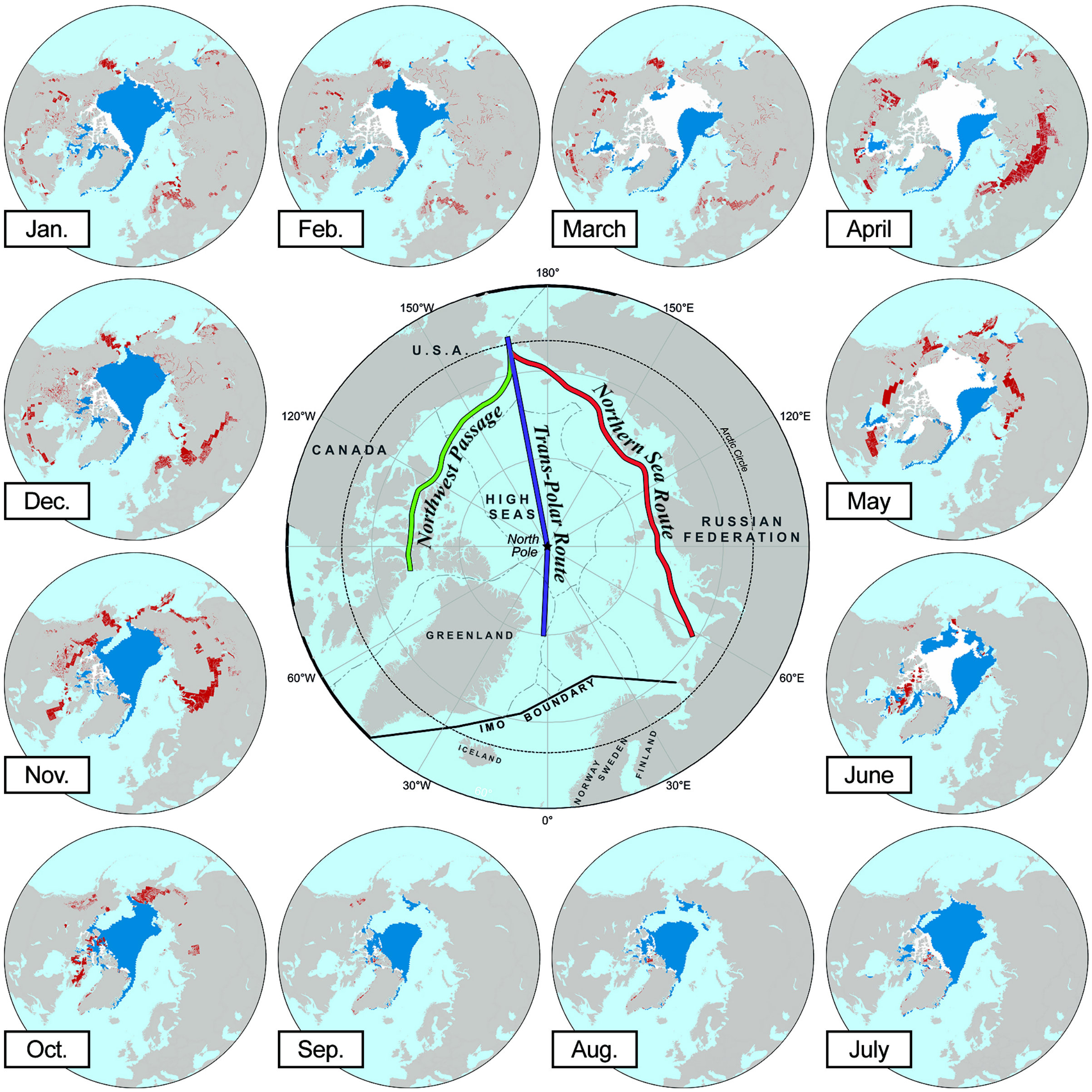

Figure 21-11: Central map: Marine exclusive environmental zones (EEZs – dashed lines) of Canada, Greenland/Denmark, Norway, Russia, and the USA, and location of the Northwest Passage, Northern Sea Route, Trans-Polar Route, and international high seas within the IMO Guidelines Boundary for Arctic shipping (thick black border). After Stephenson et al. (2013). Peripheral monthly maps: 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. Dark blue areas denote new maritime access to Polar Class 6 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). **[Illustration to be redrawn to conform to IPCC publication specifications.]**

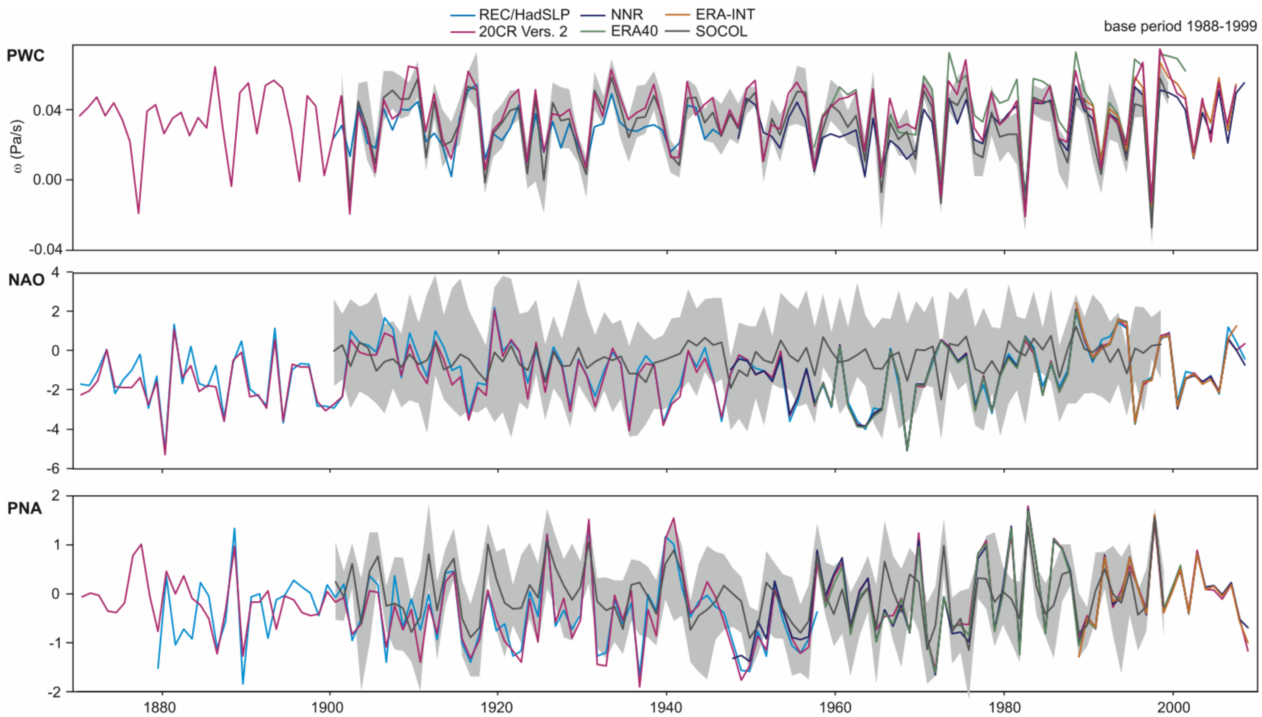

Figure 21-12: Time series of seasonally averaged climate indices representing three modes of large-scale climate variability: (a) the tropical September to January Pacific Walker Circulation (PWC); (b) the December to March North Atlantic Oscillation (NAO); (c) the December to March Pacific North America (PNA) pattern. Indices (as defined in Brönnimann etal. (2009) are calculated (with respect to the overlapping 1989–1999 period) from various observed, reanalysis and model sources: statistical reconstructions of the PWC, the PNA and the NAO, see Brönnimann et al. (2009) for details, (all cyan); 20CR (pink); NCEP–NCAR reanalyses (NNR; dark blue); ERA-40 (green); ERA-Interim (orange). The black line and grey shading represent the ensemble mean and spread from a climate model ensemble with a lower boundary condition of observed seas-surface temperatures and sea-ice from the HadISST dataset (Rayner et al. 2003), see Brönnimann etal. (2009) for details. The model results provide a measure of the predictability of these modes of variability from sea-surface temperature and sea-ice alone and demonstrate that the reanalyses have significantly higher skill in reproduces these modes of variability.
[Illustration to be redrawn to conform to IPCC publication specifications.]

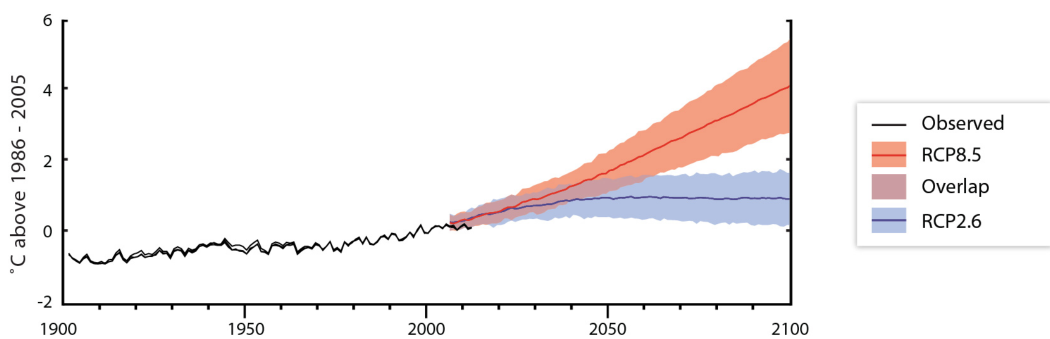

Figure RC-1: Observed and projected changes in global annual average temperature. Values are expressed relative to 1986-2005. Black lines show the GISTEMP, NCDC-MLOST, and HadCRUT4.2 estimates from observational measurements. Colored shading denotes the ±1.64 standard deviation range based on simulations from 32 models for RCP2.6 (blue) and 39 models for RCP8.5 (red). Blue and red lines denote the scenario mean for RCP2.6 and RCP8.5, respectively. **[Illustration to be redrawn to conform to IPCC publication specifications.]**

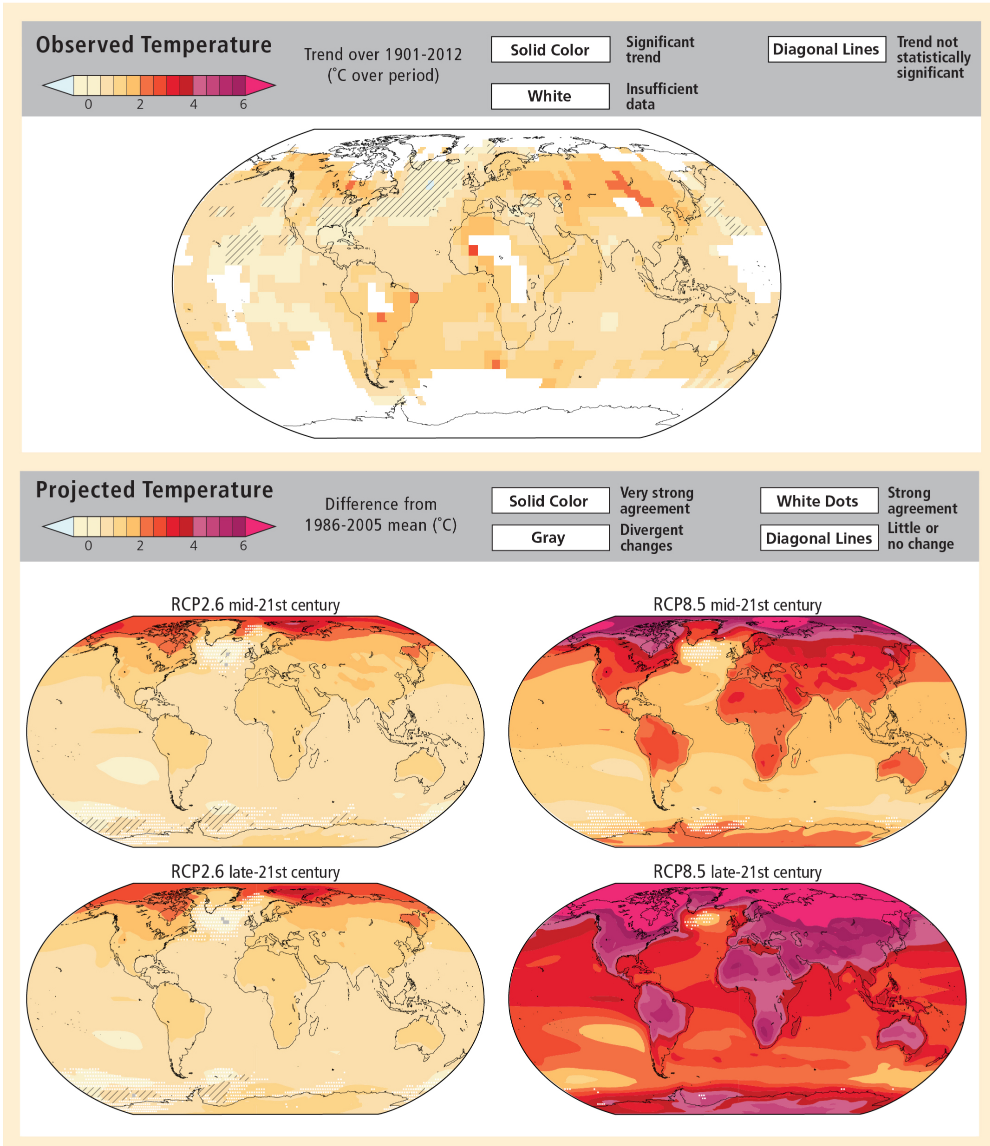

Figure RC-2: Observed and projected changes in annual average temperature. (A) Observed temperature trends from 1901-2012 are determined by linear regression. Trends have been calculated where sufficient data permit a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Solid colors indicate areas where change is significant at the 10% level (after accounting for autocorrelation effects on significance testing). Diagonal lines indicate areas where change is not significant. Observed data are from WGI AR5 Figures SPM.1 and 2.21. The range of grid-point values is -0.53 to +2.50°C over period. (B) CMIP5 multi-model mean projections of annual average temperature changes for 2046-2065 and 2081-2100 under RCP2.6 and RCP8.5, relative to 1986-2005. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability and >90% of models agree on the sign of change. Colors with white dots indicate areas with strong agreement, where >66% of models show change greater than the baseline variability and >66% of models agree on the sign of change. Gray indicates areas with divergent changes, where >66% of models show change greater than the baseline variability, but <66% agree on the sign of change. Colors with diagonal lines indicate areas with little or no change, where >66% of models show change less than the baseline variability (although there may be significant change at shorter timescales such as seasons, months, or days). Analysis uses model data from WGI AR5 Figure SPM.8, Box 12.1, and Annex I. The range of grid-point values for the multi-model mean is: +0.19 to +4.08˚C for mid-21st century of RCP2.6; +0.06 to +3.85˚C for late-21st century of RCP2.6; +0.70 to +7.04˚C for mid-21st century of RCP8.5; and +1.38 to +11.71°C for late-21st century of RCP8.5.

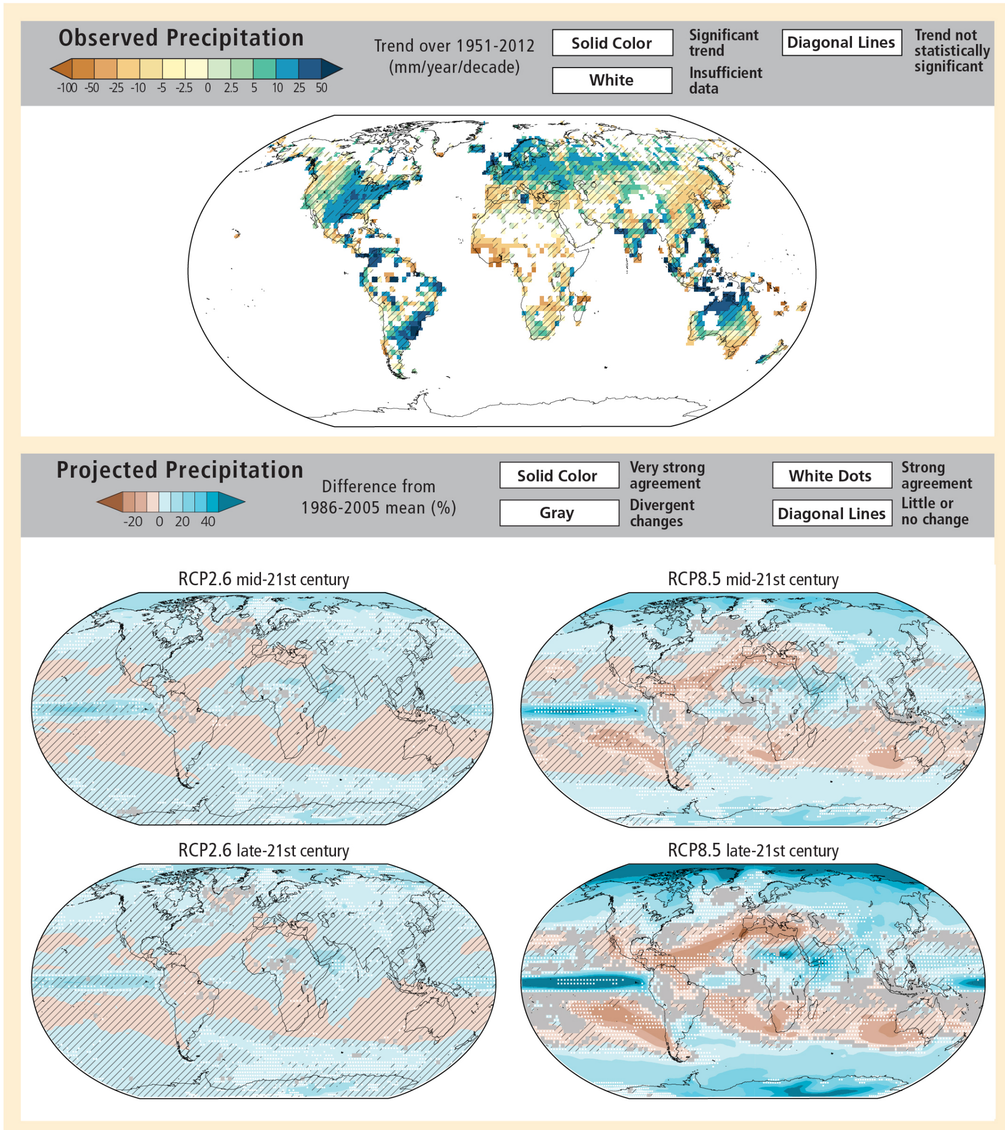

Figure RC-3: Observed and projected changes in annual average precipitation. (A) Observed precipitation trends from 1951-2010 are determined by linear regression. Trends have been calculated where sufficient data permit a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Solid colors indicate areas where change is significant at the 10% level (after accounting for autocorrelation effects on significance testing). Diagonal lines indicate areas where change is not significant. Observed data are from WGI AR5 Figures SPM.2. The range of grid-point values is -185 to +111 mm/year/decade. (B) CMIP5 multi-model mean projections of annual average precipitation changes for 2046-2065 and 2081-2100 under RCP2.6 and RCP8.5, relative to 1986-2005. Solid colors indicate areas with very strong agreement, where the multi-model mean change is greater than twice the baseline variability and >90% of models agree on the sign of change. Colors with white dots indicate areas with strong agreement, where >66% of models show change greater than the baseline variability and >66% of models agree on the sign of change. Gray indicates areas with divergent changes, where >66% of models show change greater than the baseline variability, but <66% agree on the sign of change. Colors with diagonal lines indicate areas with little or no change, where >66% of models show change less than the baseline variability (although there may be significant change at shorter timescales such as seasons, months, or days). Analysis uses model data from WGI AR5 Figure SPM.8, Box 12.1, and Annex I. The range of grid-point values for the multi-model mean is: -10 to +24% for mid-21st century of RCP2.6; -9 to +22% for late-21st century of RCP2.6; -19 to +57% for mid-21st century of RCP8.5; and -34 to +112% for late-21st century of RCP8.5.