

# 1

## Point of Departure

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## Executive Summary

**The evolution of the IPCC assessments of impacts, adaptation, and vulnerability indicates an increasing emphasis on human beings, their role in managing resources and natural systems, and the societal impacts of climate change.** The expanded focus on societal impacts and responses is evident in the composition of the IPCC author teams, the literature assessed, and the content of the IPCC assessment reports. Characteristics in the evolution of the Working Group II assessment reports are an increasing attention to (1) adaptation limits and transformation in social and natural systems; (2) synergies between multiple variables and factors that affect sustainable development; (3) risk management; and (4) institutional, social, cultural, and value-related issues. {1.1, 1.2}

**The literature available for assessing climate change impacts, adaptation, and vulnerability more than doubled between 2005 and 2010, allowing for a more robust assessment that supports policymaking (*high confidence*).** The diversity of the topics and regions covered by the literature has similarly expanded, as has the geographic distribution of authors contributing to the knowledge base for climate change assessments. Authorship of literature from developing countries has increased, although still representing a small fraction of the total. This unequal distribution of literature presents a challenge to the production of a comprehensive and balanced global assessment. {1.1.1, Figure 1-1}

**Rapidly advancing climate science provides policy-relevant information that creates opportunities for decision making that can lead to climate-resilient development pathways (*robust evidence, medium agreement*).** Climate change is just one of many stressors that influence resilience. The decisions that societies make within this opportunity space, also informed by observation, experience, and other factors, affect outcomes in human and natural systems. {1.1.1, 1.1.4, Figure 1-5}

**Adaptation has emerged as a central area of climate change research, in country level planning, and in the implementation of climate change strategies (*high confidence*).** The body of literature, including government and private sector reports, shows an increased focus on adaptation opportunities and the interrelations between adaptation, mitigation, and alternative sustainable pathways. The literature shows an emergence of studies on transformative processes that take advantage of synergies between adaptation planning, development strategies, social protection, and disaster risk reduction and management. {1.1.4}

**As a core feature and innovation of IPCC assessment, major findings are presented with defined, calibrated language that communicates the strength of scientific understanding, including uncertainties and areas of disagreement.** Each finding is supported by a traceable account of the evaluation of evidence and agreement. {1.1.2.2, Box 1-1}

**Impacts assessed in this report are based on climate model projections using both the IPCC Special Report on Emission Scenarios (SRES) and the new Representative Concentration Pathway (RCP) scenarios.** The RCPs span the range of SRES scenarios for long-lived greenhouse gases, but they have a narrower range in terms of emissions of ozone and aerosol precursors and related pollutants. The SRES scenarios were used in the Third Assessment Report (TAR) and the Fourth Assessment Report (AR4). With AR5, the RCP scenarios present both emissions and greenhouse gas concentration pathways, and corresponding Shared Socioeconomic Pathways (SSPs) have been developed. The four RCPs describe different levels of mitigation leading to 21st century radiative forcing levels of about 2.6, 4.5, 6.0, and 8.5 W m<sup>-2</sup>, whereas the SRES scenarios are policy-independent. {1.1.3, 1.3.3, 19.6.3.1, Boxes 21-1, 21.5.4, 24.3.3; see also WGI AR5 Chapters 1, 8, 11, 12}

## 1.1. The Setting

This chapter describes the information basis for the Fifth Assessment Report (AR5) of IPCC Working Group II (WGII) and the rationale for its structure. As the starting point of WGII AR5, the chapter begins with an analysis of how the literature for the assessment has developed through time and proceeds with an overview of how the framing and content of the WGII reports have changed since the first IPCC report was published in 1990. The future climate scenarios used in AR5 are a marked change from those used in the Third (TAR, 2001) and Fourth (AR4, 2007) Assessment Reports; this shift is described here, along with the new AR5 guidance for communicating scientific uncertainty. The chapter provides a summary of the most relevant key findings from the IPCC *Special Report on Renewable Energy Sources and Climate Change Mitigation* (IPCC, 2011), the IPCC *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (IPCC, 2012), and the AR5 Working Group I (*The Physical Science Basis*) and AR5 Working Group III (*Mitigation of Climate Change*). Collectively these recent reports, new scenarios, and other advancements in climate change science set the stage for an assessment of impacts, adaptation, and vulnerability that could potentially overcome many of the limitations identified in the IPCC WGII AR4, particularly with respect to the human dimensions of climate change.

The critical review and synthesis of the scientific literature published since October 2006 (effective cutoff date for AR4) has required an expanded multidisciplinary approach that, in general, has focused more heavily on societal impacts and responses. This includes an assessment of impacts associated with coupled socio-ecological systems and the rapid emergence of research on adaptation and vulnerability.

WGII AR5 differs from the prior assessments primarily in the expanded outline and diversity of content that stems directly from the growth of the scientific basis for the assessment. WGII AR5 is published in two volumes (Part A: Global and Sectoral Aspects; Part B: Regional Aspects), permitting the presentation of more detailed regional analyses and an expanded coverage of the human dimensions such as adaptation. WGI AR5 was completed approximately 6 months in advance of WGII AR5, allowing the WGII authors more time to evaluate and include where possible the WGI findings; WGIII AR5 was developed almost in parallel with the WGII report.

The point of departure in the title alludes to the availability of new information concerning the interactions between climate change and other biophysical and societal stressors. Societal stressors include poverty and inequality, low levels of human development, and psychological, institutional, and cultural factors. Even in the presence of these multiple stressors, policy relevant information from scientific research, direct experience, and observation provides an opportunity

space to choose and design climate-resilient development pathways (see Sections 1.1.4, 13.1.1, 14.2, 14.3; Figure 1-5).

### 1.1.1. Development of the Science Basis for the Assessment

The volume of literature available for assessing Climate Change Impacts, Adaptation, and Vulnerability (CCIAV) has grown significantly over the past 2 decades (Figure 1-1). A bibliometric analysis of reports produced with two bibliographic search tools (Scopus<sup>1</sup> and ISI Web of Science<sup>2</sup>) indicates that fewer than 1000 articles in journals, books, and conference proceedings were published in English on the topic of “climate change” between 1970 and 1990. By the end of 2012 the total number of such articles was reported as 102,573 (Scopus) and 62,155 (Web of Science). The current doubling rate of “climate change” publications remains short, less than 5 years: Scopus database lists 32,943 articles published between 1970 and 2005, and 76,130 published between 1970 and 2010. The number of publications per year on the topic of climate change impacts between 2005 and 2010 and on the topic of climate change adaptation between 2008 and 2010 has roughly doubled (Figure 1-1c). Thus, the total number of publications more than doubled from 2005 to 2010.

Since 1990 the geographic distribution of authors contributing to the climate change literature has expanded from Europe and North America to include a large fraction from Asia and Australasia. Literature from scientists affiliated with institutions in Africa and Central and South America, however, comprised approximately 5% of the total during 2001–2010 (Figure 1-1a). The proportion of literature focusing on individual countries within IPCC regions has also broadened over the past 3 decades, particularly for Asia (Figure 1-1b).<sup>3</sup> This brief chronicle neither differentiates across the various “subcategories” of the climate literature nor claims to be comprehensive in terms of literature produced in languages other than English.

Recent growth in the total volume of literature about climate change, and in particular that devoted to impacts and adaptation, has influenced the depth and scope of assessment reports produced by WGII, and it has enabled substantial advances in the assessment of the full range of impacts, adaptation, and vulnerability (Figure 1-1c). The unequal distribution of literature (Figure 1-1a,b,d) presents a challenge to the development of a comprehensive and balanced assessment of the global impacts of climate change. The geographical and topical distribution of literature is influenced by factors such as the availability of funding for scientific research, level of capacity building, regional experience with climate-related disasters, and the availability of long-term observational records.

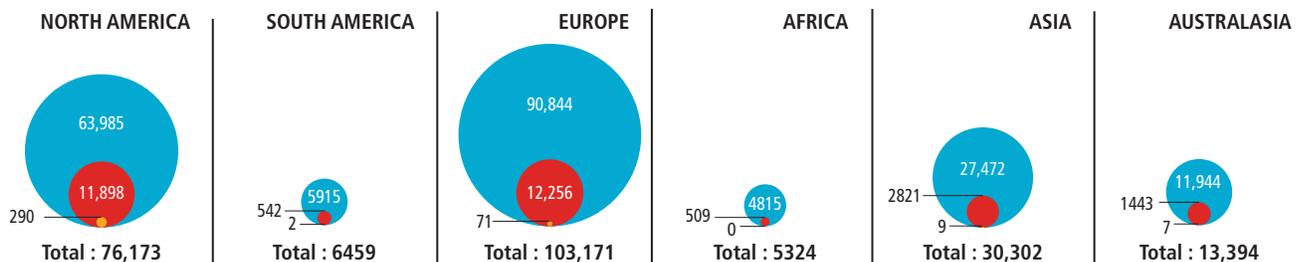
Literature published on the topic of “climate change” during 1970–1990 focused primarily on changes in the physical climate system and how these changes affected other aspects of the Earth’s physical environment.

<sup>1</sup> Scopus is a bibliographic database owned by Elsevier that contains abstracts and citations for peer-reviewed literature in the scientific, medical, and social sciences (including arts and humanities). Scopus has more than 50 million bibliographic records (about 29 million from 1995 forward and about 21 million from 1823 to 1996), as of September 2013.

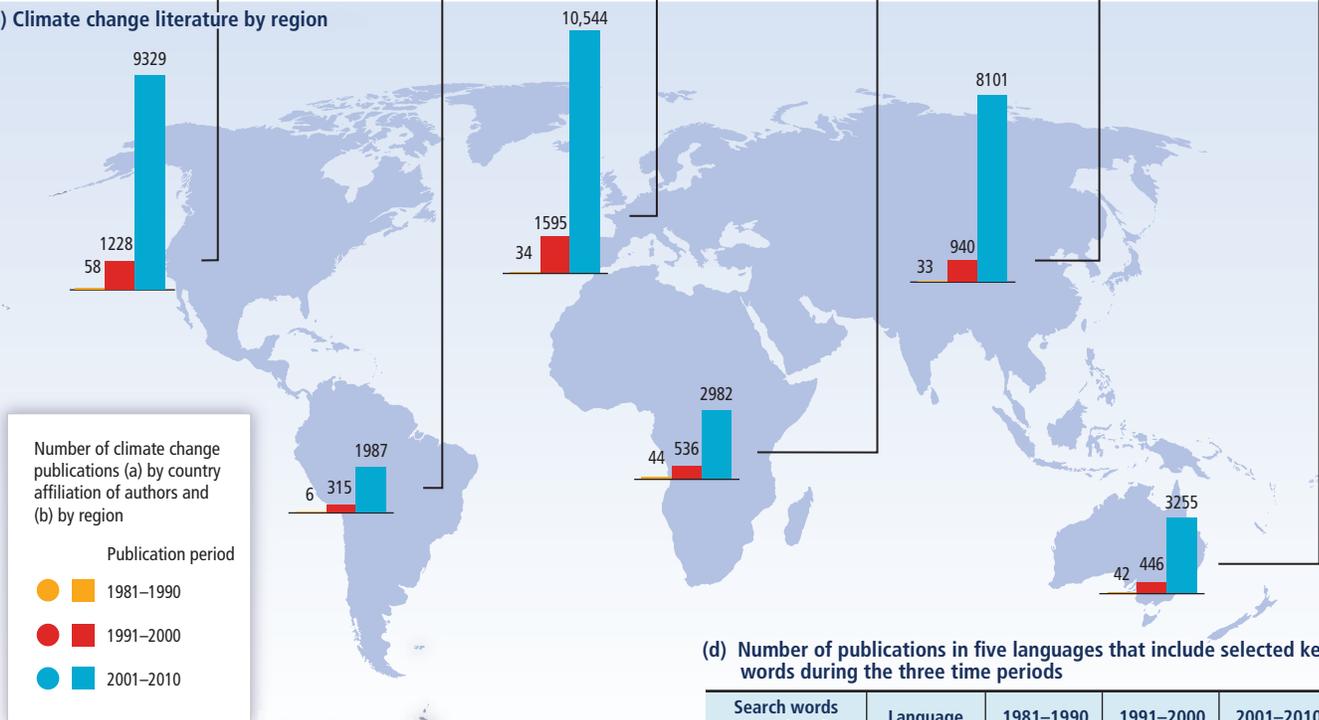
<sup>2</sup> Web of Science, owned by Thomson Reuters, is a bibliographic database of journals and conference proceedings for the sciences, social sciences, arts, and humanities. Web of Science includes records from over 12,000 journals and 148,000 conference proceedings dating from 1985 to present, as of September 2013.

<sup>3</sup> Russia, Greenland, and Iceland are included with Europe; Mexico is included with North America.

(a) Author affiliation



(b) Climate change literature by region

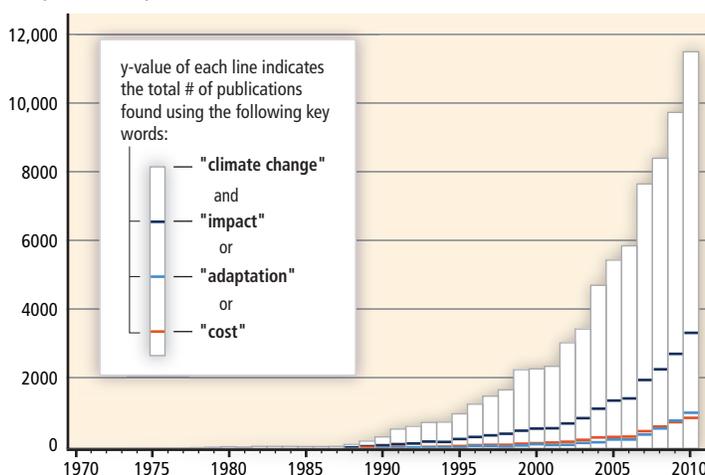


Number of climate change publications (a) by country affiliation of authors and (b) by region

Publication period

- 1981-1990
- 1991-2000
- 2001-2010

(c) Climate change literature in English, total and for selected topics (1970-2010)



(d) Number of publications in five languages that include selected key words during the three time periods

Search words (translated)	Language	1981-1990	1991-2000	2001-2010
"Climate change"	English	990	12,686	61,485
	Chinese	1454	6353	22,008
	French	1	108	815
	Russian	67	210	1443
	Spanish	3	82	1381
"Climate change" and "impacts"	English	232	3001	16,218
	Chinese	133	515	1780
	French	0	1	95
	Russian	0	72	403
	Spanish	0	7	103
"Climate change" and "adaptation"	English	14	373	3661
	Chinese	6	58	321
	French	0	7	110
	Russian	0	7	44
	Spanish	0	5	103
"Climate change" and "cost"	English	24	699	4099
	Chinese	1	22	162
	French	0	7	36
	Russian	0	1	24
	Spanish	0	2	11

**Figure 1-1** | Number of climate-change publications listed in the Scopus bibliographic database and results of literature searches conducted in four other languages. (a) Number of publications in English (as of July, 2011) summed by country affiliation of all authors of climate change publications and binned into IPCC regions. Each publication can be counted multiple times (i.e., the number of different countries in the author affiliation list). (b) Number of climate change publications in English with individual countries mentioned in title, abstract, or key words (as of July, 2011) binned into IPCC regions for the decades 1981-1990, 1991-2000, and 2001-2010. Each publication can be counted multiple times if more than one country is listed. (c) Annual global number of publications in English on climate change and related topics: impacts, adaptation, and costs for the years 1970-2010, as of September 2013. (d) Number of publications in five languages that include the words "climate change" and "climate change" plus "adaptation," "impact," and "cost" (translated) in the title, abstract, or key words during the three decades ending in 2010. The following individuals conducted these literature searches during January, 2012-March, 2013: Valentin Przulski (French), Huang Huanping (Chinese), Peter Zavalov and Vasily Kokorev (Russian), and Saúl Armendáriz Sánchez (Spanish).

## Frequently Asked Questions

**FAQ 1.1 | On what information is the new assessment based, and how has that information changed since the last report, the IPCC Fourth Assessment Report in 2007?**

Thousands of scientists from around the world contribute voluntarily to the work of the IPCC, which was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific assessment of the current scientific literature about climate change and its potential human and environmental impacts. Those scientists critically assess the latest scientific, technical, and socioeconomic information about climate change from many sources. Priority is given to peer-reviewed scientific, technical, and social-economic literature, but other sources such as reports from government and industry can be crucial for IPCC assessments.

The body of scientific information about climate change from a wide range of fields has grown substantially since 2007, so the new assessment reflects the large amount that has been learned in the past 6 years. To give a sense of how that body of knowledge has grown, between 2005 and 2010 the total number of publications just on climate change impacts, the focus of Working Group II, more than doubled. There has also been a tremendous growth in the proportion of that literature devoted to particular countries or regions.

The proportion of climate-change literature in engineering journals has not changed appreciably over the past 4 decades, but there was a significant increase in the proportion of literature published in biological and agricultural science journals. The proportion of the literature on the topic of “climate change” published in social science journals increased from 6% (1970s–1980s) to 9% (1990s–2000s). The themes covered by the literature on vulnerability to climate change have also expanded to issues of ethics, equity, and sustainable development. From the Scopus database, publications on the topic of climate change “impacts” crossed the threshold of 100 per year in 1991. Publications on climate change “adaptation” and societal “cost” reached this level in 2003.

Although authors continue to publish primarily in English, climate-change literature in other languages has also expanded. Literature searches in Chinese, French, Russian, and Spanish revealed a roughly fourfold or greater increase in literature published on the topic of “climate change” in each language during the past 2 decades (Figure 1-1d). Scientists from many countries tend to publish their work in English, as indicated by comparing the regional analysis and country affiliation of authors in Figure 1-1b with the results of the literature searches in the five languages. This process of “scientific internationalism,” by which English becomes the primary language of scientific communication, has been described as a growing trend among Russian (Kirchik et al., 2012), Spanish (Alcaide et al., 2012), and French (Gingras and Mosbah-Natanson, 2010) researchers.

### 1.1.2. Evolution of the Working Group II Assessment Reports and Treatment of Uncertainty

#### 1.1.2.1. Framing and Outlines of Working Group II Assessment Reports

The framing and contents of the IPCC WGII reports have evolved since the First Assessment Report (FAR; IPCC, 1990) as summarized in Figure 1-2. Four characteristics of this evolution are an increasing attention to

(1) adaptation limits and transformation in societal and natural systems; (2) synergies between multiple variables and factors that affect sustainable development; (3) risk management; and (4) institutional, social, cultural, and value-related issues. WGII now focuses on understanding the interactions between the natural climate system, ecosystems, human beings, and societies, this being on top of the long-standing emphasis on the biogeophysical impacts of climate change on sectors and regions.

The WGII FAR (296 pages) was organized into six major sectors: agriculture and forestry; terrestrial ecosystems; water resources; human settlements; oceans and coastal zones; and snow, ice, and permafrost. The report focused on the anticipated climate changes for a doubling of carbon dioxide (CO<sub>2</sub>). The FAR Summary for Policymakers (SPM) highlighted the coupling of anthropogenic non-climate stresses with climate variability and greenhouse gas (GHG) driven climate change. Given the state of the science in 1990, the FAR has understandably low confidence on some high-vulnerability topics (e.g., global agricultural potential may either increase or decrease), but is more quantitative on large-scale climate impacts (e.g., climatic zones shift poleward by hundreds of kilometers). Health impacts were vague, emphasizing ozone depletion and ultraviolet-B (UV-B) damage. The IPCC WGII 1992 Supplementary Report followed with four assigned topics (regional climate change; energy; agriculture and forestry; sea level rise) and was primarily a strategy report, for example, urging that studies of change in tropical cyclones are of highest priority (IPCC, 1992).

For the IPCC SAR (IPCC, 1996) WGII reviewed climate change impacts, vulnerability, and adaptation plus mitigation options for GHGs. There were two introductory primers, 18 chapters on impacts and adaptation (e.g., forests, rangelands, deserts, human settlements, agriculture, fisheries, financial services, human health), and seven chapters on sectoral mitigation (e.g., energy, industry, forests) but with cost analysis left to WGIII. The SAR made use of the new IPCC 1992 scenarios (IS92). Projections of 2100 sea level rise (15 to 95 cm) and temperature increase (1.0°C to 3.5°C) were similar to the FAR’s doubled-CO<sub>2</sub> scenario.



**Figure 1-2** | Tables of Contents for the Working Group II contributions to the IPCC Assessments since 1990. The First Assessment Report (FAR; IPCC, 1990) of IPCC Working Group II (WGII) focused on the impacts of climate change. For the Second Assessment Report (SAR; IPCC, 1996) the WGII contribution included mitigation and adaptation with the impacts assessment. With the Third Assessment Report (TAR; IPCC, 2001) and Fourth Assessment Report (AR4; IPCC, 2007) climate change mitigation reverted to WGIII, and WGII remained focused on impacts, adaptation, and vulnerability with an expanded effort on the regional scale.

The SAR notes “Impacts are difficult to quantify, and existing studies are limited in scope; detection [of climate-induced changes] will be difficult,” but some specifics are given (e.g., the number of people at risk of flooding from storm surges from sea level rise; the increase in malaria incidence). Vegetation models are used to map out projected changes in major biomes (see WGII SAR SPM Figure 2) – the first prediction figure in a WGII SPM.

WGII TAR (IPCC, 2001b) retained impacts, adaptation, and vulnerability, leaving the topic of mitigation to WGIII. It included five sectoral chapters (water resources, ecosystems, coastal and marine, human settlements and energy, and financial services), eight regional chapters, plus chapters on (1) adaptation, sustainable development, and equity, and (2) vulnerability and reasons for concern. The TAR made the first strong conclusion on attributing impacts: “recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems.” Recent increases in floods and droughts, while affecting some human systems, could not be tied to GHG-driven climate change. The TAR introduced the “burning embers” diagram (SPM Figure 2, discussed in Chapters 18 and 19 of this report) as a way to represent “reasons for concern.” The adaptive capacity, vulnerability, and key concerns for each region were laid out in detail (SPM, Table 2).

WGII AR4 (IPCC, 2007b,c) retained the basic structure of the TAR with chapters on sectors and regions. The first chapter of AR4, drawing from the expanded literature, provided an “Assessment of Observed Changes in Natural and Human Systems.” AR4 incorporated several cross-chapter themes with case studies (such as impacts on deltas) as a unifying construct. Two graphics in the AR4 SPM (SPM Figure 1-2 and Table 1-1) give many examples of projected impacts of climate change, but the state of the science—both of WGI climate projections and WGII impacts—remained too uncertain at the time to give more quantitative estimates of the impacts or necessary adaptation.

This WGII fifth assessment continues and expands the sectoral and regional parts. The AR5 considers a wide and complex range of multiple stresses that influence the sustainability of human and ecological systems. The focus on climate change and related stressors, and the

resulting vulnerability and risk, continues throughout this report, including the expanded “reasons for concern” (Chapters 2 and 19; see also Section 1.2.3).

### 1.1.2.2. Treatment of Uncertainties in IPCC Assessment Reports: A Brief History and Terms Used in the Fifth Assessment Report

An integral feature of IPCC reports is communication of the strength of and uncertainties in scientific understanding underlying assessment findings. Treatment of uncertainties and corresponding use of calibrated uncertainty language in IPCC reports have evolved across IPCC assessment cycles (Swart et al., 2009; Mastrandrea and Mach, 2011). In WGII, the use of calibrated language began in the SAR (1996), in which most chapters used qualitative levels of confidence in Executive Summary findings. With the TAR (2001), formal guidance across the Working Groups was developed (Moss and Schneider, 2000) recognizing that “guidelines such as these will never truly be completed,” and an iterative process of learning and improvement of guidance has ensued, informed by experience in each assessment cycle (IPCC, 2005; Mastrandrea et al., 2010). Each subsequent guidance paper has presented related but distinct approaches for evaluating and communicating the degree of certainty in findings of the assessment process.

The AR5 Guidance Note (summarized in Box 1-1) continues to emphasize an overriding theme of clearly linking each key finding and corresponding assignment of calibrated uncertainty language to associated chapter text, as part of the traceable account of the author team’s evaluation of evidence and agreement supporting that finding.

### 1.1.3. Scenarios Used as Inputs to Working Group II Assessments

A scenario is a storyline or image that describes a potential future, developed to inform decision making under uncertainty (Parson et al., 2007). Scenarios have been part of IPCC future climate projections since

#### Frequently Asked Questions

### FAQ 1.2 | How is the state of scientific understanding and uncertainty communicated in this assessment?

While the body of scientific knowledge about climate change and its impacts has grown tremendously, future conditions cannot be predicted with absolute certainty. Future climate change impacts will depend on past and future socioeconomic development, which influences emissions of heat-trapping gases, the exposure and vulnerability of society and ecosystems, and societal capacity to respond.

Ultimately, anticipating, preparing for, and responding to climate change is a process of risk management informed by scientific understanding and the values of stakeholders and society. The Working Group II assessment provides information to decision makers about the full range of possible consequences and associated probabilities, as well as the implications of potential responses. To clearly communicate well-established knowledge, uncertainties, and areas of disagreement, the scientists developing this assessment report use specific terms, methods, and guidance to characterize their degree of certainty in assessment conclusions.

### Box 1-1 | Communication of Uncertainty in the Working Group II Fifth Assessment

Based on the ‘Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties’ (Mastrandrea et al., 2010), the WGII AR5 relies on two metrics for communicating the degree of certainty in key findings:

- Confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement. Confidence is expressed qualitatively.
- Quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations, model results, or expert judgment).

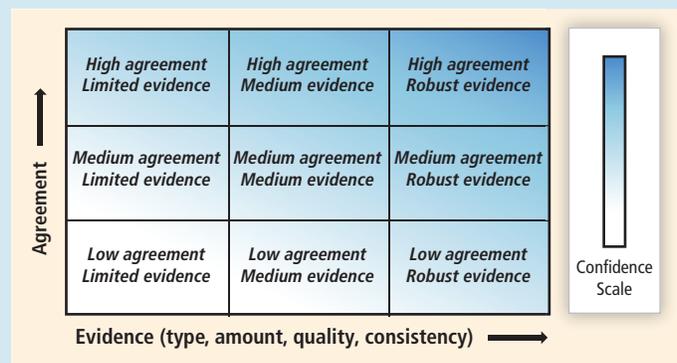
Each finding has its foundation in an author team’s evaluation of associated evidence and agreement. The type and amount of evidence available vary for different topics, and that evidence can vary in quality. The consistency of different lines of evidence can also vary. Beyond consistency of evidence, the degree of agreement indicates the consensus within the scientific community on a topic and the degree to which established, competing, or speculative scientific explanations exist.

The Guidance Note provides summary terms to describe the available evidence: *limited*, *medium*, or *robust*; and the degree of agreement: *low*, *medium*, or *high*. These terms are presented with some key findings. In many cases, author teams in addition evaluate their confidence about the validity of a finding, providing a synthesis of the evaluation of evidence and agreement. Levels of confidence include five qualifiers: *very low*, *low*, *medium*, *high*, and *very high*. Figure 1-3 illustrates the relationship between the summary terms for evidence and agreement and the confidence metric. There is flexibility in this relationship; increasing confidence is associated with increasing evidence and agreement, but different levels of confidence can be assigned for a given evidence and agreement statement. The degree of certainty in findings based on qualitative evidence is expressed using levels of confidence and summary terms.

In some cases, available evidence incorporates quantitative analyses, based on which uncertainties can be expressed probabilistically. In such cases, a finding can include calibrated likelihood language or a more precise presentation of probability. The likelihood terms and their corresponding probability ranges are presented below. Use of likelihood is not an alternative to use of confidence: an author team will have a level of confidence about the validity of a probabilistic finding. Unless otherwise indicated, findings assigned a likelihood term are associated with *high* or *very high* confidence. When authors evaluate the likelihood of some well-defined outcome having occurred or occurring in the future, the terms and associated meanings are:

Term*	Likelihood of the outcome
<i>Virtually certain</i>	99–100% probability
<i>Very likely</i>	90–100% probability
<i>Likely</i>	66–100% probability
<i>About as likely as not</i>	33–66% probability
<i>Unlikely</i>	0–33% probability
<i>Very unlikely</i>	0–10% probability
<i>Exceptionally unlikely</i>	0–1% probability

\* Additional terms used more occasionally are *extremely likely*: 95–100% probability, *more likely than not*: >50–100% probability, and *extremely unlikely*: 0–5% probability.



**Figure 1-3 |** Evidence and agreement statements and their relationship to confidence. The coloring increasing toward the top-right corner indicates increasing confidence. Generally, evidence is most robust when there are multiple, consistent independent lines of high-quality evidence.

the FAR (IPCC, 1990), where WGIII generated four scenarios (Bau = business-as-usual, B, C, and D) used by WGI to project climate change. The IPCC Supplementary Report (IPCC, 1992), a joint effort of WGI and WGIII, defined six new scenarios (IS92a–f) used in the SAR (1996). For the TAR (2001), the IPCC *Special Report on Emissions Scenarios* (SRES; Nakicenovic et al., 2000) created many scenarios from four Integrated Assessment Models (IAMs), out of which a representative range of marker scenarios were selected (A1B, A1T, A1FI, A2, B1, B2). In the SRES, scenarios had had socioeconomic storylines but climate-mitigation options were not included. The SRES scenarios carried over into the AR4 (2007a,b) and formed the basis for the large number of ensemble climate simulations (Coupled Model Intercomparison Project Phase 3 (CMIP3)), which are still in use for climate-change studies relevant to WGII AR5.<sup>4</sup>

With AR5, the development of scenarios fundamentally changed from the IPCC-led SRES process. An ad hoc group of experts, anticipating AR5, built a new structure for scenarios called Representative Concentration Pathways (RCPs) (Moss et al., 2010; van Vuuren et al., 2011) using updated IAMs and intended to provide a flexible, interactive, and iterative approach to climate change scenarios. The four RCPs are keyed to a range of trajectories of GHG concentrations and climate forcing. They are labeled by their approximate radiative forcing (RF,  $W\ m^{-2}$ ) that is reached during or near the end of the 21st century (RCP2.6, RCP4.5, RCP6.0, RCP8.5). The quantitative link between the socioeconomic pathway, human activities, and GHG emissions, and subsequently RF, is weaker or nonexistent with current RCP than with SRES scenarios. For example, the RCPs rely on a single parametric model (Meinshausen et al., 2011) to map from emissions to RF, whereas IPCC WGI traditionally assesses this critical linkage using the current state of scientific knowledge (see AR5 WGI Chapters 6, 11, 12, Annex II). In addition, socioeconomic scenarios, emissions, and subsequent radiative forcing pathways were not linked one-to-one in the initial RCPs; however, efforts to derive socioeconomic pathways consistent with each RCP are discussed in Chapter 20.

### 1.1.3.1. Comparison of RCP and SRES Scenarios

Whereas WGI AR5 is based primarily on results from the RCP CMIP5, the WGII AR5 also uses results from the SRES CMIP3, and thus identifies similar or parallel scenarios from each set. The radiative forcing from the SRES and RCP scenarios is compared in Figure 1-4a. For the latter half of the 21st century, SRES A1FI lies above all RCP and other SRES; SRES A2 has a similar trajectory to RCP8.5 with both reaching about  $8\ W\ m^{-2}$  by 2100; and SRES B1 approximately matches RCP4.5 with both leveling off at about  $4\ W\ m^{-2}$ . RCP6.0 starts similarly to both RCP4.5 and SRES B1, but after 2060 it increases to about  $5\ W\ m^{-2}$ . RCP2.6, a strong mitigation scenario with net  $CO_2$  removal by 2100, falls well outside the SRES range B1 to A2, peaking at about  $2.6\ W\ m^{-2}$  in 2040 and dropping thereafter (WGI AR5 Figure 1-15, Tables All.6.1 to All.6.10).

Total RF does not adequately describe the differences in climate change between SRES and RCP scenarios. All RCPs adopted stringent air pollution mitigation policies and thus have much lower tropospheric ozone and aerosol abundances than the SRES scenarios, which ignored the role of air quality regulations (WGI AR5 Tables All.2.16 to All.2.22). In terms of ozone and particulate matter precursor emissions, there is almost no overlap between SRES and RCP scenarios (WGI AR5 Tables All.2.16 to All.2.22). In terms of surface ozone at the continental scale, after 2060 the RCPs are similar to low-end SRES B1 (WGI AR5 Tables All.7.1 and All.7.2).

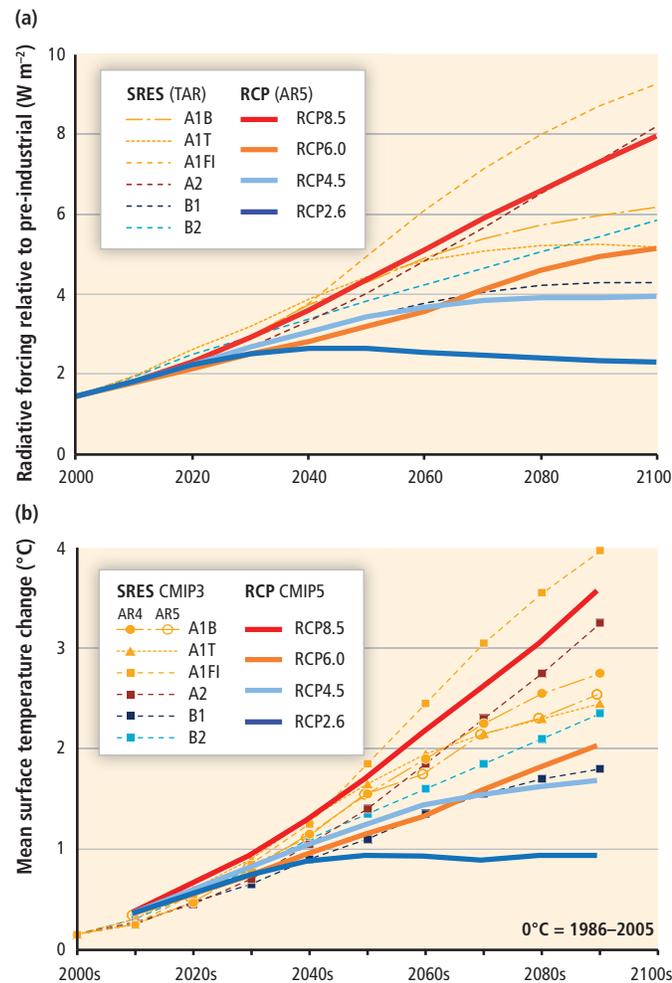
Global mean surface temperature change for these scenarios is shown in Figure 1-4b, based on WGI AR5 (Chapters 11, 12; Tables All.7.5 and All.7.6) and WGI AR4 (Figure 10.26). For purposes here, that is, of understanding differences in impact studies using different scenarios, only model CMIP5 ensemble means are shown for the RCPs. If the standard deviation of the models were plotted, all RCPs would touch or overlap through the century (WGI AR5 Table All.7.5), but even this range underestimates the uncertainties in temperature change for those scenarios (see WGI AR5 Chapter 12). The AR5 RCP data are taken directly from the CMIP5 runs, whereas the AR4 data are based on a simple model, parameterized to match the different CMIP3 models (see Figure 1-4 caption). In terms of temperature change, RCP8.5 is close to SRES A2, but below SRES A1FI. RCP4.5 follows SRES B2 up to 2060, but then drops to track SRES B1. RCP6.0 has lower temperature change to start, following SRES B1, but then increases toward SRES B2 by 2100. In general, scenarios SRES A1B, A1T, and B2 lie in the large gap between RCP8.5 and RCP4.5/6.0. The RCP2.6 temperature change stabilizes at about  $1^\circ C$  above the reference period (1986–2005). The other RCPs and all SRES scenarios span the range  $1.8^\circ C$  to  $4.1^\circ C$  for the 2090s. The CMIP5 reference period is about  $0.6^\circ C$  above earliest observing period 1850–1900 (WGI AR5 Chapter 2).

### 1.1.3.2. Shared Socioeconomic Pathways

Shared Socioeconomic Pathways (SSPs) are being generated (Arnell et al., 2011; Kriegler et al., 2012) to form more complete scenarios that link each RCP's climate path to a range of human development pathways. The SSPs include three elements: (1) storylines, which are descriptions of the state of the world; (2) IAM quantitative variables (such as population, gross domestic product (GDP), technology availability); and (3) other variables, not included in the IAMs, such as ecosystem productivity and sensitivity or governance index. With these elements a goal of the SSP effort is to characterize a global socioeconomic future for the 21st century as a reference for climate change analysis (O'Neill et al., 2012). Combined SSP–RCP scenarios are needed to support synthesis across all IPCC Working Groups and, particularly for WGII, to facilitate the use of new climate modeling results with impacts, adaptation, and vulnerability (IAV) research. Five basic SSPs have been proposed, representing a wide range of possible development pathways,

<sup>4</sup> The Coupled Model Intercomparison Project is an activity of the World Climate Research Programme's Working Group on Coupled Modelling. Climate model output from simulations of the past, present, and future climate archived mainly in 2005–2006 constituted Phase 3 of the Coupled Model Intercomparison Project (CMIP3). Similar climate simulations by an expanded set of models with a close off date of March 2013 are being used in AR5 and constitute Phase 5 of the project (CMIP5). CMIP3 used the SRES scenarios, and CMIP5 used the Reference Concentration Pathway (RCP) scenarios.

primarily at global or large regional scales. For each RCP it is expected that one or more SSP could lead to that climate path. Several chapters of this report refer to the SSPs in their discussion of analyses of future impacts and vulnerability. Chapter 20 (Section 20.6.1) describes SSPs in more detail, and Chapter 21 (Section 21.2.2) notes how the time lags in producing SSPs has limited the use of CMIP5–RCP scenarios in AR5.



**Figure 1-4** | (a) Projected radiative forcing (RF,  $W m^{-2}$ ) and (b) global mean surface temperature change ( $^{\circ}C$ ) over the 21st century using the Special Report on Emissions Scenarios (SRES) and Representative Concentration Pathway (RCP) scenarios. RF for the RCPs are taken from their published  $CO_2$ -equivalent (Meinshausen et al., 2011), and RF for SRES are from the Third Assessment Report Appendix II (Table II.3.11). For RF derived from the Coupled Model Intercomparison Project Phase 5 (CMIP5) models, see WGI (Section 12.3; Tables AII.6.9, 6.10). The ensemble total effective RF at 2100 for CMIP5 concentration-driven projections are 2.2, 3.8, 4.8, and 7.6  $W m^{-2}$  for RCP2.6, RCP4.5, RCP6.0, and RCP8.5, respectively. The SRES RF are shifted upward by 0.12  $W m^{-2}$  to match the RCPs at year 2000 because the climate change over the 21st century is driven primarily by the changes in RF and the offset is due primarily to improvements in model physics including the aerosol RF. For more details and comparison with pre-SRES scenarios, see WGI AR5 Chapter 1 (Figure 1-15). Temperature changes are decadal averages (e.g., 2020s = 2016–2025) based on the model ensemble mean CMIP5 data for the RCPs (colored lines). The same analysis is applied to CMIP3 SRES A1B (yellow circles). See WGI AR5 Chapters 11, 12; Table AII.7.5. The colored squares show the temperature change for all six SRES scenarios based on a simple climate model tuned to the CMIP3 models (WGI AR4 Figure 10.26). The difference between the yellow circles and yellow squares reflects differences between the simple model and analysis of the CMIP3 model ensemble in parallel with the CMIP5 data. For an assessment of uncertainties and likely ranges of temperature change, see WGI AR5 Figures 11.24, 11.25, 12.4, 12.5, 12.40.

#### 1.1.4. Evolution of Understanding the Interaction between Climate Change Impacts, Adaptation, and Vulnerability with Human and Sustainable Development

The continuing increase in GHG emissions has highlighted the commitment to climate change and its varied impacts and has contributed to an increasing emphasis on vulnerability, adaptation, and sustainability. The possible range of socioeconomic trajectories in countries with low, medium, high, and very high human development is among the largest sources of uncertainty in scenario building and climate projections. A deeper understanding of development patterns, adaptation limits, and maladaptation, as well as options for more climate resilient pathways, has helped identify a larger range of potential climate change impacts and the risks they pose to society.

The first three WGII reports focused primarily on characterizing the biophysical impacts of climate change, with a progressively more elaborated understanding of economic and social impacts. The literature of the last decade indicates a more integrated understanding of the physical and social impacts of climate change. The extent and structure of WGII AR5 shows such advancements. The AR4 Synthesis Report asserted that “climate change impacts depend on the characteristics of natural and human systems, their development pathways and their specific locations” (IPCC, 2007d, p. 64). WGII AR4 Chapter 20 offered a catalog of multiple stresses jointly impacting people and communities and also highlighted questions of justice and equity in shaping development pathways in the context of climate change.

##### 1.1.4.1. Vulnerability and Multiple Stressors

Climate-related risks interact with other biophysical and social stressors. Vulnerability is defined in the WGII TAR Glossary in terms of susceptibility and as a “function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.” Since then, the understanding of vulnerability has acquired increased complexity as a multidimensional concept, with more attention to the relation with structural conditions of poverty and inequality. WGII AR5 defines vulnerability simply as the propensity or predisposition to be adversely affected, and many chapters identify such vulnerabilities through societal risks, particularly in low-income economies. Recent studies suggest that climate impacts could slow down or reverse past development achievements; hinder global efforts on poverty reduction; and lead to human and environmental insecurity, displacement and conflict, maladaptation, and negative synergies (Jerneck and Olsson, 2008; Boyd and Juhola, 2009; Barnett and O’Neill, 2010; Ogallo, 2010; see also Sections 3.5.1, 8.2.4, 12.2.1, 12.4.1, 12.5.1, 13.2.1, 14.7).

The concept of resilience emerged from ecological sciences and has been increasingly used by social sciences. In climate change literature it describes the ability of a system to respond to disturbances, self-organize, learn, and adapt (Turner, 2010; Brown, 2013; WGII AR5 Glossary). Vulnerability, adaptation, and resilience are determined by multiple stressors, a combination of biophysical and social factors that jointly determine the propensity and predisposition to be adversely affected. For example, adaptive capacity in many urban centers in less

## Frequently Asked Questions

**FAQ 1.3 | How has our understanding of the interface between human, natural, and climate systems expanded since the 2007 IPCC Assessment?**

Advances in scientific methods that integrate physical climate science with knowledge about impacts on human and natural systems have allowed the new assessment to offer a more comprehensive and finer-scaled view of the impacts of climate change, vulnerabilities to those impacts, and adaptation options, at a regional scale. That's important because many of the impacts of climate change on people, societies, infrastructure, industry, and ecosystems are the result of interactions between humans, nature, and specifically climate and weather, at the regional scale.

In addition, this new assessment from Working Group II greatly expands the use of the large body of evidence from the social sciences about human behavior and the human dimensions of climate change. It also reflects improved integration of what is known about physical climate science, which is the focus of Working Group I of the IPCC, and what is known about options for mitigating greenhouse gas emissions, the focus of Working Group III. Together this coordination and expanded knowledge inform a more advanced and finer-scaled, regionally detailed assessment of interactions between human and natural systems, allowing more detailed consideration of sectors of interest to Working Group II such as water resources, ecosystems, food, forests, coastal systems, industry, and human health.

developed countries is constrained by poverty, unemployment, quality of housing, or lack of access to potable water, sanitation, health care, and education interacting with land degradation, water stress, or biodiversity loss (Sections 8.2.4, 11.6.2, 22.4.4). Adaptation options and limits for high-end warming scenarios are often contextualized in relation to socioeconomic vulnerabilities and other stressors (Gupta et al., 2010; New et al., 2010; Stafford Smith et al., 2011; Brown, 2012; World Bank, 2012; see also Section 16.4.2.4).

**1.1.4.2. Adaptation, Mitigation, and Development**

Impacts of climate change will vary across regions and populations, through space and time, dependent on myriad factors including non-climate stressors and the extent of mitigation and adaptation. Changes in both climate and development are key drivers of the core components of risk (exposure, vulnerability, and physical hazards). The relations with development are complex and contested. There is disagreement about fundamental issues, such as the compatibility of development goals and climate change mitigation, the prioritization of responses (reducing consumption versus investment in sustainable technologies), and the stage of development at which countries should take action (see Box 1-2 for terms used to characterize stages of development) (Schipper, 2007; Grist, 2008; Brooks et al., 2009). The literature points to how inequalities, trade imbalances, intellectual property rights, gender injustice, or agricultural systems, *inter alia*, cannot be addressed with development focusing solely on increasing economic growth (Pogge, 2008; McMichael, 2009; Alston, 2011; UNDP, 2007, 2011; Büscher et al., 2012; OECD, 2013).

The recent literature shows increasing attention to questions of ethics, justice, and responsibilities relating to climate change (Timmons and Parks, 2007; O'Brien et al., 2010; Pelling, 2010; Arnold, 2011; Gardiner, 2011; Caney, 2012; Marino and Ribot, 2012). As basic resources such as energy, land, food, or water become threatened, inequalities and unfairness may deepen, leading to maladaptation and new forms of vulnerability. Responses to climate change may have consequences and

outcomes that favor certain populations or regions. For example, there are increasing cases of land-grabbing and large acquisitions of land or water rights for industrial agriculture, mitigation projects, or biofuels that have negative consequences on local and marginalized communities (Borras et al., 2011; see also Section 14.7). Ethical perspectives are also important in relation to adaptation constraints and limits (see Section 16.7) and mitigation (see Section 1.3.4 and WGIII AR5).

Climate change impacts have become a central issue in the work of developmental organizations such as the United Nations specialized agencies, bilateral donor institutions, and non-governmental organizations (NGOs) that link adaptation concerns with ongoing development efforts. The increase in adaptation literature and experience, however, has led to the development of adaptation policies in many parts of the world, as reflected in four chapters here devoted to adaptation (14 to 17) and all of the regional chapters of this report. At the policy level, individual country National Adaptation Programmes of Action and National Communication reports to the United Nations Framework Convention on Climate Change (UNFCCC) had in the past focused primarily on physical climate change drivers and impacts. An analysis of National Communications documents submitted through 2004 by many of the Annex 1 countries, for example, showed that climate change impacts and adaptation receive very limited attention relative to the discussion of GHG emissions and mitigation policies (Gagnon-Lebrun and Agrawala, 2006). However, concern and actual progress toward adaptation is evident in Latin America (Gutierrez and Espinosa, 2010) and in recent National Communications of some non-Annex 1 countries, such as India (2012) and Iran (2010), which devoted a substantive part of their recent reports to the topic of adaptation.

Some researchers and institutions have sought to identify a continuum between development, adaptation strategies, and financing, including increasing attention to co-benefits with mitigation (USAID, 2008; Heltberg et al., 2009; Mearns and Norton, 2010; World Bank, 2010; Richardson et al., 2011; OECD, 2013). "Greener" development and market-based mechanisms are being explored as instruments to achieve synergies

## Box 1-2 | Country Development Terminology

There are diverse approaches for categorizing countries on the basis of their level of development and for defining terms such as industrialized, developed, or developing. Table 1-1 presents selected categorizations used in this report. In the United Nations system,

**Table 1-1** | Selected country development categorizations used in this report.

Categorization approach	Categories	Criteria	Reference
United Nations	<ul style="list-style-type: none"> <li>Developing regions</li> <li>Developed regions</li> </ul>	Common practice	UN DESA (2012)
	Least developed countries	<ul style="list-style-type: none"> <li>Gross National Income (GNI) per capita</li> <li>Human assets</li> <li>Economic vulnerability to external shocks</li> </ul>	UN DESA (2008)
	Landlocked developing countries	<ul style="list-style-type: none"> <li>Lack of territorial access to the sea</li> <li>Remoteness and isolation from world markets</li> <li>High transit costs</li> </ul>	UN (2003)
	Small island developing states	Low-lying coastal countries sharing similar socioeconomic and environmental vulnerabilities	UN (1993)
	Economies in transition/transition economies	Countries changing from central planning to free markets	UN DESA (2013)
World Bank	<ul style="list-style-type: none"> <li>Low income</li> <li>Lower middle income</li> <li>Upper middle income</li> <li>High income</li> </ul>	GNI per capita	World Bank (2013)
UNDP	<ul style="list-style-type: none"> <li>Low human development</li> <li>Medium human development</li> <li>High human development</li> <li>Very high human development</li> </ul>	<ul style="list-style-type: none"> <li>GNI per capita</li> <li>Life expectancy at birth</li> <li>Mean years of schooling</li> <li>Expected years of schooling</li> </ul>	UNDP (2013)

there is no established convention for the designation of developed and developing countries or areas (UN DESA, 2012). The United Nations Statistics Division specifies developed and developing regions based on “common practice.” In addition, specific countries are designated as least developed countries, landlocked developing countries, small island developing states, and transition economies. Many countries appear in more than one of these categories. The World Bank uses income as the main criterion for classifying countries (World Bank, 2013). The UNDP aggregates indicators for life expectancy, educational attainment, and income into a single composite Human Development Index (HDI) (UNDP, 2013).

between mitigation and adaptation efforts, development financing, and planning, and links to energy needs are some of the instruments explored. Large concerns remain, however, about the preconditions needed for market mechanisms to work as intended, the problems of carbon leakage, and the potential negative effects of some mitigation strategies (Liverman, 2010; see also Section 13.1.3 and WGIII AR5 Chapter 15).

### 1.1.4.3. Transformation and Climate-Resilient Pathways

Transformation—a change in the fundamental attributes of a system including altered goals or values—has emerged as a key concept in describing the dimensions, types, and rates of societal response to climate change. In the context of adaptation, we can distinguish between incremental and transformative adaptation, the latter referring to changes in the fundamental attributes of a system in response to climate change and its effects (WGII AR5 Glossary; Park et al., 2012). The *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX) recognized transformation in technological, financial, regulatory, legislative, and administrative systems (IPCC, 2012; see Sections 1.3.1, 20.5). Recent

literature points to changes in values, norms, belief systems, culture, and conceptions of progress and well-being as either facilitating or preventing transformation (Pelling, 2010; Stafford Smith et al., 2011; Kates et al., 2012; O’Brien, 2013). Transformation of this nature requires a particular understanding of risks, adaptive management, learning, innovation, and leadership, and may lead to climate resilient development pathways (see Section 1.2.3 and Chapter 20). Transformational change is not called for in all circumstances (Pelling, 2010) and in some cases may lead to negative consequences for some locations or social groups, contributing to social inequities (O’Brien, 2013). Climate resilient pathways include actions, strategies, and choices that reduce climate change impacts while assuring that risk management and adaptation can be implemented and sustained.

### 1.1.4.4. The Opportunity Space for Decision Making

Recognizing the need for policy-relevant science, much scientific activity tends to be coordinated through international programs that focus on, for example, biodiversity, desertification, food security, impacts on social practices and institutions, and monitoring sea level rise. The trend in

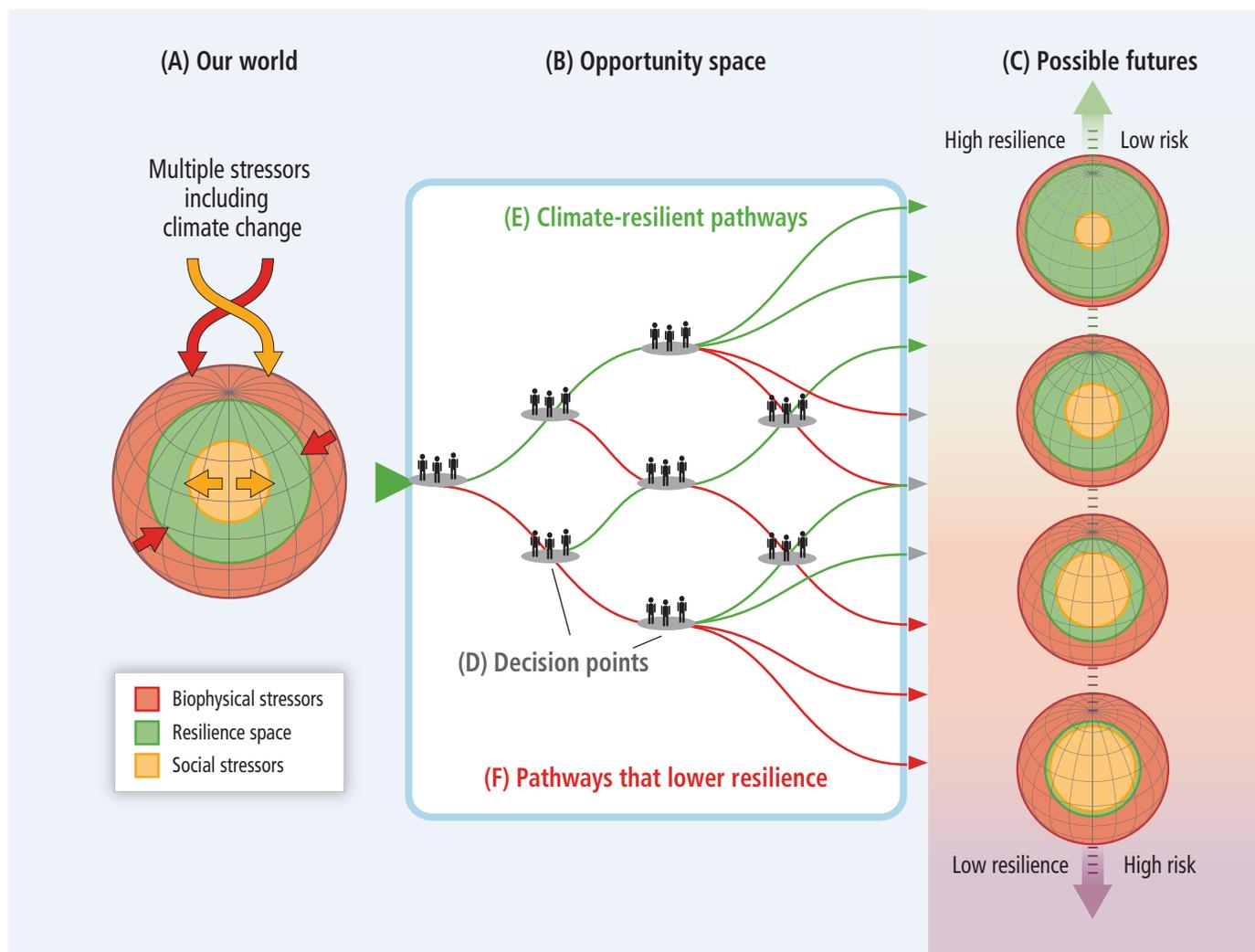
research is to create synergies across the sciences by including social and human sciences perspectives and transdisciplinarity. The production of information with non-scientific sources such as indigenous knowledge or stakeholder views is also enriching climate change research. This trend has led to the merging of relevant global programs of the international councils for science and for social science (ICSU and ISSC) under the umbrella “Future Earth” (see also ISSC and UNESCO, 2013). This expanded scientific focus combined with increased practice and experience with adaptation creates a new opportunity space for evaluating policy options and their risks in the search for climate resilient development pathways (Figure 1-5) (Sections 2.1, 2.4.3, 20.2, 20.3.3). Human and social-ecological systems can build resilience through adaptation, mitigation, and sustainable development.

Over the next few decades, global temperatures are projected to increase along broadly similar pathways, whether or not mitigation of

GHGs occurs (Section 1.3.3). During this near-term era of committed climate change, risks will evolve as socioeconomic trends interact with the changing climate and societal responses, including adaptation, will influence near-term outcomes. In the second half of the 21st century and beyond, global temperature increases diverge across emissions scenarios. During this longer term era of climate options, near-term and ongoing mitigation efforts as well as development trajectories will determine the risks associated with climate change.

## 1.2. Major Conclusions of the Working Group II Fourth Assessment Report

This section presents highlights of the IPCC Fourth Assessment Report that are particularly relevant to AR5 as a point of departure. These highlights are drawn from the AR4 Synthesis Report, the WGII AR4



**Figure 1-5** | Opportunity space and climate-resilient pathways. (a) Our world is threatened by multiple stressors that impinge on resilience from many directions, represented here simply as biophysical and social stressors. Stressors include climate change, climate variability, land-use change, degradation of ecosystems, poverty and inequality, and cultural factors. (b) Opportunity space refers to decision points and pathways that lead to a range of (c) possible futures with differing levels of resilience and risk. (d) Decision points result in actions or failures-to-act throughout the opportunity space, and together they constitute the process of managing or failing to manage risks related to climate change. (e) Climate-resilient pathways (in green) within the opportunity space lead to a more resilient world through adaptive learning, increasing scientific knowledge, effective adaptation and mitigation measures, and other choices that reduce risks. (f) Pathways that lower resilience (in red) can involve insufficient mitigation, maladaptation, failure to learn and use knowledge, and other actions that lower resilience; and they can be irreversible in terms of possible futures.

Summary for Policymakers (SPM), and the WGII AR4 chapter Executive Summaries.

### 1.2.1. Observed Impacts

Evidence presented in WGII AR4 Chapter 1 indicated that physical and biological systems on all continents and in most oceans were being affected by recent climate changes, particularly regional temperature increases (Rosenzweig et al., 2007, p. 81). In terrestrial ecosystems, warming trends were consistent with observed change in the timing of spring events and poleward and upward shifts in plant and animal ranges. The authors found that the geographical locations of observed changes during the period 1970–2004 are consistent with spatial patterns of atmospheric warming. The types of hydrologic changes reported included effects on snow, ice, and frozen ground; the number and size of glacial lakes; increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers; thermal structure and water quality of rivers and lakes; and more intense drought and heavy rains in some regions. The authors concluded from a synthesis of studies “that the spatial agreement between regions of significant warming and the locations of significant observed changes is *very unlikely* to be due solely to natural variability of temperatures or natural variability of the systems” (IPCC, 2007c, p. 9).

Observed regional impacts to human systems were less obviously attributed to anthropogenic climate change. AR4 authors concluded that “**There is *medium confidence* that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers**” (IPCC, 2007d, p. 3). They presented evidence on the effects of temperature increases on agricultural and forest management at Northern Hemisphere (NH) higher latitudes (e.g., earlier spring planting of crops, alterations in disturbance regimes of forests due to fires and pests); on some aspects of human health (e.g., heat-related mortality in Europe, changes in infectious disease vectors in some areas, and allergenic pollen in NH high and mid-latitudes); and some human activities in the Arctic (e.g., hunting and travel over snow and ice) and in lower-elevation alpine areas (such as mountain sports).

The authors of AR4 concluded that “Recent climate changes and climate variations are beginning to have effects on many other natural and human systems. However, based on published literature, the impacts have not yet become established trends” (IPCC, 2007c, p. 9). Three examples were cited: in mountain regions melting glaciers enhanced risk of glacier lake outburst floods on settlements; in the Sahelian region of Africa warmer and drier conditions had detrimental effects on some crops; and in coastal areas sea level rise and human development contributed to losses of coastal wetlands and mangroves and to increases in damage from coastal flooding.

### 1.2.2. Key Vulnerabilities, Risks, and Reasons for Concern

In an effort to provide some insights into the seriousness of the impacts of climate change WGII TAR (Chapter 19) identified five “Reasons for Concern” (RFC) focusing on (1) unique and threatened systems, (2)

extreme climate events, (3) distribution of impacts, (4) aggregate impacts, and (5) large-scale discontinuities (see Figure SPM-2 in IPCC, 2001b). Considering new evidence of observed changes on every continent, coupled with more thorough understanding of the concept of vulnerability, the AR4 concluded that the five “reasons for concern identified in the TAR remained a viable framework to consider key vulnerabilities” (IPCC, 2007d, p. 19).

The AR4 Synthesis Report SPM concluded with the following key message: **Responding to climate change involves an iterative risk management process that includes both adaptation and mitigation and takes into account climate change damages, co-benefits, sustainability, equity and attitudes to risk** (IPCC, 2007d, p. 22). The concept of risk (the confluence of likelihood and consequence) is the focus of this AR5 Report. All chapters, especially 2, 18, and 19, now focus on climate change, related stressors, resulting vulnerabilities, and associated risks. Correlating the risk-based framing of the RFC in WGII AR5 with the conclusions reported in the AR4 SPM is straightforward (*italics indicate new terms that have been added to the RFC definitions from the IPCC, 2007d, p. 19*):

- **Risks to Unique and Threatened Systems:** “There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase.”
- **Risks Associated with Extreme Weather Events:** “Responses to some recent extreme events reveal higher levels of vulnerability than the TAR. There is now higher confidence in the projected increases in droughts, heat waves, and floods, as well as their adverse impacts.”
- **Risks Associated with the Distribution of Impacts:** “There are sharp differences across regions and those in the weakest economic position are often the most vulnerable to climate change. There is increasing evidence of greater vulnerability of specific groups such as the poor and elderly not only in developing but also in developed countries. Moreover, there is increased evidence that low-latitude and less developed areas generally face greater risk, for example, in dry areas and megadeltas.”
- **Risks Associated with Aggregate Impacts:** “Compared to the TAR, initial net market-based benefits from climate change are projected to peak at a lower magnitude of warming, while damages would be higher for larger magnitudes of warming.”
- **Risks Associated with Large-Scale Discontinuities:** “There is high confidence that global warming over many centuries would lead to a sea level rise contribution from thermal expansion alone that is projected to be much larger than observed over the 20th century, with loss of coastal area and associated impacts. There is better understanding than in the TAR that the risk of additional contributions to sea level rise from both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century time scales.”

WGII AR5 Chapters 18 and 19 recognize new evidence about the RFC in the context of risk. Chapter 18 expands our understanding of how observed and attributed impacts, vulnerabilities, and associated risks support the identification of the dependence of the RFC on temperature “up to the present.” Chapter 19 extends this analysis to future temperatures. Both chapters demonstrate how accounting for both

components of risk in assessing the RFC permits a clearer understanding of “key vulnerabilities.”

### 1.2.3. Interaction of Adaptation and Mitigation in a Policy Portfolio

A conclusion of AR4 is that coping with risks of climate change will involve a portfolio of initiatives that will evolve iteratively over time as new information about the workings of the climate system and new insights into how various responses are actually working and penetrating the global socioeconomic structure. The WGII AR4 concluded that (1) neither adaptation nor mitigation alone can avoid all climate change impacts, though together they can significantly reduce the risks of climate change; (2) adaptation is necessary in the short and longer term to address impacts, even for the lowest stabilization scenarios assessed, but there are barriers, limits, and costs, though these are not fully understood; (3) unmitigated climate change would *likely* exceed the adaptive capacity of natural, managed, and human systems in the long term; and (4) while many impacts can be reduced, delayed, or avoided by mitigation, delayed emission reductions “significantly constrain the opportunities to achieve lower stabilization levels and increase the risk of more severe climate change impacts.” (IPCC, 2007d, p. 19).

WGII AR5 devotes considerable attention to the interface of adaptation and mitigation and the mechanisms for iterating decisions as described in a collection of chapters (16, 17, 19, and 20) designed explicitly for this purpose. These chapters build substantially upon key messages from the AR4 chapter entitled “Inter-relationships between adaptation and mitigation” (IPCC, 2007b, p. 747), including:

- Even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades, which makes adaptation unavoidable.
- Without mitigation, a magnitude of climate change is likely to be reached that makes adaptation impossible for some natural systems, while for most human systems it would involve very high social and economic costs.
- **“Creating synergies between adaptation and mitigation can increase the cost-effectiveness of actions and make them more attractive to stakeholders, including potential funding agencies (medium confidence).”** Such synergies, however, provide no guarantee that resources are used in the most efficient manner

and opportunities for synergies are greater in some sectors (e.g., agriculture and forestry) than others (e.g., energy, health, and coastal systems).

- **“It is not yet possible to answer the question as to whether or not investment in adaptation would buy time for mitigation (high confidence).”** Barriers to understanding the trade-offs of the immediate benefits of localized adaptation and the longer term global benefits of mitigation, coupled with the limitation of models to simulate the intricacies of the interactions of the two, present a challenge to designing and implementing an “optimal mix” of response strategies.
- **“People’s capacities to adapt and mitigate are driven by similar sets of factors (high confidence).** These factors represent a generalized response capacity that can be mobilized for both adaptation and mitigation.” The authors noted that even societies with high adaptive capacity can be vulnerable to climate change, variability, and extremes.

## 1.3. Major Conclusions of More Recent IPCC Reports

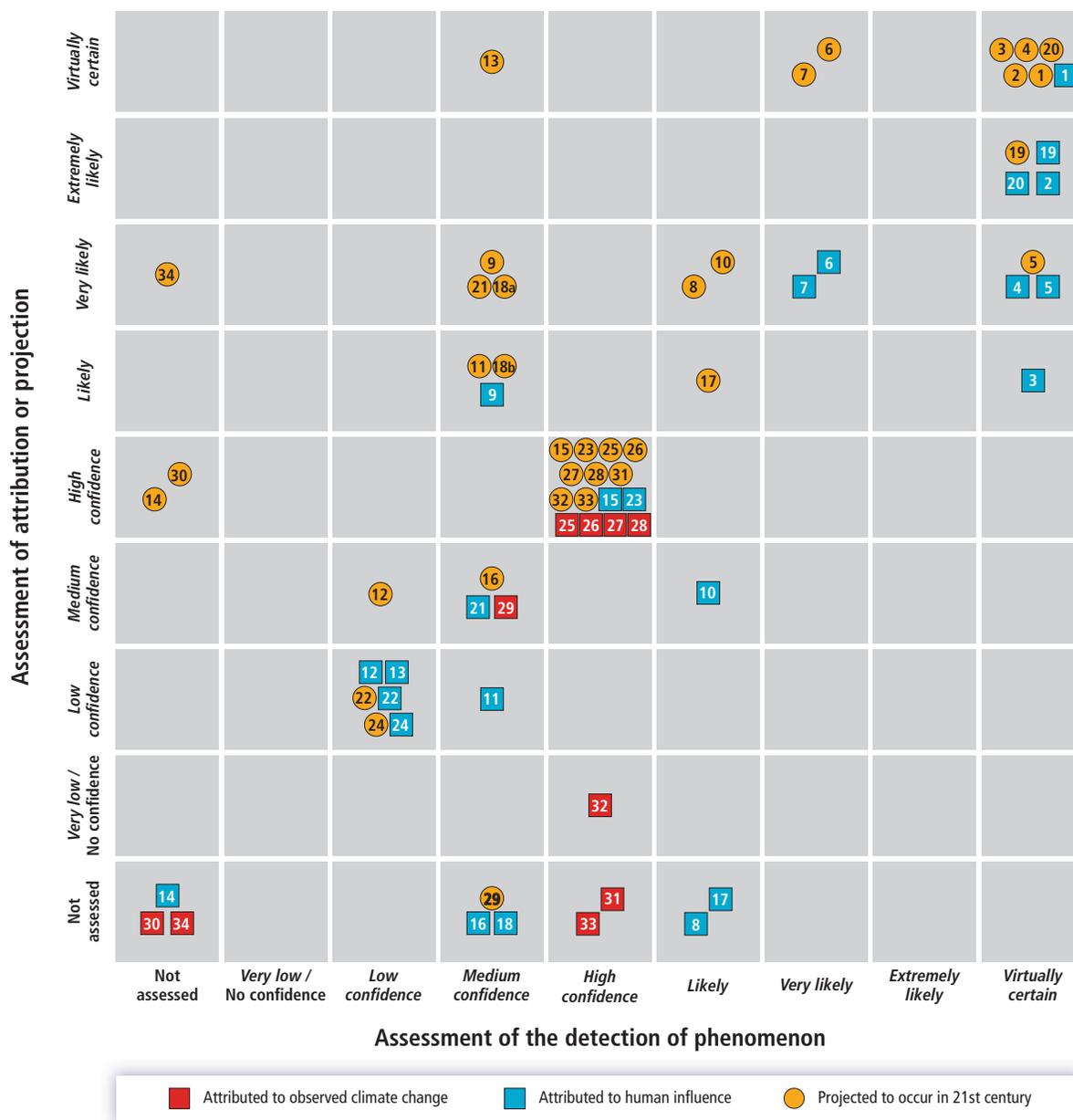
Since publication of the AR4 in 2007, the IPCC has produced two Special Reports: the *Special Report on Renewable Energy Sources and Climate Change Mitigation*, produced by Working Group III and published in 2011; and the *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, produced jointly by WGI and WGII and published in 2012. In addition, the AR5 cycle has staggered the assessment work for its three working groups. WGI AR5 was released in September 2013, and WGIII AR5 will be published after WGII AR5 in 2014. In this section we summarize the major conclusions of the SREX, the SRREN, WGI AR5, and preliminary findings from WGIII AR5. We focus on the key findings, framings, and conceptual innovations these reports bring to WGII AR5.

One common theme that cuts across the Working Groups is the connection of three basic elements of climate change: (1) detection of climate change or its impacts; (ii) attribution of that observed climate change to the increases in GHGs (i.e., human cause, WGI) or attribution of local impacts to the observed climate change in that region; and (3) projection of these impacts and climate change into the 21st century. Table 1-2 gives a summary of phenomena for which such detection,

Trend	Attribution	Confidence assessment	Likelihood assessment
 Increasing overall	 Attributable to observed climate change	<b>HC</b> <i>High</i> or <i>Very High</i> confidence	Findings assigned a likelihood term are associated with high or very high confidence.
 Decreasing overall	 Attributable to human influence	<b>MC</b> <i>Medium</i> confidence	<b>*****</b> <i>Virtually certain</i> 99–100%
 More regions increasing than decreasing	 Projected Occurs in 21st century	<b>LC</b> <i>Low</i> confidence	<b>***</b> <i>Extremely likely</i> 95–100%
 More regions decreasing than increasing		<b>X</b> <i>Very low</i> confidence or No formal confidence level given	<b>**</b> <i>Very likely</i> 90–100%
 Regionally varies or no clear trend		<b>–</b> No explicit assessment made	<b>*</b> <i>Likely</i> 66–100%

Table 1-2 | Confidence in the observation, attribution, and projection of changes in climate system phenomena.

	Phenomenon	Change	Observed to 2010 (X-axis, Figure 1-6)	Y-axis, Figure 1-6		Source
				Attribution	Projected 2050-2100	
1	Greenhouse gases: CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O	∧	****	****	**** (RCPs: CO <sub>2</sub> , N <sub>2</sub> O)	AR5 I-2, I-10, I-11, I-12
2	Global Mean Surface Air Temperature (GMST)	∧	****	***	****	AR5 I-2, I-10, I-11, I-12
3	GMST over all continents except Antarctica	∧	****	*	****	AR5 I-2, I-10, I-11, I-12
4	Global mean sea level	∧	****	**	****	AR5 I-3, I-10, I-13
5	Arctic sea ice cover	∨	****	**	**	AR5 I-4, I-10, I-11, I-12
6	Hot days and nights over land (warmth, frequency)	∧	**	**	****	AR5 SPM-1
7	Cold days and nights over land (warmth, frequency)	∨	**	**	****	AR5 SPM-1
8	Extreme high sea level (incidence, magnitude)	∧	* (since 1970)	X	**	AR5 SPM-1
9	Heat waves and warm spells over land (frequency, duration)	◇	MC	*	**	AR5 SPM-1
10	Heavy precipitation events	◇	*	MC	**	AR5 I-2, I-10, I-12
11	Drought (intensity, duration)	◇	MC (some regions)	LC	*	AR5 SPM-1, SREX-4
12	Tropical cyclones (intensity, frequency, some basins)	~	LC	LC	MC (intensity increase, some basins)	AR5 SPM-1
13	Global mean precipitation	∧	LC	LC	****	AR5 I-2, I-10, I-11, I-12
14	Contrast between wet and dry regions	∧	X	X	HC	AR5 I-12
15	Snow cover (Northern Hemisphere, extent)	∨	HC	HC	HC	AR5 I-4, I-10, I-12
16	Permafrost regions (degrade)	∨	MC	X	MC	AR5 I-4, I-12
17	Storm tracks (shift poleward)	∧	*	X	*	AR5 I-2, I-12
18	Wave heights (different oceans)	∧	MC (N. Atlantic)	X	** * (Arctic a) (Southern b)	AR5 I-3, I-13
19	Upper ocean (warming)	∧	****	***	***	AR5 I-3, I-10, I-11, I-12
20	Ocean acidification	∧	****	***	****	AR5 I-3, I-10, I-6
21	Oceanic oxygen	∨	MC	MC	**	AR5 I-3, I-10, I-6
22	Floods (magnitude, frequency)	~	LC	LC	LC	SREX-3
23	Mountain phenomena (slope instabilities, mass movement, glacial lake outbursts)	∧	HC	HC	HC	SREX-3, AR4 SyR
24	Monsoons	~	LC	LC	LC	SREX-3
25	Plant and animal species (move poleward or up in altitude)	∧	HC	HC	HC	AR4 II-SPM, AR4-SyR
26	Mountain phenomena (slope instabilities, mass movement, glacial lake outbursts)	∧	HC	HC	HC	SREX-3, AR4 SyR
27	Timing of spring events (earlier leafing, greening, planting, bird migration, etc.)	∧	HC	HC	HC	AR4 SyR
28	Marine/freshwater biological systems (shifts in algal, plankton, and fish ranges)	~	HC	HC	HC	AR4 SyR
29	Human health (heat-related mortality, infectious disease vectors)	∧	MC	MC	X	AR4 SyR
30	Water resources	∨	X	X	HC (many regions)	AR4 SyR-SPM
31	Mountain glaciers	∨	HC	X	HC	AR4 II-SPM
32	Coral degradation, bleaching	∧	HC	–	HC	AR4 II-SPM, SyR-SPM
33	Economic losses from weather- and climate- related disasters	∧	HC	X	HC	SREX-4
34	Annual costs of climate change	∧	X	X	**	AR4 SyR-SPM



**Figure 1-6 |** Confidence in the attributed (squares) and projected 21st century (yellow circles) changes in climate system phenomena plotted as a function of confidence in their detection to date. Phenomena and sources (AR4, SREX, WGI AR5) are given in Table 1-2. Strength of confidence is sorted into the nine bins as noted on the axes (no assessment was made; a statement was made and assigned no formal confidence level or *very low confidence*; *low confidence*; *medium confidence*; *high confidence* (no quantification); or *likely*; *very likely*; *extremely likely*; *virtually certain*). Attribution is to either human influence (blue squares, as used by WGI) or observed local/regional climate change (red squares, as used by WGII). Projections assume global warming exceeding 2°C. For AR5 WGII results see, *inter alia*, Chapters 18 and 19.

attribution, or projection has been made across the Working Groups. A schematic presentation of this detection–attribution–projection sequence from preceding reports is given in Figure 1-6. For WGII AR5 attributions, see Chapter 18; and for projections, see the other chapters.

### 1.3.1. Special Report on Renewable Energy Sources and Climate Change Mitigation

SRREN (IPCC, 2011) assesses literature on the challenges of integrating renewable energy sources into existing energy sources to meet the goals of climate change mitigation and sustainable development. More

specifically, it examines six renewable energy sources (bioenergy, direct solar energy, geothermal energy, hydropower, ocean energy, and wind energy) in terms of available technologies, technological potential, and associated costs. SRREN found that the deployment of renewable energy technologies has increased rapidly in recent years, often associated with cost reductions that are expected to continue with advancing technology. Despite the small contribution of renewable energy to current energy supplies, SRREN shows the global potential of renewable energy to be substantially higher than the global energy demand. It is therefore not the technological potential of renewable energy that constrains its development, but rather economic factors, system integration, infrastructure constraints, public acceptance, and sustainability concerns

**Table 1-3** | Examples of linkages between the Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) and the AR5 WGII with chapter references in parentheses.

	SRREN findings	WGII AR5 findings
Water resources	Water availability limits the development of water cooled thermal power and hydropower. Environmental issues will continue to affect hydropower opportunities. (5.1, 5.6, 9.3)	Climate change is predicted to affect surface and groundwater supplies. Development of water-dependent energy resources can also affect freshwater ecosystems. (4.4, 19.3)
Ocean systems	Most ocean energy technologies are at the conceptual phase. Potential technologies include submarine turbines for tidal currents, ocean thermal energy conversion, and devices that harness energy of waves and salinity gradients. (6.2, 6.3, 6.5)	Offshore renewable energy introduces additional drivers of change for near- and offshore coastal and marine ecosystems and species. Ocean geoengineering approaches may have large environmental footprints. (5.5, 6.4)
Land cover changes	The sustainability of bioenergy (i.e., lifecycle GHG emissions) is influenced by land and biomass resource management practices. (2.2, 2.8, 9.3)	Land cover change associated with biofuel production has food security implications; related land use change can alter ecosystems, species, and carbon storage. (19.3, 19.4, 27.2)
Resilient pathways	Higher energy prices associated with transitions from fossil fuels to biofuels and other renewable energy sources may have adverse effects on socioeconomic development. (9.4, 10.5)	The challenge is to identify and implement mixes of technological options that reduce net carbon emissions and support sustained economic and social growth. (20.3)
Regional effects	Latin America is second to Africa for technical potential in producing bioenergy from rain-fed lignocellulosic feedstocks on unprotected grassland and woodlands. (2.2)	Bioenergy production requires large areas with risk of environmental degradation and may involve strong economic teleconnections (e.g., Latin America). (27.2, 27.3)
	The quantity of water resources availability in Central and South America is the largest in the world. The region has the largest proportion of electricity generated through hydropower facilities. (5.2)	Hydropower, the main source of renewable energy available in Central and South America, is prone to serious effects of climate change. Altered river flows affect development in this region and use of land for biofuel production. (27.3, 27.6, 27.8)

(IPCC, 2011). Several SRREN findings have clear linkages with this assessment of climate change impacts, adaptation, and vulnerability, as summarized in Table 1-3.

### 1.3.2. Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation

SREX (IPCC, 2012) is the first IPCC Special Report produced jointly by Working Groups I and II and is the first IPCC report focused specifically on risk management. The report integrates perspectives from historically distinct research communities studying climate science, climate impacts, extreme events and impacts, climate adaptation, and disaster risk management. It assesses relationships between climate change and the characteristics of extreme weather and climate events. SREX provides information on existing societal exposure and vulnerability to climate-related extreme events and disasters; observed trends in weather- and climate-related disasters, disaster losses, and in disaster risk management; projected changes in weather and climate extremes during the 21st century; approaches for managing the increasing risks of climate extremes and disasters; and implications for sustainable development. SREX Chapter 9 is devoted to 14 case studies that illustrate the impacts of extreme climate-related events and options for risk management and adaptation, such as early-warning systems, new forms of insurance coverage, and expansion of social safety nets.

#### 1.3.2.1. Themes and Findings of Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation

The most relevant results of the SREX assessment follow. They are synthesized along these major themes: changing weather and climate-related extreme events, trends in disaster losses, and managing the risks of extreme events and disasters. Other examples of findings presented in SREX concerning the type, magnitude, and frequency of extreme weather and climate events are presented in Table 1-2 of this chapter.

- Based on observations since 1950 there is evidence of changes in some climate-related extremes. It is *very likely* that there has been an overall decrease in the number of cold days and nights, and increase in the number of warm days and nights, at the global scale (SREX SPM, Section 3.3.1, Table 3-2). It is *likely* that there has been an increase in extreme coastal high water events related to increases in mean sea level (SREX SPM, 3.5.3). It is *likely* that anthropogenic influences have led to warming of extreme daily minimum and maximum temperatures at the global scale (SREX SPM, Sections 3.2.2, 3.3.1, 3.3.2, 3.4.4, 3.5.3, Table 3-1).
- The models project substantial warming in temperature extremes by the end of the 21st century. It is *virtually certain* that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century at the global scale. It is *very likely* that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas (SREX SPM, Sections 3.3.2, 3.3.4, Table 3-3, Figure 3-5).
- It is *likely* that the frequency of heavy precipitation will increase in the 21st century over many areas of the globe (SREX SPM, Sections 3.3.2, 3.4.4, Table 3-3, Figure 3-7).
- Economic losses from weather- and climate-related disasters have increased, but with large spatial and interannual variability (*high confidence*, based on *high agreement*, *medium evidence*) (SREX SPM, Sections 4.5.1, 4.5.3, 4.5.4). Trends in losses have been heavily influenced by increasing exposure of people and economic assets (*high confidence*) (SREX SPM, Section 4.5.3).
- Economic, including insured, disaster losses associated with weather, climate-related events, and geophysical events are higher in developed countries. Fatality rates and economic losses expressed as a proportion of GDP are higher in developing countries (*high confidence*). Deaths from natural disasters occur much more in developing countries. From 1970 to 2008, for example, more than 95% of deaths from natural disasters were in developing countries (SREX SPM, Sections 4.5.2, 4.5.4).
- Development practice, policy, and outcomes contribute to shaping disaster risks (*high confidence*): skewed development that may lead to environmental degradation, unplanned urbanization, failure of governance, or reduction of livelihood options result in increased

- exposure and vulnerability to disasters (SREX SPM, Sections 1.1.2, 1.1.3, 2.2.2, 2.5).
- Post-disaster recovery and reconstruction provide an opportunity for reducing the risks posed by future weather- and climate-related disasters (*robust evidence, high agreement*) (SREX SPM, Sections 5.2.3, 8.4.1, 8.5.2).
  - Socioeconomic, demographic, health-related differences, access to livelihoods, good governance, and entitlements are some of the factors that lead to inequalities between people and countries. Inequalities influence local coping and adaptive capacity and pose challenges for risk management systems from local to national levels (*high agreement, robust evidence*) (SREX SPM, Sections 5.5.1, 6.2, 6.3.2, 6.6).
  - The incorporation of climate change adaptation and disaster risk management into local, national, and international development practices and policies could bring benefits (*medium evidence, high agreement*) (SREX SPM, Sections 5.4, 5.5, 5.6, 6.3.1, 6.3.2, 6.4.2, 6.6, 7.4).
  - Combining local knowledge with scientific and technical expertise helps communities reduce their risk and adapt to climate change (*robust evidence, high agreement*). Risk management works best when tailored to local circumstances (SREX SPM, Section 5.4.4).
  - Many measures for managing current and future risks have additional benefits, such as improving peoples' livelihoods, conserving biodiversity, and improving human well-being (*medium evidence, high agreement*) (SREX SPM, Section 6.3.1, Table 6-1).
  - Many measures, when implemented effectively, make sense under a range of future climates. These "low regrets" measures include systems that warn people of impending disasters; changes in land use planning; sustainable land management; ecosystem management; improvements in health surveillance, water supplies, and drainage systems; development and enforcement of building codes; and better education and awareness (SREX SPM, Sections 5.3.1, 5.3.4.3, 6.3.1, 6.5.1, 6.5.2, 7.4.3, Case Studies 9.2.11, 9.2.14).
  - An iterative process involving monitoring, research, evaluation, learning, and innovation can promote adaptive management and reduce disaster risk in the context of climate extremes (*robust evidence, high agreement*) (SREX SPM, Sections 8.6.3, 8.7).
  - Actions ranging from incremental improvements in governance and technology to more transformational changes are essential for reducing risk from climate extremes (*robust evidence, high agreement*) (SREX SPM, Sections 8.6, 8.6.3, 8.7).

### 1.3.2.2. Advances in Conceptualizing Climate Change Vulnerability, Adaptation, and Risk Management in the Context of Human Development

SREX conceptual framing reflects the diversity of expert communities involved in the assessment. It links exposure and vulnerability with

socioeconomic development pathways as determinants of impacts and disaster risk for both human society and natural ecosystems. It is important to note that SREX acknowledges the fundamental role that values and aspirations play in people's perception of risk, of change and causality, and of imagining present and future situations. This value-based approach is put to work as a tool for managing the risks of extreme events and disasters enabling the recognition that socioeconomic systems are in constant flux, and that there are many conflicting and contradictory values in play. The conceptual framing of the problem space offered by SREX (SREX Figure SPM 1-1) serves as a point of departure for many WGII AR5 chapters. Equally important is the conceptualization of a feasible solution space offered in SREX. The solution space is further refined in the WGII AR5 through emphasis on co-benefits of adaptation and mitigation and the further development of transformational change to enable climate resilient development.

### 1.3.3. Relevant Findings from IPCC Working Group I Fifth Assessment Report

This section is a WGII synthesis of the WGI AR5 report that focuses on topics relevant to WGII science.<sup>5</sup> The relevant WGI AR5 chapters and sections are denoted in parentheses. Where statements have *high confidence* or *likely* or better quantification, these qualifiers are dropped for readability. Likewise, many phrases are exact quotations but are not presented in quotes. An overall assessment of climate change over the last several decades from WGI is: Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. Human influence on the climate system is clear; it has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes (SPM).

*Greenhouse gases and climate forcing.* Human activities are the dominant cause of the observed increase in well mixed GHGs since 1750 and of the consequent increase in climate forcing. The GHGs and their forcing continued to increase since AR4 (2, 6, 8). Ozone and stratospheric water vapor also contribute to this forcing (8). Aerosols partially offset this forcing and dominate the uncertainty in determining total anthropogenic forcing of climate change (8). Total anthropogenic climate forcing is positive and has increased more rapidly since 1970 than during prior decades (8). Present-day (2011) abundances of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) exceed the range over the past 800,000 years found in ice cores (5, 6). Annual emission of CO<sub>2</sub> from fossil fuels and cement production was 9.5 GtC in 2011, 54% above the 1990 level (SPM). More than 20% of added CO<sub>2</sub> will remain in the atmosphere for longer than 1000 years (6). Anthropogenic land use change has increased the land surface albedo (a negative forcing) and has also affected climate through the hydrologic cycle, but these effects

<sup>5</sup> This narrative is taken primarily from the executive summaries of the WGI Final Draft chapters and reflects the WGI SPM approved on 27 September 2013 in Stockholm. For the most part, WGI findings summarized here have *high confidence* or a *likely* or better quantification, and hence the confidence and likelihood statements have been dropped for readability. All quantitative ranges are *likely* (66% confidence) or *very likely* (90% confidence) or the modeled range (where noted). In a few instances, assessments with *low confidence* are included and so noted. This WGII narrative is intended to be accurate, but for the purpose here the exact WGI language has been edited and concatenated where possible (e.g., 1950 is substituted for "the middle of the 20th century"). Although quotation marks are not used, there remain long phrases that are direct quotes from the WGI AR5 chapters. All numerical values are verbatim. For the level of uncertainty and the precise wording of the WGI assessment refer directly to the WGI approved SPM and the accepted chapters.

are more uncertain and difficult to quantify (8.3.5). Spatial gradients in forcing (i.e., aerosols, ozone, land use change) affect regional temperature responses (8). Cumulative CO<sub>2</sub> emissions from 1750 to 2011 are 365 GtC (fossil fuel and cement) plus 180 GtC (deforestation and other land use change) (SPM). This 545 GtC represents about half of the 1000 GtC total that can be emitted and still keep global warming under 2°C relative to the reference period 1861–1880 (SPM).

*Air quality on continental scales.* Future surface ozone (air pollution) decreases over most continents for RCP2.6, RCP4.5, and RCP6.0; but it increases for RCP8.5 due to rising CH<sub>4</sub> (11). Changes in air quality for the RCPs are driven primarily by pollutant emissions and secondarily by climate change (11). Air pollution is less under RCP scenarios than under SRES scenarios (11).

*Surface Temperatures.* Global mean surface temperature increased by 0.85°C (0.65°C to 1.06°C) over the period 1880–2012 (linear trend) (SPM) and by 0.72°C over the period 1951–2012 (2). Each of the last 3 decades (from 1983 to 2012) has been successively warmer than any preceding decade since 1850 (SPM). The decade 2003–2012 has been the warmest over the instrumental record, even though the rate of warming over 1998–2012 is smaller than the average rate since 1951 (0.05°C vs. 0.12°C per decade) (2). For the NH, the period 1983–2012 was the warmest of the last 1.400 kyr (5). The slower surface warming trend over the period 1998–2012 vs. 1951–2012 is due in roughly equal measure to a reduced trend in radiative forcing and a cooling contribution from internal, possibly oceanic variability (SPM). Models reproduce the overall 1951–2012 warming trend, but not the smaller trend for 1998–2012 (9). More than half of the 1951–2010 temperature increase is due to the observed anthropogenic increase in GHGs (10). The projected near term (2016–2035) mean surface temperature increase is 0.9°C to 1.3°C (11), and the long term (2081–2100) ranges from 0.9°C to 2.3°C (RCP2.6) to 3.2°C to 5.4°C (RCP8.5) (values are relative to 1850–1900, the earliest period for which global mean surface temperatures have been measured, and include the 0.6°C offset from that period to the model reference period 1986–2005) (SPM, 2, 12).

Global temperatures during the last interglacial period (about 120,000 years ago) were never more than 2°C higher than preindustrial levels (5). By 2050 the global warming range is 1.5°C to 2.3°C above the 1850–1900 period based on the range across all RCPs and models (11.3.6). Near the end of the century (2081–2100) warming above 4°C is typical of RCP8.5, while that of RCP2.6 remains below 2°C (12). Orbital forcing will not trigger widespread glaciation during the next 1000 years (5).

Climate models reproduce observed continental-scale mean surface temperature patterns; on sub-continental and smaller scales model capability is reduced, but is better than in AR4 (9). Regional downscaling provides climate information at the smaller scales needed for impact studies and adds value in regions with highly variable topography and for various small-scale phenomena (9). Anthropogenic warming in the 21st century will proceed more rapidly over land areas than over oceans, and the Arctic region is projected to warm the most (11, 12).

*Precipitation.* Observed trends in global land-average precipitation have *low confidence* prior to 1950 and *medium confidence* thereafter (2).

Simulation of large-scale precipitation patterns has improved somewhat since AR4, but precipitation at regional scales is not well simulated (9). Precipitation (global annual averages) will increase as temperatures increase, and the contrast between dry and wet regions and that between wet and dry seasons will increase over most of the globe (12). By 2100 under RCP8.5, high latitudes will experience more precipitation; many moist mid latitude regions will also experience more; while many mid-latitude and subtropical arid and semi-arid regions will experience less (12). These patterns are also typical of near-term climate change (11). Trends will not be apparent in all regions, especially in the near term, because of natural variability and possible influences of aerosols and land use change (11).

*Extreme temperatures and precipitation.* Since 1950, the numbers of cold days/nights have decreased and the numbers of warm days/nights have increased globally (2); and model simulation of these extreme events has improved since AR4 (9). Since 1950, anthropogenic forcing has contributed to the observed changes in daily temperature extremes on the global scale (10). In most regions the frequency of warm days/nights will increase in the next decades, while that of cold days/nights will decrease (11). Increases in the frequency, duration, and magnitude of hot extremes along with heat stress are expected; however, occasional cold winter extremes will occur (12). Extreme high temperatures (20-year return values) are projected to increase at a rate similar to or greater than the rate of increase of summer mean temperatures in most regions (12). There is a *no confidence* level assigned to projected near-term increases in the duration, intensity, and spatial extent of heat waves and warm spells (11), but in the long term heat waves will occur at higher frequency and longer duration in response to increased seasonal mean temperatures (12.4.3). Since 1950, the frequency or intensity of heavy precipitation events has increased in North America and Europe (2, SPM). Trends in small-scale severe weather events (e.g., hail, thunderstorms) have *low confidence* (2). With global warming, the frequency and intensity of heavy/extreme precipitation events will increase over most mid-latitude land and over wet tropical regions (12), and extreme daily precipitation rates will increase faster than the mean time average (7). Most models underestimate the sensitivity of extreme precipitation to temperature variability/trends, and thus projections may underestimate these extremes (9).

*Floods and droughts.* In many regions, historical droughts (last 1000 years) and historical floods (last 500 years) have been more severe than those observed since 1900 (5). Global-scale trends in drought or dryness since 1950 have *low confidence* due to lack of direct observations, methodological uncertainties, and geographical inconsistencies; hence confidence levels in global drought trends since the 1970s as reported in AR4 are overstated (2). Regional trends are found: the frequency and intensity of drought has increased in the Mediterranean and West Africa, and it has decreased in central North America and northwest Australia since 1950 (2, 2.6.2.2). There is *low confidence* in attributing drought changes to human influence (10). Projected changes in soil moisture and surface runoff have low confidence in the near term (11), but by 2100 under RCP8.5, annual runoff will decrease in parts of southern Europe, Middle East, and southern Africa, and increase in high northern latitudes (12). Decreases in soil moisture with increased risk of agricultural drought are projected in presently dry regions (12).

*Tropical cyclones, storms, and wave heights.* Observed changes in tropical cyclone activity on a centennial scale as well as attribution to human influence have *low confidence* (2, 10); however, the frequency and intensity of the strongest tropical cyclones in the North Atlantic have increased since the 1970s (2). In a few studies, high-resolution atmospheric models have reproduced the year-to-year variability of Atlantic hurricane counts (9). Future changes in intensity and frequency of tropical cyclones will vary by region, but basin-specific projections have *low confidence* (11, 14). The maximum wind speed and precipitation rates of tropical cyclones will increase (14).

Atmospheric circulation features have moved poleward since the 1970s, including a poleward shift of storm tracks and jet streams (2), and model simulation of these patterns has improved since AR4 (9). Large-scale trends in storminess over the last century have *low confidence* (2, 2.6.4). Projections of the position and strength of NH storm tracks, especially for the North Atlantic basin, have *low confidence* (11, 12, 14). With global warming, a shift to more intense individual storms and fewer weak storms is projected (12).

Mean significant wave height has increased over much of the Atlantic Ocean north of 45°N since 1950, with winter season trends of up to 20 cm per decade (*medium confidence*) (3, 3.4.5). Wave heights and the duration of the wave season will increase in the Arctic Ocean as a result of reduced sea ice extent (13). Wave heights will increase in the Southern Ocean as a result of enhanced wind speeds (13).

*Ocean warming, stratification, and circulation.* Overall, the ocean has warmed throughout most of its depth over some periods since 1950, and this warming accounts for about 93% of the increase in the Earth's energy inventory between 1971 and 2010 (3). The upper ocean above 700 m has warmed from 1971 to 2010, and the thermal stratification has increased by about 4% above 200 m depth (3). Anthropogenic forcings have made a substantial contribution to this upper ocean warming (10). Measurement errors in the temperature data sets have been corrected since the AR4 (10). The global ocean continues to warm in all RCP scenarios (11, 12). To date there is no observational evidence of a long-term trend in Atlantic Meridional Overturning Circulation (3); and over the 21st century it is projected to weaken but not undergo an abrupt transition or collapse (12).

*Ocean acidification and low oxygen.* Oceanic uptake of anthropogenic CO<sub>2</sub> results in gradual acidification of the ocean (3). Since 1750 the pH of seawater has decreased by 0.1 (a 26% increase in hydrogen ion concentration) (3). Increased storage of carbon by the oceans over the 21st century will increase acidification, decreasing pH further by 0.065 for RCP2.6 and 0.31 for RCP8.5 (6). Aragonite under-saturation becomes widespread in parts of the Arctic and Southern Oceans and in some coastal upwelling systems at atmospheric CO<sub>2</sub> levels of 500 to 600 ppm (6). Oxygen concentrations have decreased since the 1960s in the open ocean thermocline of many regions (*medium confidence*) (3). By 2100, the oxygen content of the ocean will decrease by a few percent (6). There is no consensus on projection of the very low oxygen (hypoxic or suboxic) waters in the open ocean (6).

*Sea ice.* Continuing the trends reported in AR4, the annual Arctic sea ice extent decreased at rate of 3.5 to 4.1% per decade between 1979 and

2012 (4). Over the past 3 decades, Arctic summer sea ice retreat was unprecedented and Arctic sea surface temperatures were anomalously high, compared with the last 1450 years (SPM). The Arctic average winter sea ice thickness decreased between 1980 and 2008 (4). Current climate models reproduce the seasonal cycle and downward trend of Arctic sea ice extent (9). Anthropogenic forcings have contributed to Arctic sea ice loss since 1979 (10). With global warming, further shrinking and thinning of Arctic sea ice cover is projected, and the Arctic Ocean will be nearly ice free in September before 2050 for the high-warming scenarios like RCP8.5 (11, 12). There is little evidence in climate models of an Arctic Ocean tipping point, that is, the transition from a perennially ice covered to a seasonally ice-free expanse beyond which further sea ice loss is unstoppable and irreversible (12). Annual Antarctic sea ice extent increased by 1.2 to 1.8% per decade between 1979 and 2012 (4). The scientific understanding of this observed increase has *low confidence* (10). With global warming, Antarctic sea ice extent and volume is expected to decrease (*low confidence*) (12).

*Ice sheets, glaciers, snow cover, and permafrost.* During periods over the past few million years that were globally warmer than present, the Greenland and West Antarctic ice sheets were smaller (5). The Antarctic and Greenland ice sheets have on average lost ice during the last 2 decades, and the rate of loss has increased over the most recent decade to a sea level rise equivalent of 0.6 mm yr<sup>-1</sup> for Greenland and 0.4 mm yr<sup>-1</sup> for Antarctica (4). Anthropogenic influences have contributed to Greenland ice loss since 1990 and to the retreat of glaciers since the 1960s, but there is *low confidence* in attributing the causes of Antarctic ice loss (10). With global warming, model studies agree that the Greenland ice sheet will significantly decrease in area and volume, while the Antarctic ice sheet increases in most projections (*confidence not assessed*) (12, 13.4.4). Global warming above a certain threshold (e.g., 2°C to 4°C above the 1850–1900 period) would lead to the near-complete loss of the Greenland Ice Sheet over a millennium or more (*confidence not assessed*) (13). There is *low confidence* and little consensus on the likelihood of abrupt or nonlinear changes in components of the climate system over the 21st century (12).

Multiple lines of evidence support very substantial Arctic warming since the mid-20th century (SPM). Almost all glaciers world-wide have continued to shrink since AR4 (4). Over the last decade, most ice was lost from glaciers in the Canadian Arctic, Greenland ice sheet periphery, Southern Andes, Asian Mountains, and Alaska (4). Current glacier extents are out of balance with current climate, and glaciers will continue to shrink even without further warming (4). Snow cover extent has decreased in the NH, particularly in spring (4); and reductions since 1970 have an anthropogenic component (10). Permafrost temperatures have increased in most regions since the early 1980s: observed warming was up to 3°C in parts of Northern Alaska and 2°C in parts of the Russian European North (4, SPM). With global warming, NH snow cover extent and permafrost extent will decrease further (11, 12). By 2100 the decrease in near-surface permafrost area ranges from 37% (RCP2.6) to 81% (RCP8.5) (*medium confidence*) (12).

*Sea level rise.* During the last interglacial period, when global mean temperatures were no more than 2°C above pre-industrial values (*medium confidence*), maximum global mean sea level was, for several thousand years, 5 m to 10 m higher than present (SPM, 5, 5.3.4, 5.6.1,

5.6.2, 13, 13.2.1) with substantial contributions from Greenland and Antarctic Ice Sheets (5, 13). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous 2 millennia (SPM). Global mean sea level has risen at an average rate of 1.7 mm yr<sup>-1</sup> from 1901 to 2010 and at a faster rate, 3.2 mm yr<sup>-1</sup>, from 1993 to 2010 (3). There is a substantial anthropogenic contribution to the global mean sea level rise since the 1970s (10). The rate of global mean sea level rise during the 21st century will exceed that observed during 1971–2010 for all RCP scenarios (13). For the period 2081–2100 compared to 1986–2005, process-based models project a global mean sea level rise ranging from 0.26 to 0.55 m (RCP2.6) up to 0.45 to 0.82 m (RCP8.5) (13). By 2100 for RCP8.5, this rise is 0.52 to 0.98 m, with a rate of rise reaching 8 to 16 mm yr<sup>-1</sup> (SPM, 13). Only collapse of marine-based sectors of the Antarctic ice sheet could cause global mean sea level to rise substantially above these projections, probably not exceeding several tenths of a meter (*medium confidence*) by 2100 (13). Semi-empirical projections of 2100 sea level rise have a wide spread across models, some overlapping with the process-based models and some twice as large; however, there is *low confidence* in these projections (13, 13.5.2, 13.5.3). If global warming exceeds a certain threshold resulting in near-complete loss of the Greenland Ice Sheet over a millennium or more (*confidence* not assessed), global mean sea level would rise about 7 m (13). Future sea level change will vary regionally, but about 70% of the global coastlines are projected to experience a sea level change within 20% of the global mean (13).

The magnitude of extreme high sea level events has increased since 1970 (3). Future sea level extremes will become more frequent beyond 2050, primarily as a result of increasing mean sea level (13). By 2100 the frequency of current sea level extremes will increase by large factors in some regions (13, 13.7.2). Region-specific projections of storminess and associated storm surges have low confidence (13).

*Climate patterns.* The El Niño-Southern Oscillation (ENSO) system has remained highly variable throughout the past 7000 years with no discernible evidence of orbital modulation (5). The observed variability of the ENSO in the tropical Pacific is now reproduced in most climate models (9). Models project an eastward shift in the ENSO teleconnection patterns of temperature and precipitation variations over the North Pacific and North America (14). ENSO remains the dominant mode of interannual climate variability in the future, and the ENSO precipitation anomalies will intensify due to increased moisture (14). Aggregated over all monsoon systems and over the 21st century, the monsoon will increase in area and intensity while its circulation weakens (14). Monsoon onset dates become earlier or do not change and monsoon retreat dates delay, lengthening the monsoon season (14). Reduced warming and decreased precipitation is projected in the eastern tropical Indian Ocean, with increased warming and precipitation in the western, influencing East Africa and Southeast Asia precipitation (14).

### 1.3.4. Relevant Findings from IPCC Working Group III Fifth Assessment Report

The WGIII report assesses scientific research related to the mitigation of climate change. Because mitigation lowers the effects of climate change as well as the risks of extreme impacts, it is part of a broader

policy strategy that includes adaptation to climate impacts. Both mitigation (WGIII) and adaptation (WGII) involve risk management in the context of many prevailing uncertainties. Uncertainties arise not only in the natural but also in human and social systems, including responses of these to policy interventions. It is possible that extreme climate impacts could play a central role in determining the level of mitigation, adaptation, and other policy responses to climate change (WGIII AR5 Chapter 2).

Over the last two WGIII assessment reports, one of the most important shifts in the scientific literature reflects underlying changes in the structure of the world economy: the underlying determinants of emissions—such as technologies, investment patterns, resource use, lifestyles, and development pathways in general—have not substantially shifted toward a low-GHG pattern despite the adoption of the UNFCCC and the Kyoto Protocol. In 2010, GHG emissions surpassed 50 Gt CO<sub>2</sub>-eq (13.6 GtC), higher than in any previous year since 1750. Most of the emission growth between 2000 and 2010 came from fossil-fuel use in the energy and industry sectors, and took place in emerging economies. This emission growth was not met by significant GHG emission cuts in the industrialized country group, which continued to dominate historical long-term contributions to global CO<sub>2</sub> emissions. In 2010, median per capita GHG emissions in high-income countries were roughly 10 times higher than in low-income countries (WGIII AR5 Chapters 1, 5).

One of the central messages of WGIII AR5 is that technological and behavioral options exist that would allow the world's economies to follow pathways to much lower future emissions of GHGs. Since AR4 a substantial scenario literature has emerged on the technological, economic, and institutional conditions needed to achieve different long-term pathways leading to a stabilization of atmospheric GHG concentrations in 2100. A continuation of current trends of technological change in the absence of explicit climate change mitigation policies is not sufficient to bring about stabilization of GHGs. Scenarios that are *more likely than not* to limit temperature increase to 2°C are becoming increasingly challenging, and most of these include a temporary overshoot of this concentration goal requiring net negative CO<sub>2</sub> emissions after 2050 and thus large-scale application of carbon dioxide removal (CDR) technologies (WGIII AR5 Chapter 6). CDR methods are not mature and have biogeochemical and technological limitations to their potential on a global scale and carry side effects and long-term consequences on a global scale (WGI AR5 SPM; WGIII AR5 Chapter 6). The increasing dependence of pathways on CDR options reduces the ability of policymakers to hedge risks freely across the mitigation technology portfolio (WGIII AR5 Chapter 6). The literature highlights the importance of a systemic, cross-sectoral approach to mitigation. Approaches that emphasize only a subset of sectors or a subset of actions may miss synergies between sectors, raise the costs of mitigation, cause unexpected consequences, and prove insufficient to meet long-term mitigation goals (WGIII AR5 Chapters 6 to 11). The costs of mitigation grow over-proportionally with the stringency of the stabilization target. Delays in mitigation and the unavailability of individual mitigation technologies increase the cost of mitigation and negatively affect the probability of meeting ambitious long-term atmospheric stabilization goals (WGIII AR5 Chapter 6).

Mitigation policies involve multiple actors and institutions at the international, regional, national, and sub-national scales—from global

treaties to firms and individual households. Since AR4 a body of literature has been emerging to explain how this multiplicity of actors and levels, focused on a multiplicity of interacting goals, affects the design and evolution of mitigation policy (WGIII AR5 Chapters 13, 14, 15). Approaches to international cooperation in climate policies have increased and become more diverse ranging from strong multi-lateralism to harmonized national and regional policies (WGIII AR5 Chapter 13). Linkages among regional, national, and sub-national programs may complement international cooperation. Carbon markets have been the focus of regional policy due, in part, to the greater opportunities for trade as carbon markets expand (WGIII AR5 Chapters 13, 14). A combination of policies that address providing a price signal, removing barriers, and promoting long-term investments could be most effective. If there is no coordination within an integrated perspective then results in one area may be counteracted by results in another area, for instance through leakage and rebound effects (WGIII AR5 Chapter 15).

While mitigation efforts generate costs and trade-offs, they also offer possible synergies because many of the policies that can mitigate GHGs also help address other policy goals, such as managing air pollution, water scarcity, or energy security. Since AR4 a substantial literature has emerged on this topic, underscoring the link of mitigation to a wide range of societal goals, often designated as sustainable development (WGIII AR5 Chapters 3, 4, 15).

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