A report accepted by Working Group II of the Intergovernmental Panel on Climate Change but not approved in detail

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Technical Summary

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Summary of main findings

- Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.

- A global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems.

- Other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers.

- More specific information is now available across a wide range of systems and sectors concerning the nature of future impacts, including for some fields not covered in previous assessments.

- More specific information is now available across the regions of the world concerning the nature of future impacts, including for some places not covered in previous assessments.

- Magnitudes of impact can now be estimated more systematically for a range of possible increases in global average temperature.

- Impacts due to altered frequencies and intensities of extreme weather, climate and sea-level events are very likely to change.

- Some large-scale climate events have the potential to cause very large impacts, especially after the 21st century.

- Impacts of climate change will vary regionally but, aggregated and discounted to the present, they are very likely to impose net annual costs which will increase over time as global temperatures increase.

- Some adaptation is occurring now, to observed and projected future climate change, but on a limited basis.

- Adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions.

- A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to future climate change. There are barriers, limits and costs, but these are not fully understood.

- Vulnerability to climate change can be exacerbated by the presence of other stresses.

- Future vulnerability depends not only on climate change but also on development pathway.

- Sustainable development can reduce vulnerability to climate change, and climate change could impede nations' abilities to achieve sustainable development pathways.

- Many impacts can be avoided, reduced or delayed by mitigation.

- A portfolio of adaptation and mitigation measures can diminish the risks associated with climate change.

TS.1 Scope, approach and method of the Working Group II assessment

The decision to produce a Fourth Assessment Report (AR4) was taken by the 19th Session of the Intergovernmental Panel on Climate Change (IPCC) in April 2002.

The Working Group II Report has twenty chapters. The core chapters (3 – 16) address the future impacts of climate change on sectors and regions, the potential for adaptation and the implications for sustainability. Chapter 1 looks at observed changes and Chapter 2 assesses new methodologies and the characterisation of future conditions. Chapters 17 – 20 assess responses to impacts through adaptation (17), the inter-relationships between adaptation and mitigation (18), key vulnerabilities and risks (19) and, finally, perspectives on climate change and sustainability (20).

The Working Group II Fourth Assessment, in common with all IPCC reports, has been produced through an open and peer-reviewed process. It builds upon past assessments and IPCC Special Reports, and incorporates the results of the past 5 years of climate change impacts, adaptation and vulnerability research. Each chapter presents a balanced assessment of the literature which has appeared since the Third Assessment Report[1] (TAR), including non-English language and, where appropriate, 'grey' literature.[2]

This Assessment aims to describe current knowledge of climate-change impacts, adaptation and vulnerability. Specifically it addresses five questions:

- What is the current knowledge about impacts of climate change which are observable now? (addressed in Section TS.2 of the Technical Summary)
- What new scenarios and research methods have led to improvements in knowledge since the Third Assessment? (addressed in Section TS.3)
- What is the current knowledge about future effects of climate change on different sectors and regions? (addressed in Section TS.4)
- What is the current knowledge about adaptation, the interaction between adaptation and mitigation, key vulnerabilities, and the role of sustainable development in the context of climate change? (addressed in Section TS.5)
- What gaps exist in current knowledge and how best can these be filled? (addressed in Section TS.6).

Each of the twenty chapters of the Working Group II Fourth Assessment had a minimum of two Coordinating Lead Authors, six Lead Authors and two Review Editors. The writing team and review editors were appointed by the IPCC Bureau on the recommendation of the Working Group II Co-Chairs and Vice-Chairs. They were selected from the pool of nominated experts, in consultation with the international community of scientists active in the field, and taking into consideration expertise and experience. In total, the Working Group II Fourth Assessment involved 48 Coordinating Lead Authors, 125 Lead Authors and 45 Review Editors, drawn from 70 countries. In addition there were 183 Contributing Authors and 910 Expert Reviewers.

This Technical Summary is intended to capture the most important scientific aspects of the full Working Group II Assessment. Reducing the information from 800 pages to 50 requires much condensing; consequently every statement in the Summary appears with its source in the Assessment, enabling the reader to pursue more detail. Sourcing information is provided in square brackets in the text (see Box TS.1). Uncertainty information is provided in parentheses (see Box TS.2 for definitions of uncertainty). Key terms are defined in Box TS.3.

TS.2 Current knowledge about observed impacts on natural and managed systems

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases (very high confidence). A global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems.

The IPCC Working Group II Third Assessment found evidence that recent regional climate changes, particularly temperature increases, have already affected physical and biological systems [1.1.1].[3] The Fourth Assessment has analysed studies since the Third Assessment showing changes in physical, biological and human systems, mainly from 1970 to 2005, in relation to climate drivers, and has found stronger quantitative evidence [1.3, 1.4]. The major focus is on global and regional surface temperature increases [1.2].

Evaluation of evidence on observed changes related to climate change is made difficult because the observed responses of systems and sectors are influenced by many other factors. Non-climatic drivers can influence systems and sectors directly and/or indirectly through their effects on climate variables such as reflected solar radiation and evaporation [1.2.1]. Socio-economic processes, including land-use change (e.g., agriculture

[1] McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White, Eds., 2001: *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, 1032 pp.

[2] 'Grey' literature is defined as literature which is not available through traditional commercial publication channels, such as working papers, government reports and theses, which therefore may be difficult to access.

[3] See Box TS.1

Box TS.1. Sourcing in the Technical Summary

For example, source [3.3.2] refers to Chapter 3, Section 3, Sub-section 2. In the sourcing, F = Figure, T = Table, B = Box, ES = Executive Summary.

References to the Working Group I Fourth Assessment are shown as, for example, [WGI AR4 SPM] which refers to the Working Group I Fourth Assessment Summary for Policymakers, [WGI AR4 10.3.2] which refers to Chapter 10 Section 10.3.2, and [WGI AR4 Chapter 10] when the whole chapter is referred to. Where a source refers to both the WGI and WGII Fourth Assessments, these are separated by a semi-colon, for example [WGI AR4 10.2.1; 2.1.4]. References to Working Group III are treated in the same way.

Box TS.2. Communication of uncertainty in the Working Group II Fourth Assessment

A set of terms to describe uncertainties in current knowledge is common to all parts of the IPCC Fourth Assessment, based on the *Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties*[4], produced by the IPCC in July 2005.

Description of confidence
On the basis of a comprehensive reading of the literature and their expert judgement, authors have assigned a confidence level to the major statements in the Technical Summary on the basis of their assessment of current knowledge, as follows:

Terminology	*Degree of confidence in being correct*
Very high confidence	At least 9 out of 10 chance of being correct
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than a 1 out of 10 chance

Description of likelihood
Likelihood refers to a probabilistic assessment of some well-defined outcome having occurred or occurring in the future, and may be based on quantitative analysis or an elicitation of expert views. In the Technical Summary, when authors evaluate the likelihood of certain outcomes, the associated meanings are:

Terminology	*Likelihood of the occurrence/outcome*
Virtually certain	>99% probability of occurrence
Very likely	90 to 99% probability
Likely	66 to 90% probability
About as likely as not	33 to 66% probability
Unlikely	10 to 33% probability
Very unlikely	1 to 10% probability
Exceptionally unlikely	<1% probability

Box TS.3. Definitions of key terms

Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where *climate change* refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. *Vulnerability* is a function of the character, magnitude and rate of climate change and the variation to which a system is exposed, its sensitivity and its adaptive capacity.

[4] See http://www.ipcc.ch/activity/uncertaintyguidancenote.pdf.

to urban area), land-cover modification (e.g., ecosystem degradation), technological change, pollution, and invasive species constitute some of the important non-climate drivers [1.2.1].

Much more evidence has accumulated over the past 5 years to indicate that the effects described above are linked to the anthropogenic component of warming.[5] There are three sets of evidence which, taken together, support this conclusion (see Box TS.4).

1. There have been several studies that have linked responses in some physical and biological systems to the anthropogenic component of warming by comparing observed trends with modelled trends in which the natural and anthropogenic forcings are explicitly separated [1.4].

2. Observed changes in many physical and biological systems are consistent with a warming world. The majority (>89% of the >29,000 data sets whose locations are displayed in Figure TS.1) of changes in these systems have been in the direction expected as a response to warming [1.4].

3. A global synthesis of studies in this Assessment strongly demonstrates that the spatial agreement between regions of significant regional warming across the globe and the locations of significant observed changes in many systems consistent with warming is very unlikely[6] to be due solely to natural variability of temperatures or natural variability of the systems [1.4].

For physical systems, (i) climate change is affecting natural and human systems in regions of snow, ice and frozen ground, and (ii) there is now evidence of effects on hydrology and water resources, coastal zones and oceans.

The main evidence from regions of snow, ice and frozen ground is found in ground instability in permafrost regions, and rock avalanches; decrease in travel days of vehicles over frozen roads in the Arctic; increase and enlargement of glacial lakes, and destabilisation of moraines damming these lakes, with increased risk of outburst floods; changes in Arctic and Antarctic Peninsula ecosystems, including sea-ice biomes and predators high on the food chain; and limitations on mountain sports in lower-elevation alpine areas (high confidence)[7] [1.3.1]. These changes parallel the abundant evidence that Arctic sea ice, freshwater ice, ice shelves, the Greenland ice sheet, alpine and Antarctic Peninsula glaciers and ice caps, snow cover and permafrost are undergoing enhanced melting in response to global warming (very high confidence) [WGI AR4 Chapter 4].

Recent evidence in hydrology and water resources shows that spring peak discharge is occurring earlier in rivers affected by snow melt, and there is evidence for enhanced glacial melt in the tropical Andes and in the Alps. Lakes and rivers around the world are warming, with effects on thermal structure and water quality (high confidence) [1.3.2].

Sea-level rise and human development are together contributing to losses of coastal wetlands and mangroves and increasing damage from coastal flooding in many areas (medium confidence) [1.3.3.2].

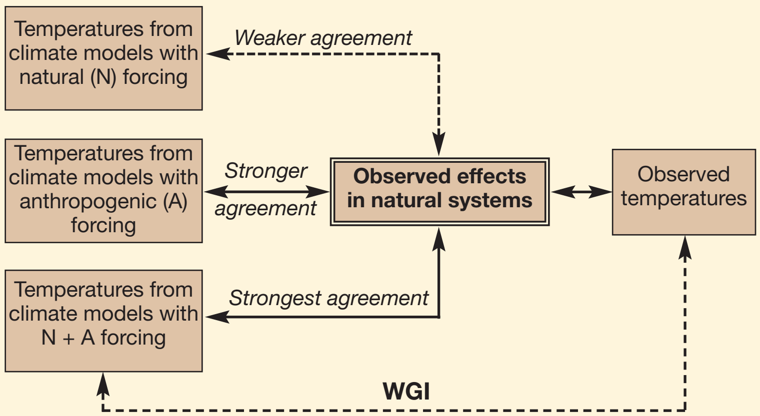
There is more evidence, from a wider range of species and communities in terrestrial ecosystems than reported in the Third Assessment, that recent warming is already strongly affecting natural biological systems. There is substantial new evidence relating changes in marine and freshwater systems to warming. The evidence suggests that both terrestrial and marine biological systems are now being strongly influenced by observed recent warming.

The overwhelming majority of studies of regional climate effects on terrestrial species reveal consistent responses to warming trends, including poleward and elevational range shifts of flora and fauna. Responses of terrestrial species to warming across the Northern Hemisphere are well documented by changes in the timing of growth stages (i.e., phenological changes), especially the earlier onset of spring events, migration, and lengthening of the growing season. Based on satellite observations since the early 1980s, there have been trends in many regions towards earlier 'greening' of vegetation in the spring[8] and increased net primary production linked to longer growing seasons. Changes in abundance of certain species, including limited evidence of a few local disappearances, and changes in community composition over the last few decades have been attributed to climate change (very high confidence) [1.3.5].

Many observed changes in phenology and distribution of marine and freshwater species have been associated with rising water temperatures, as well as other climate-driven changes in ice cover, salinity, oxygen levels and circulation. There have been poleward shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans. For example, plankton has moved polewards by 10° latitude (about 1,000 km) over a period of four decades in the North Atlantic. There have also been documented increases in algal and zooplankton abundance in high-latitude and high-altitude lakes, and earlier fish migration and range changes in rivers [1.3]. While there is increasing evidence for climate change impacts on coral reefs, differentiating the impacts of climate-related stresses from other stresses (e.g., over-fishing and pollution) is difficult. The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic, with an average decrease in pH of 0.1 units [WGI AR4 SPM]. However, the effects of observed

[5] Warming over the past 50 years at the continental scale has been attributed to anthropogenic effects [WGI AR4 SPM].
[6] See Box TS-2.
[7] See Box TS-2.
[8] Measured by the Normalised Difference Vegetation Index (NVDI), which is a relative measure of vegetation greenness in satellite images.

Box TS.4. Linking the causes of climate change to observed effects on physical and biological systems



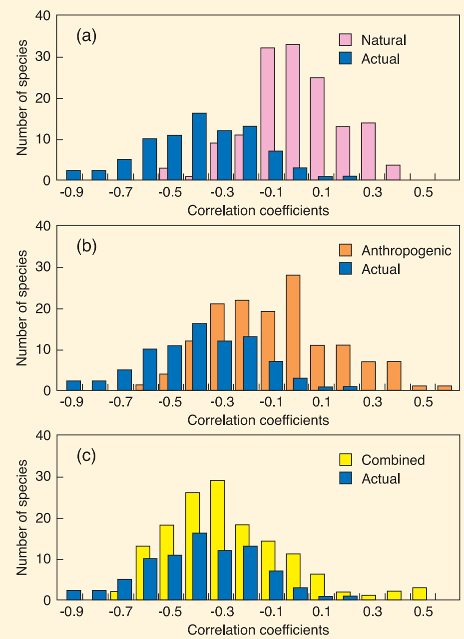
The figure to the left demonstrates the linkages between observed temperatures, observed effects on natural systems, and temperatures from climate model simulations with natural, anthropogenic, and combined natural and anthropogenic forcings. Two ways in which these linkages are utilised in detection and attribution studies of observed effects are described below.

1. Using climate models

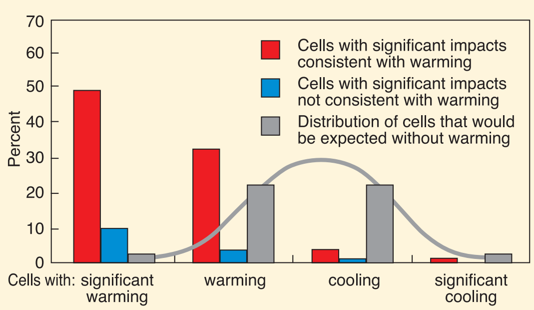
The study of causal connection by separation of natural and anthropogenic forcing factors (Set of Evidence 1 on the preceding page) compares observed temporal changes in animals and plants with changes over the same time periods in observed temperatures as well as modelled temperatures using (i) only natural climate forcing; (ii) only anthropogenic climate forcing; and (iii) both forcings combined.

The panel to the right shows the results from a study employing this methodology[9]. The locations for the modelled temperatures were individual grid boxes corresponding to given animal and plant study sites and time periods.

The agreement (in overlap and shape) between the observed (blue bars) and modelled plots is weakest with natural forcings, stronger with anthropogenic forcings, and strongest with combined forcings. Thus, observed changes in animals and plants are likely responding to both natural and anthropogenic climate forcings, providing a direct cause-and-effect linkage [F1.7, 1.4.2.2].



2. Using spatial analysis



The study of causal connection by spatial analysis (Set of Evidence 3 on the preceding page) follows these stages: (i) it identifies 5° × 5° latitude/longitude cells across the globe which exhibit significant warming, warming, cooling, and significant cooling; (ii) it identifies 5° × 5° cells of significant observed changes in natural systems that are consistent with warming and that are not consistent with warming; and (iii) it statistically determines the degree of spatial agreement between the two sets of cells. In this assessment, the conclusion is that the spatial agreement is significant at the 1% level and is very unlikely to be solely due to natural variability of climate or of the natural systems.

Taken together with evidence of significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica [WGI AR4[10] SPM], this shows a discernible human influence on changes in many natural systems [1.4.2.3].

[9] Plotted are the frequencies of the correlation coefficients (associations) between the timing of changes in traits (e.g., earlier egg-laying) of 145 species and modelled (HadCM3) spring temperatures for the grid-boxes in which each species was examined. (Continues next page after Figure TS.1).

[10] IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge, 996 pp.

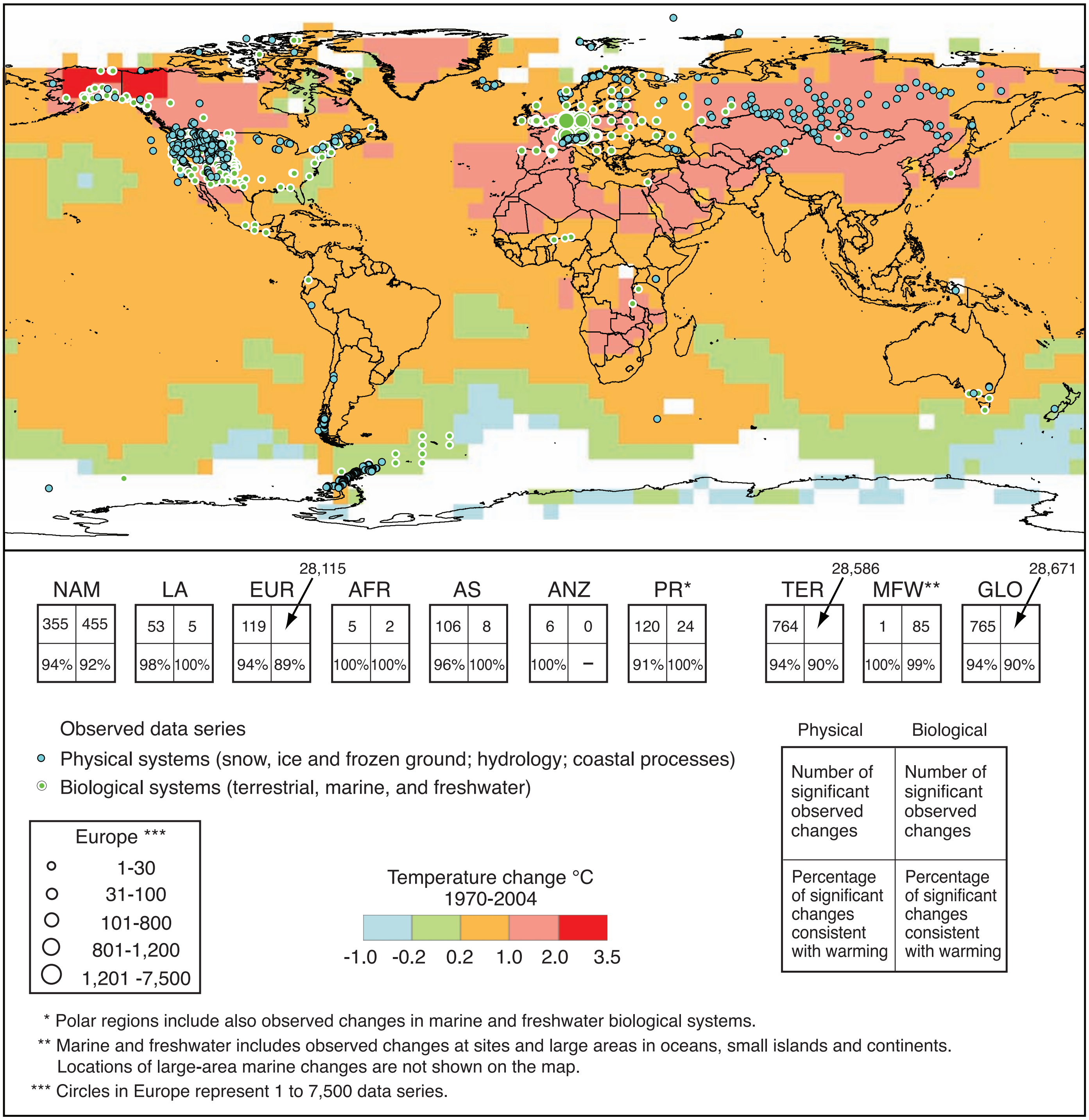


Figure TS.1. *Locations of significant changes in data series of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine and freshwater biological systems), are shown together with surface air temperature changes over the period 1970-2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (i) ending in 1990 or later; (ii) spanning a period of at least 20 years; and (iii) showing a significant change in either direction, as assessed in individual studies. These data series are from about 75 studies (of which about 70 are new since the Third Assessment) and contain about 29,000 data series, of which about 28,000 are from European studies. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2 × 2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR); and (ii) global scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). The numbers of studies from the seven regional boxes (NAM, …, PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFR) systems. Locations of large-area marine changes are not shown on the map. [F1.8, F1.9; Working Group I AR4 F3.9b]* ocean acidification on the marine biosphere are as yet undocumented [1.3]. Warming of lakes and rivers is affecting abundance and productivity, community composition, phenology and the distribution and migration of freshwater species (high confidence) [1.3.4].

Effects of regional increases in temperature on some managed and human systems are emerging, although these are more difficult to discern than those in natural systems, due to adaptation and non-climatic drivers.

Effects have been detected in agricultural and forestry systems [1.3.6]. Changes in several aspects of the human health system have been related to recent warming [1.3.7]. Adaptation to recent warming is beginning to be systematically documented (medium confidence) [1.3.9].

In comparison with other factors, recent warming has been of limited consequence in the agriculture and forestry sectors. A significant advance in phenology, however, has been observed for agriculture and forestry in large parts of the Northern Hemisphere, with limited responses in crop management such as earlier spring planting in northern higher latitudes. The lengthening of the growing season has contributed to an observed increase in forest productivity in many regions, while warmer and drier conditions are partly responsible for reduced forest productivity and increased forest fires in North America and the Mediterranean Basin. Both agriculture and forestry have shown vulnerability to recent trends in heatwaves, droughts and floods (medium confidence) [1.3.6].

While there have been few studies of observed health effects related to recent warming, an increase in high temperature extremes has been associated with excess mortality in Europe, which has prompted adaptation measures. There is emerging evidence of changes in the distribution of some human disease vectors in parts of Europe and Africa. Earlier onset and increases in the seasonal production of allergenic pollen have occurred in mid- and high latitudes in the Northern Hemisphere (medium confidence) [1.3.7].

Changes in socio-economic activities and modes of human response to climate change, including warming, are just beginning to be systematically documented. In regions of snow, ice and frozen ground, responses by indigenous groups relate to changes in the migration patterns, health, and range of animals and plants on which they depend for their livelihood and cultural identity [1.3.9]. Responses vary by community and are dictated by particular histories, perceptions of change and range, and the viability of options available to groups (medium confidence) [1.3.9].

While there is now significant evidence of observed changes in physical and biological systems in every continent, including Antarctica, as well as from most oceans, the majority of studies come from mid- and high latitudes in the Northern Hemisphere. Documentation of observed changes in tropical regions and the Southern Hemisphere is sparse [1.5].

TS.3 Methods and scenarios

TS.3.1 Developments in methods available to researchers on climate change impacts, adaptation and vulnerability

Since the Third Assessment (TAR), the need for improved decision analysis has motivated an expansion in the number of climate-change impacts, adaptation and vulnerability (CCIAV) approaches and methods in use. While scientific research aims to reduce uncertainty, decision-making aims to manage uncertainty by making the best possible use of the available knowledge [2.2.7, 2.3.4]. This usually involves close collaboration between researchers and stakeholders [2.3.2].

Therefore, although the standard climate scenario-driven approach is used in a large proportion of assessments described in this Report, the use of other approaches is increasing [2.2.1]. They include assessments of current and future adaptations to climate variability and change [2.2.3], adaptive capacity, social vulnerability [2.2.4], multiple stresses and adaptation in the context of sustainable development [2.2.5, 2.2.6].

Risk management can be applied in all of these contexts. It is designed for decision-making under uncertainty; several detailed frameworks have been developed for CCIAV assessments and its use is expanding rapidly. The advantages of risk management include the use of formalised methods to manage uncertainty, stakeholder involvement, use of methods for evaluating policy options without being policy-prescriptive, integration of different disciplinary approaches, and mainstreaming of climate-change concerns into the broader decision-making context [2.2.6].

Stakeholders bring vital input into CCIAV assessments about a range of risks and their management. In particular, how a group or system can cope with current climate risks provides a solid basis for assessments of future risks. An increasing number of

Footnote 9, continued from below Box TS.4. At each location, all of which are in the Northern Hemisphere, the changing trait is compared with modelled temperatures driven by: (a) Natural forcings (pink bars), (b) anthropogenic (i.e., human) forcings (orange bars), and (c) combined natural and anthropogenic forcings (yellow bars). In addition, on each panel the frequencies of the correlation coefficients between the actual temperatures recorded during each study and changes in the traits of 83 species, the only ones of the 145 with reported local-temperature trends, are shown (dark blue bars). On average the number of years species were examined is about 28 with average starting and ending years of 1960 to 1998. Note that the agreement: a) between the natural and actual plots is weaker ($K=60.16$, $p>0.05$) than b) between the anthropogenic and actual ($K=35.15$, $p>0.05$), which in turn is weaker than c) the agreement between combined and actual ($K=3.65$, $p<0.01$). Taken together, these plots show that a measurable portion of the warming regional temperatures to which species are reacting can be attributed to humans, therefore showing joint attribution (see Chapter 1).

assessments involve, or are conducted by, stakeholders. This establishes credibility and helps to confer 'ownership' of the results, which is a prerequisite for effective risk management [2.3.2].

TS.3.2 Characterising the future in the Working Group II IPCC Fourth Assessment

CCIAV assessments usually require information on how conditions such as climate, social and economic development, and other environmental factors are expected to change in the future. This commonly entails the development of scenarios, storylines or other characterisations of the future, often disaggregated to the regional or local scale [2.4.1, 2.4.6].

Scenarios are plausible descriptions, without ascribed likelihoods, of possible future states of the world. Storylines are qualitative, internally consistent narratives of how the future may evolve, which often underpin quantitative projections of future change that, together with the storyline, constitute a scenario [B2.1]. The IPCC Special Report on Emissions Scenarios (SRES), published in 2000, provided scenarios of future greenhouse gas emissions accompanied by storylines of social, economic and technological development that can be used in CCIAV studies (Figure TS.2). Although there can be methodological problems in applying these scenarios (for example, in downscaling projections of population and gross domestic product (GDP) from the four SRES large world regions to national or sub-national scales), they nevertheless provide a coherent global quantification of socio-economic development, greenhouse gas emissions and climate, and represent some of the most comprehensive scenarios presently available to CCIAV researchers. A substantial number of the impact studies assessed in this volume that employed future characterisations made use of the SRES scenarios. For some other studies, especially empirical analyses of adaptation and vulnerability, the scenarios were of limited relevance and were not adopted [2.4.6].

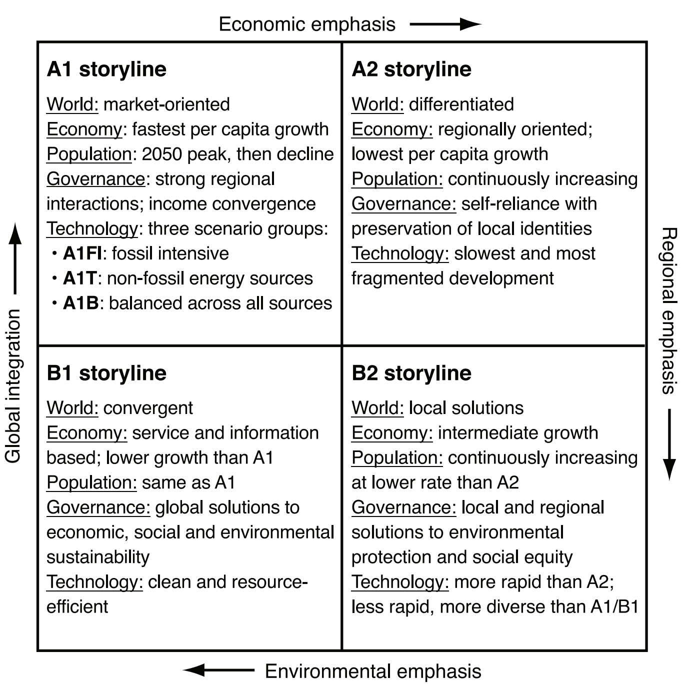


Figure TS.2. *Summary characteristics of the four SRES storylines [F2.5]*

In the future, better integration of climate-related scenarios with those widely adopted by other international bodies (mainstreaming) is desirable, and enhanced information exchange between research and policy communities will greatly improve scenario usage and acceptance. Improved scenarios are required for poorly specified indicators such as future technology and adaptive capacity, and interactions between key drivers of change need to be better specified [2.5].

Characterising future climate

Sensitivity studies
A substantial number of model-based CCIAV studies assessed in this Report employ sensitivity analysis to investigate the behaviour of a system by assuming arbitrary, often regularly spaced, adjustments in important driving variables. Using a range of perturbations allows construction of impact response surfaces, which are increasingly being used in combination with probabilistic representations of future climate to assess risks of impacts [2.4.3, 2.3.1, 2.4.8].

Analogues
Historical extreme weather events, such as floods, heatwaves and droughts, are increasingly being analysed with respect to their impacts and adaptive responses. Such studies can be useful for planning adaptation responses, especially if these events become more frequent and/or severe in the future. Spatial analogues (regions having a present-day climate similar to that expected in a study region in the future) have been adopted as a heuristic device for analysing economic impacts, adaptation needs and risks to biodiversity [2.4.4].

Climate model data
The majority of quantitative CCIAV studies assessed in the AR4 use climate models to generate the underlying scenarios of climate change. Some scenarios are based on pre-SRES emissions scenarios, such as IS92a, or even on equilibrium climate model experiments. However, the greatest proportion is derived from SRES emissions scenarios, principally the A2 scenario (assuming high emissions), for which the majority of early SRES-based climate model experiments were conducted. A few scenario-driven studies explore singular events with widespread consequences, such as an abrupt cessation of the North Atlantic Meridional Overturning Circulation (MOC) [2.4.6.1, 2.4.7].

The CCIAV studies assessed in the Working Group II Fourth Assessment (WGII AR4) are generally based on climate model simulations assessed by Working Group I (WGI) in the TAR. Since the TAR, new simulations have been performed with coupled Atmosphere-Ocean General Circulation Models (AOGCMs) assuming SRES emissions. These are assessed in the WGI AR4, but most were not available for the CCIAV studies assessed for the WGII AR4. Figure TS.3 compares the range of regional temperature and precipitation projections from recent A2-forced AOGCM simulations (assessed by WGI AR4: red bars) with earlier A2-forced simulations assessed in WGI TAR and used for scenario construction in many CCIAV studies assessed for the WGII AR4 (blue bars). The figure supports the WGI AR4 conclusion that the basic pattern of projected warming is little changed from previous assessments (note the positions of the blue and red bars), but confidence in regional projections is now higher for most regions for temperature and in some regions for precipitation (i.e., where red bars are shorter than blue bars) [B2.3].

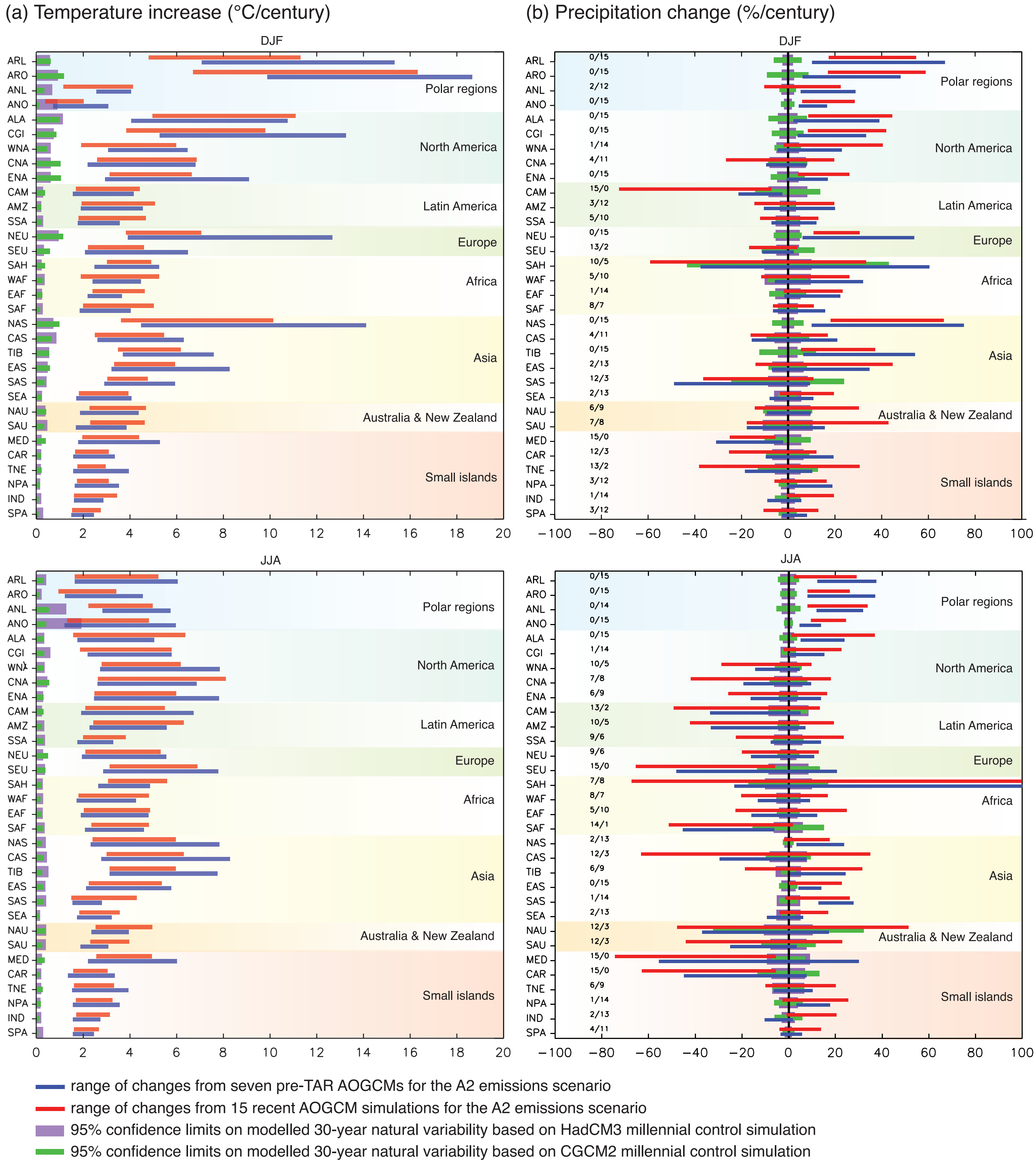


Figure TS.3. *Range of winter and summer temperature and precipitation changes up to the end of the 21st century across recent (fifteen models – red bars) and pre-TAR (seven models – blue bars) AOGCM projections under the SRES A2 emissions scenarios for thirty-two world regions, expressed as rate of change per century. Mauve and green bars show modelled 30-year natural variability. Numbers on precipitation plots show the number of recent A2 runs giving negative/positive precipitation change. DJF: December, January, February; JJA: June, July, August. [F2.6, which includes map of regions]*

Non-climate scenarios

While the CCIAV studies reported in the TAR typically applied one or more climate scenarios, very few applied contemporaneous scenarios of socio-economic, land-use or other environmental changes. Those that did used a range of sources to develop them. In contrast, AR4 studies which include SRES assumptions may now have several estimates, taking into account different storylines. The role of non-climate drivers such as technological change and regional land-use policy is shown in some studies to be more important in determining outcomes than climate change [2.4.6].

Scenarios of CO_2 concentration are required in some studies, as elevated concentrations can affect the acidity of the oceans and the growth and water use of many terrestrial plants. The observed CO_2 concentration in 2005 was about 380 ppm and was projected in the TAR using the Bern-CC model to rise to the following levels by the year 2100 for the SRES marker scenarios – B1: 540 ppm (range 486-681 ppm); A1T: 575 (506-735); B2: 611 (544-769); A1B: 703 (617-918); A2: 836 (735-1,080); A1FI: 958 (824-1,248) ppm. Values similar to these reference levels are commonly adopted in SRES-based impact studies [2.4.6.2]. Moreover, a multi-stressor approach can reveal important regional dependencies between drivers and their impacts (e.g., the

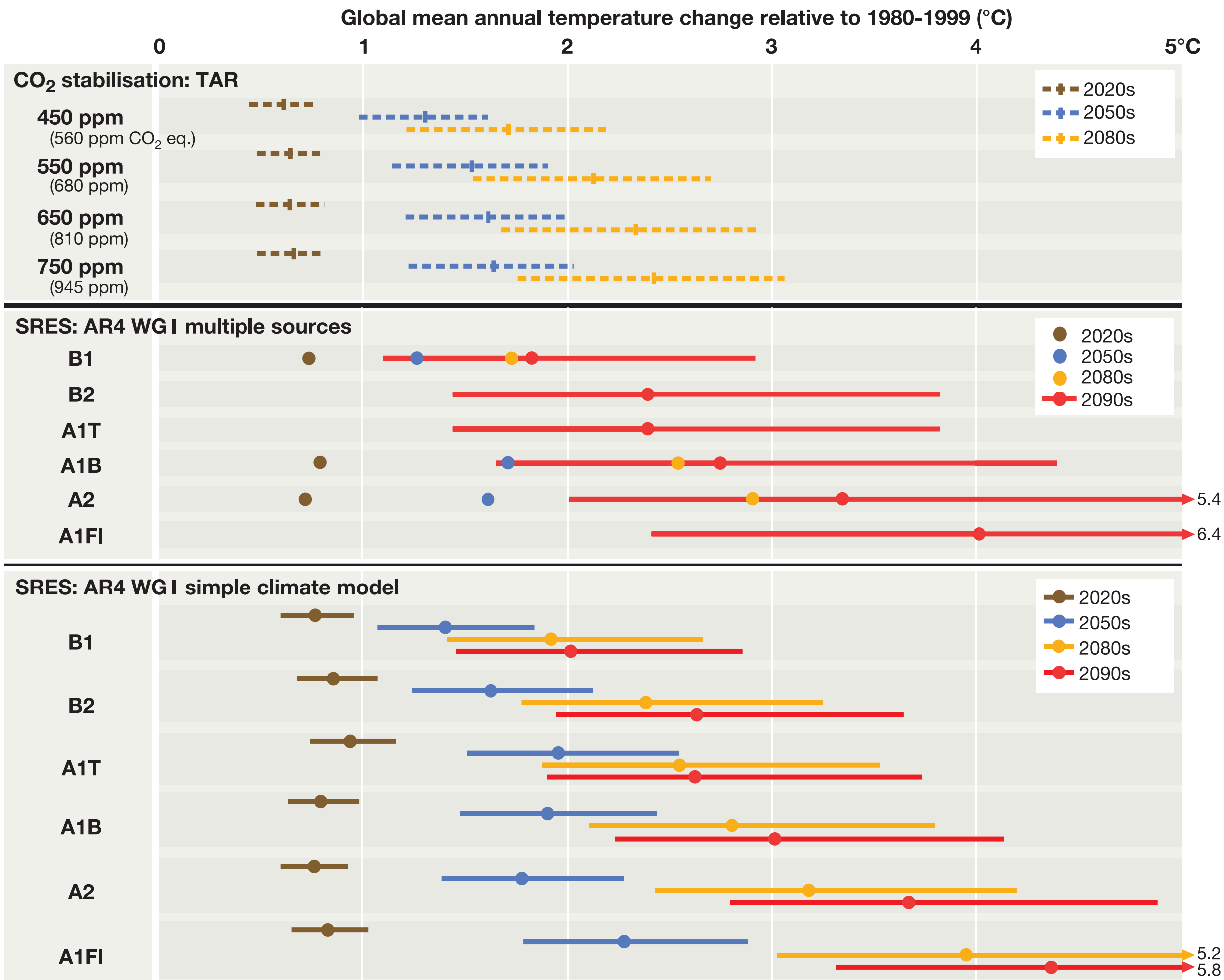


Figure TS.4. *Global temperature changes for selected time periods, relative to 1980-1999, projected for SRES and stabilisation scenarios. To express the temperature change relative to 1850-1899, add 0.5°C. More detail is provided in Chapter 2 [Box 2.8]. Estimates are for the 2020s, 2050s and 2080s, (the time periods used by the IPCC Data Distribution Centre and therefore in many impact studies) and for the 2090s. SRES-based projections are shown using two different approaches.* ***Middle panel:*** *projections from the WGI AR4 SPM based on multiple sources. Best estimates are based on AOGCMs (coloured dots). Uncertainty ranges, available only for the 2090s, are based on models, observational constraints and expert judgement.* ***Lower panel:*** *best estimates and uncertainty ranges based on a simple climate model (SCM), also from WGI AR4 (Chapter 10).* ***Upper panel:*** *best estimates and uncertainty ranges for four CO_2-stabilisation scenarios using an SCM. Results are from the TAR because comparable projections for the 21st century are not available in the AR4. However, estimates of equilibrium warming are reported in the WGI AR4 for CO_2-equivalent stabilisation[11]. Note that equilibrium temperatures would not be reached until decades or centuries after greenhouse gas stabilisation. Uncertainty ranges: middle panel, likely range (> 66% probability); lower panel, range between 19 estimates calculated assuming low carbon-cycle feedbacks (mean - 1 standard deviation) and those assuming high carbon-cycle feedbacks (mean + 1 standard deviation); upper panel, range across seven model tunings for medium carbon-cycle settings.*

[11] Best estimate and likely range of equilibrium warming for seven levels of CO_2-equivalent stabilisation from the WG1 AR4 are: 350 ppm, 1.0°C [0.6–1.4]; 450 ppm, 2.1°C [1.4–3.1]; 550 ppm, 2.9°C [1.9–4.4]; 650 ppm, 3.6°C [2.4–5.5]; 750 ppm, 4.3°C [2.8–6.4]; 1,000 ppm, 5.5°C [3.7–8.3] and 1,200 ppm, 6.3°C [4.2–9.4].

combined effects of extreme weather and air-pollution events on human health). This expansion of scenario scope and application has brought into focus the wide range of potential future impacts and their associated uncertainties [2.2.5, 2.5].

Mitigation/stabilisation scenarios

The SRES storylines assume that no specific climate policies will be implemented to reduce greenhouse gas emissions (i.e. mitigation). Projections of global mean warming during the 21st century for the six SRES scenarios using two different approaches reported by the WGI AR4 (Chapter 10) are depicted in the middle and lower panels of Figure TS-4. Even without assuming explicit climate policies, differences between projections of warming for alternative emissions scenarios by the end of the century can exceed 2°C [B2.8].

CCIAV studies assuming mitigated futures are beginning to assess the benefits (through impacts ameliorated or avoided) of climate policy decisions. Stabilisation scenarios are a type of mitigation scenario describing futures in which emissions reductions are undertaken so that greenhouse gas concentrations, radiative forcing or global average temperature changes do not exceed a prescribed limit. There have been very few studies of the impacts of climate change assuming stabilisation. One reason for this is that relatively few AOGCM stabilisation runs have been completed so far, although the situation is rapidly changing [2.4.6].

Greenhouse gas mitigation is expected to reduce global mean warming relative to baseline emissions, which in turn could avoid some adverse impacts of climate change. To indicate the projected effect of mitigation on temperature during the 21st century, and in the absence of more recent, comparable estimates in the WGI AR4, results from the Third Assessment Report using a simple climate model are reproduced in the upper panel of Figure TS-4. These portray the temperature response for four CO_2-stabilisation scenarios by three dates in the early (2025), mid (2055), and late (2085) 21st century[12] [B2.8].

Large-scale singularities

Very few studies have been conducted on the impacts of large-scale singularities, which are extreme, sometimes irreversible, changes in the Earth system such as an abrupt cessation of the North Atlantic Meridional Overturning Circulation, or rapid global sea-level rise due to Antarctic and/or Greenland ice sheet melting [2.4.7]. Due to incomplete understanding of the underlying mechanisms of these events, or their likelihood, only exploratory studies have been carried out. For example, in terms of exploring the worst-case scenario of abrupt sea-level rise, impact assessments have been conducted for the coastal zone for a 5 m rise, and for a 2.2 m rise by 2100 [2.4.7]. This is the first time these scenarios have been included in any WGII assessment, and the expectation is that many more such studies will become available for assessment in the future.

Probabilistic characterisations

Probabilistic characterisations of future climate and non-climate conditions are increasingly becoming available. A number of studies focused on the climate system have generated probabilistic estimates of climate change, conditional on selected or probabilistic emissions scenarios, the latter being a subject of considerable debate [2.4.8]. Probabilistic futures have been applied in a few CCIAV studies to estimate the risk of exceeding predefined thresholds of impact and the associated timing of such exceedances [2.3.1].

TS.4 Current knowledge about future impacts

This section summarises the main projected impacts in each system and sector (Section TS.4.1) and region (Section TS.4.2) over this century,[13] judged in terms of relevance for people and the environment. It assumes that climate change is not mitigated, and that adaptive capacity has not been enhanced by climate policy. All global temperature changes are expressed relative to 1990 unless otherwise stated.[14] The impacts stem from changes in climate and sea-level changes associated with global temperature change, and frequently reflect projected changes in precipitation and other climate variables in addition to temperature.

TS.4.1 Sectoral impacts, adaptation and vulnerability

A summary of impacts projected for each sector is given in Box TS.5.

Freshwater resources and their management

The impacts of climate change on freshwater systems and their management are mainly due to the observed and projected increases in temperature, evaporation, sea level and precipitation variability (very high confidence).
More than one-sixth of the world's population live in glacier- or snowmelt-fed river basins and will be affected by a decrease in water volume stored in glaciers and snowpack, an increase in the ratio of winter to annual flows, and possibly a reduction in low flows caused by decreased glacier extent or melt-season snow water storage [3.4.1, 3.4.3]. Sea-level rise will extend areas of salinisation of groundwater and estuaries, resulting in a decrease in freshwater availability for humans and ecosystems in coastal areas [3.2, 3.4.2]. Increased precipitation intensity and variability is projected to increase the risk of floods and droughts in many areas [3.3.1]. Up to 20% of the world's population live in river basins that are likely to be affected by increased flood hazard by the 2080s in the course of global warming [3.4.3].

[12] WRE stabilisation profiles were used in the TAR, and a description is given in the TAR Synthesis Report.
[13] Unless otherwise stated.
[14] To express the temperature change relative to pre-industrial (about 1750) levels, add 0.6°C.

The number of people living in severely stressed river basins is projected to increase significantly from 1.4-1.6 billion in 1995 to 4.3-6.9 billion in 2050, for the SRES A2 scenario (medium confidence).
The population at risk of increasing water stress for the full range of SRES scenarios is projected to be: 0.4-1.7 billion, 1.0-2.0 billion and 1.1-3.2 billion, in the 2020s, 2050s and 2080s, respectively [3.5.1]. In the 2050s (A2 scenario), 262-983 million people are likely to move into the water-stressed category [3.5.1]. Water stress is projected to decrease by the 2050s on 20-29% of the global land area (considering two climate models and the SRES scenarios A2 and B2) and to increase on 62-76% of the global land area [3.5.1].

Semi-arid and arid areas are particularly exposed to the impacts of climate change on freshwater (high confidence).
Many of these areas (e.g., Mediterranean Basin, western USA, southern Africa, north-eastern Brazil, southern and eastern Australia) will suffer a decrease in water resources due to climate change (see Figure TS.5) [3.4, 3.7]. Efforts to offset declining surface water availability due to increasing precipitation variability will be hampered by the fact that groundwater recharge is likely to decrease considerably in some already water-stressed regions [3.4.2], where vulnerability is often exacerbated by the rapid increase of population and water demand [3.5.1].

Higher water temperatures, increased precipitation intensity and longer periods of low flows are likely to exacerbate many forms of water pollution, with impacts on ecosystems, human health, and water system reliability and operating costs (high confidence).
These pollutants include sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt and thermal pollution [3.2, 3.4.4, 3.4.5].

Climate change affects the function and operation of existing water infrastructure as well as water management practices (very high confidence).
Adverse effects of climate on freshwater systems aggravate the impacts of other stresses, such as population growth, changing economic activity, land-use change and urbanisation [3.3.2, 3.5]. Globally, water demand will grow in the coming decades, primarily due to population growth and increased affluence. Regionally, large changes in irrigation water demand as a result of climate change are likely [3.5.1]. Current water management practices are very likely to be inadequate to reduce the negative impacts of climate change on water-supply reliability, flood risk, health, energy and aquatic ecosystems [3.4, 3.5]. Improved incorporation of current climate variability into water-related management is likely to make adaptation to future climate change easier [3.6].

Adaptation procedures and risk management practices for the water sector are being developed in some countries and regions (e.g., Caribbean, Canada, Australia, Netherlands, UK, USA, Germany) that recognise the uncertainty of projected hydrological changes (very high confidence).
Since the IPCC Third Assessment, uncertainties have been evaluated and their interpretation has improved, and new methods (e.g., ensemble-based approaches) are being developed for their characterisation [3.4, 3.5]. Nevertheless, quantitative projections of changes in precipitation, river flows and water levels at the river-basin scale remain uncertain [3.3.1, 3.4].

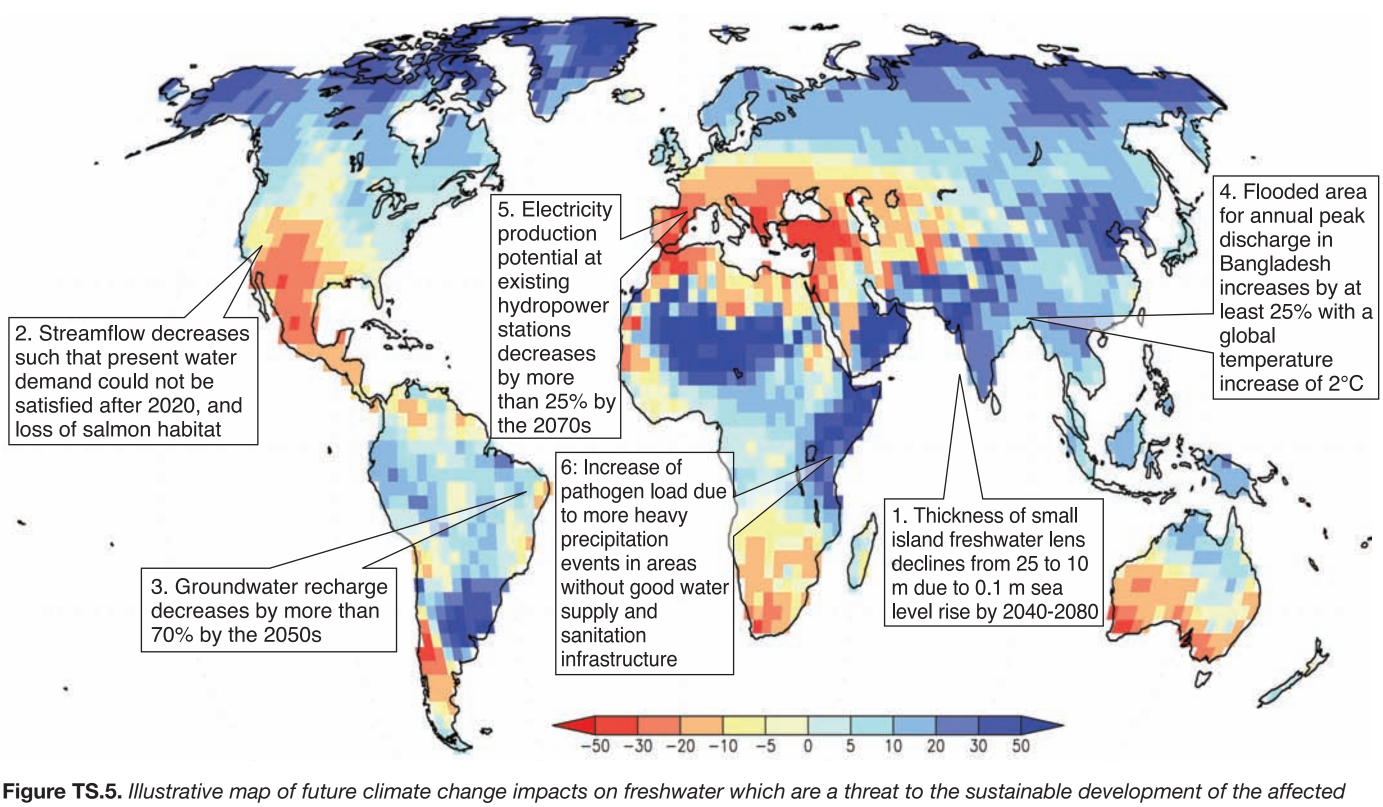


Figure TS.5. *Illustrative map of future climate change impacts on freshwater which are a threat to the sustainable development of the affected regions. Background shows ensemble mean change of annual runoff, in percent, between the present (1981-2000) and 2081-2100 for the SRES A1B emissions scenario; blue denotes increased runoff, red denotes decreased runoff. Underlying map from Nohara et al. (2006) [F3.8].*

The negative impacts of climate change on freshwater systems outweigh its benefits (high confidence).

All IPCC regions show an overall net negative impact of climate change on water resources and freshwater ecosystems. Areas in which runoff is projected to decline are likely to face a reduction in the value of the services provided by water resources. The beneficial impacts of increased annual runoff in other areas is likely to be tempered in some areas by negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality and flood risks (see Figure TS.5) [3.4, 3.5].

Ecosystems

Records of the geological past show that ecosystems have some capacity to adapt naturally to climate change [WGI AR4 Chapter 6; 4.2], but this resilience[15] has never been challenged by a large global human population and its multi-faceted demands from and pressures on ecosystems [4.1, 4.2].

The resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by 2100 by an unprecedented combination of change in climate, associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification), and other global change drivers (e.g., land-use change, pollution, over-exploitation of resources) (high confidence).

Ecosystems are very likely to be exposed to atmospheric CO_2 levels much higher than in the past 650,000 years, and global mean temperatures at least as high as those in the past 740,000 years [WGI AR4 Chapter 6; 4.2, 4.4.10, 4.4.11]. By 2100, ocean pH is very likely to be lower than during the last 20 million years [4.4.9]. Extractive use from and fragmentation of wild habitats are very likely to impair species' adaptation [4.1.2, 4.1.3, 4.2, 4.4.5, 4.4.10]. Exceedance of ecosystem resilience is very likely to be characterised by threshold-type responses, many irreversible on time-scales relevant to human society, such as biodiversity loss through extinction, disruption of species' ecological interactions, and major changes in ecosystem structure and disturbance regimes (especially wildfire and insects) (see Figure TS.6). Key ecosystem properties (e.g., biodiversity) or regulating services (e.g., carbon sequestration) are very likely to be impaired [4.2, 4.4.1, 4.4.2 to 4.4.9, 4.4.10, 4.4.11, F4.4, T4.1].

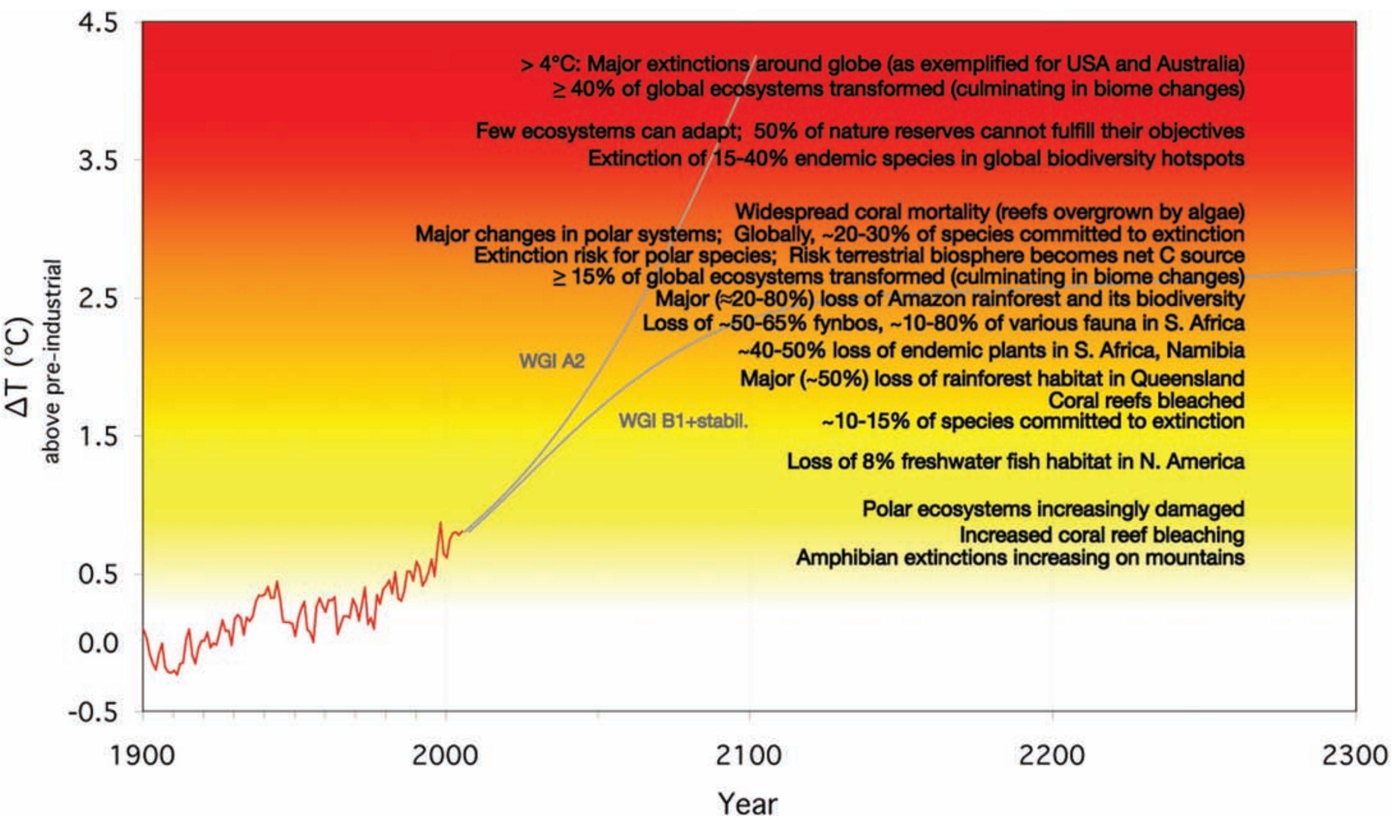


Figure TS.6. *Compendium of projected risks due to critical climate change impacts on ecosystems for different levels of global mean annual temperature rise, ΔT, relative to pre-industrial climate, used as a proxy for climate change. The red curve shows observed temperature anomalies for the period 1900-2005 [WGI AR4 F3.6]. The two grey curves provide examples of the possible future evolution of global average temperature change (ΔT) with time [WGI AR4 F10.4] exemplified by WGI simulated, multi-model mean responses to (i) the A2 radiative forcing scenario (WGI A2) and (ii) an extended B1 scenario (WGI B1+stabil.), where radiative forcing beyond 2100 was kept constant at the 2100 value [WGI AR4 F10.4, 10.7]. White shading indicates neutral, small negative, or positive impacts or risks; yellow indicates negative impacts for some systems or low risks; and red indicates negative impacts or risks that are more widespread and/or greater in magnitude. Illustrated impacts take into account climate change impacts only, and omit effects of land-use change or habitat fragmentation, over-harvesting or pollution (e.g., nitrogen deposition). A few, however, take into account fire regime changes, several account for likely productivity-enhancing effects of rising atmospheric CO_2 and some account for migration effects. [F4.4, T4.1]*

[15] *Resilience* is defined as the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt naturally to stress and change.

The terrestrial biosphere is likely to become a net carbon source by 2100, thus amplifying climate change, given continued greenhouse gas emissions at or above current rates and other unmitigated global changes, such as land-use changes (high confidence).

Several major terrestrial carbon stocks are vulnerable to climate change and/or land-use impacts [F4.1, 4.4.1, F4.2, 4.4.5, 4.4.6, 4.4.10, F4.3]. The terrestrial biosphere currently serves as a variable, but generally increasing, carbon sink (due to CO_2-fertilisation, moderate climate change and other effects) but this is likely to peak before mid-century and then tend towards a net carbon source, thus amplifying climate change [F4.2, 4.4.1, 4.4.10, F4.3, 4.4.11], while ocean buffering capacity begins saturating [WGI AR4, e.g., 7.3.5]. This is likely to occur before 2100, assuming continued greenhouse gas emissions at or above current rates and unmitigated global change drivers including land-use changes, notably tropical deforestation. Methane emissions from tundra are likely to accelerate [4.4.6].

Roughly 20 to 30% (varying among regional biotas from 1% to 80%) of species assessed so far (in an unbiased sample) are likely to be at increasingly high risk of extinction as global mean temperatures exceed 2 to 3°C above pre-industrial levels (medium confidence).

Global losses of biodiversity are of key relevance, being irreversible [4.4.10, 4.4.11, F4.4, T4.1]. Endemic species richness is highest where regional palaeo-climatic changes have been muted, indicating that endemics are likely to be at a greater extinction risk than in the geological past [4.4.5, 4.4.11, F4.4, T4.1]. Ocean acidification is likely to impair aragonite-based shell formation in a wide range of planktonic and shallow benthic marine organisms [4.4.9, B4.4]. Conservation practices are generally ill-prepared for climate change, and effective adaptation responses are likely to be costly to implement [4.4.11, T4.1, 4.6.1]. Although links between biodiversity intactness and ecosystem services remain quantitatively uncertain, there is high confidence that the relationship is qualitatively positive [4.1, 4.4.11, 4.6, 4.8].

Substantial changes in structure and functioning of terrestrial and marine ecosystems are very likely to occur with a global warming of 2 to 3°C above pre-industrial levels and associated increased atmospheric CO_2 (high confidence).

Major biome changes, including emergence of novel biomes, and changes in species' ecological interactions, with predominantly negative consequences for goods and services, are very likely by, and virtually certain beyond, those temperature increases [4.4]. The previously overlooked progressive acidification of oceans due to increasing atmospheric CO_2 is expected to have negative impacts on marine shell-forming organisms (e.g., corals) and their dependent species [B4.4, 6.4].

Food, fibre and forest products

In mid- to high-latitude regions, moderate warming benefits cereal crop and pasture yields, but even slight warming decreases yields in seasonally dry and tropical regions (medium confidence).

Modelling results for a range of sites find that, in temperate regions, moderate to medium increases in local mean temperature (1 to 3°C), along with associated CO_2 increase and rainfall changes, can have small beneficial impacts on crop yields. At lower latitudes, especially the seasonally dry tropics, even moderate temperature increases (1 to 2°C) are likely to have negative yield impacts for major cereals, which would increase the risk of hunger. Further warming has increasingly negative impacts in all regions (medium to low confidence) (see Figure TS.7) [5.4].

Climate change increases the number of people at risk of hunger marginally, with respect to overall large reductions due to socio-economic development (medium confidence).

Compared with 820 million undernourished today, SRES scenarios of socio-economic development, without climate change, project 100-240 million undernourished for the SRES A1, B1 and B2 scenarios (770 million under the A2 scenario) in 2080 (medium confidence). Scenarios with climate change project 100-380 million undernourished for the SRES A1, B1 and B2 scenarios (740-1,300 million under the A2 scenario) in 2080 (low to medium confidence). The ranges here indicate the extent of effects of the exclusion and inclusion of CO_2 effects in the scenarios. Climate change and socio-economics combine to alter the regional distribution of hunger, with large negative effects on sub-Saharan Africa (low to medium confidence) [5.4, T5.6].

Projected changes in the frequency and severity of extreme climate events have significant consequences on food and forestry production, and food insecurity, in addition to impacts of projected mean climate (high confidence).

Recent studies indicate that increased frequency of heat stress, droughts and floods negatively affects crop yields and livestock beyond the impacts of mean climate change, creating the possibility for surprises, with impacts that are larger, and occur earlier, than predicted using changes in mean variables alone [5.4.1, 5.4.2]. This is especially the case for subsistence sectors at low latitudes. Climate variability and change also modify the risks of fires, pest and pathogen outbreaks, negatively affecting food, fibre and forestry (high confidence) [5.4.1 to 5.4.5, 5.ES].

Simulations suggest rising relative benefits of adaptation with low to moderate warming (medium confidence), although adaptation may stress water and environmental resources as warming increases (low confidence).

There are multiple adaptation options that imply different costs, ranging from changing practices in place to changing locations of food, fibre and forest activities [5.5.1]. Adaptation effectiveness varies from only marginally reducing negative impacts to changing a negative impact into a positive one. On average, in cereal-cropping systems, adaptations such as changing varieties and planting times enable avoidance of a 10 to 15% reduction in yield, corresponding to 1 to 2°C local temperature increases. The benefit from adapting tends to increase with the degree of climate change [F5.2]. Changes in policies and institutions are needed to facilitate adaptation. Pressure to cultivate marginal land or to adopt unsustainable cultivation practices may increase land degradation and resource use, and endanger biodiversity of both wild and domestic species

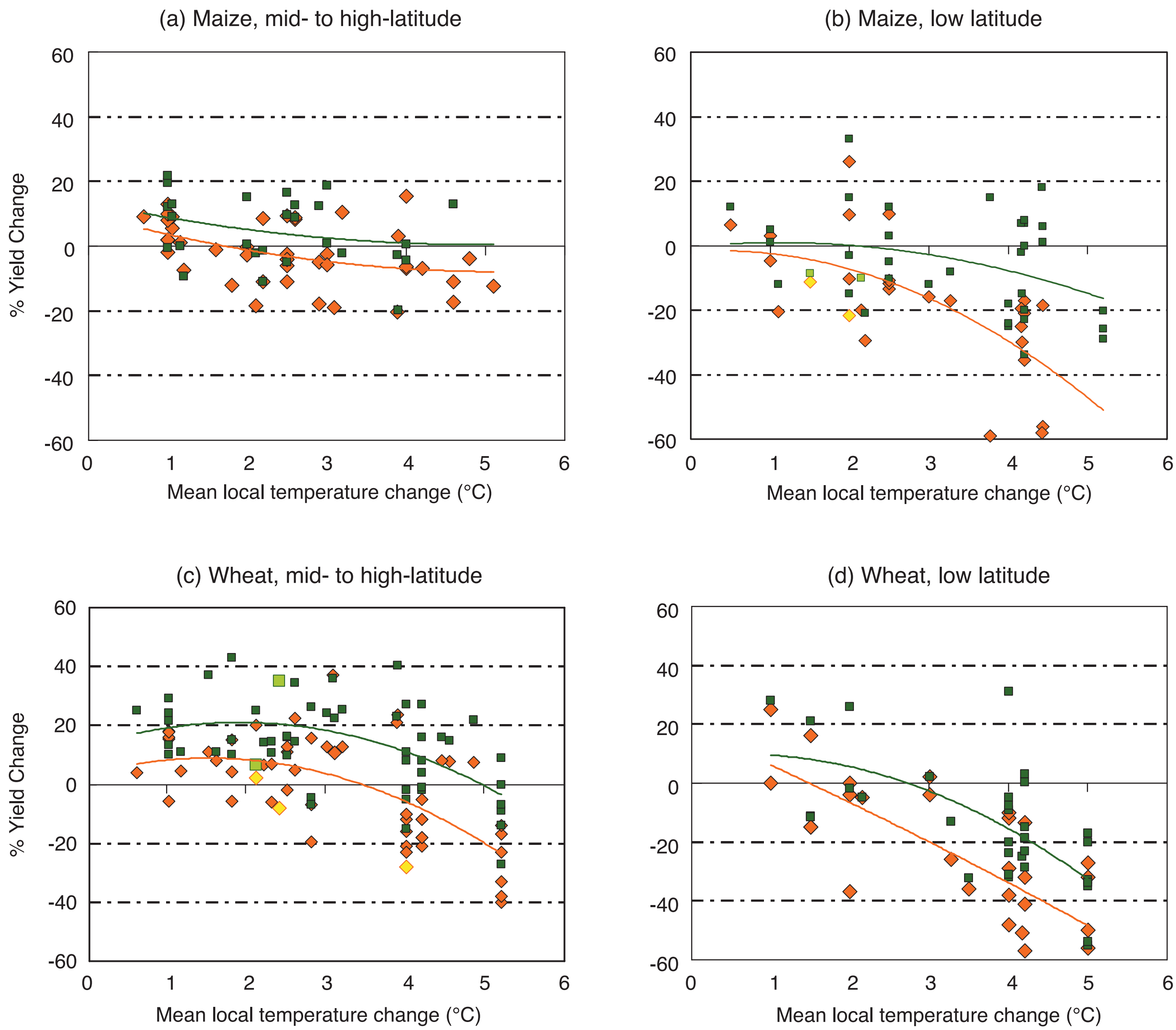


Figure TS.7. *Sensitivity of cereal yield to climate change for maize and wheat. Responses include cases without adaptation (orange dots) and with adaptation (green dots). The studies on which this figure is based span a range of precipitation changes and CO_2 concentrations, and vary in how they represent future changes in climate variability. For instance, lighter-coloured dots in (b) and (c) represent responses of rain-fed crops under climate scenarios with decreased precipitation. [F5.4]*

[5.4.7]. Adaptation measures should be integrated with development strategies and programmes, country programmes and poverty-reduction strategies [5.7].

Smallholder and subsistence farmers, pastoralists and artisanal fisherfolk are likely to suffer complex, localised impacts of climate change (high confidence).
These groups, whose adaptive capacity is constrained, are likely to experience negative effects on yields of tropical crops, combined with a high vulnerability to extreme events. In the longer term, there are likely to be additional negative impacts of other climate-related processes such as snowpack decrease especially in the Indo-Gangetic Plain, sea-level rise, and a spread in the prevalence of human diseases affecting agricultural labour supply (high confidence) [5.4.7].

Globally, forestry production is estimated to change only modestly with climate change in the short and medium term (medium confidence).
The change in global forest product outputs ranges from a modest increase to a slight decrease, although regional and local changes are likely to be large [5.4.5.2]. Production increase is likely to shift from low-latitude regions in the short term, to high-latitude regions in the long term [5.4.5].

Local extinctions of particular fish species are expected at edges of ranges (high confidence).
It is likely that regional changes in the distribution and productivity of particular fish species will continue and local extinctions will occur at the edges of ranges, particularly in freshwater and diadromous species (e.g., salmon, sturgeon). In

some cases, ranges and productivity are likely to increase [5.4.6]. Emerging evidence suggests concern that the Meridional Overturning Circulation is slowing down, with potentially serious consequences for fisheries [5.4.6].

Food and forestry trade is projected to increase in response to climate change, with increased food-import dependence of most developing countries (medium to low confidence). While the purchasing power for food is likely to be reinforced in the period to 2050 by declining real prices, it would be adversely affected by higher real prices for food from 2050 to 2080 due to climate change [5.6.1, 5.6.2]. Exports of temperate-zone food products to tropical countries are likely to rise [5.6.2], while the reverse is likely in forestry in the short term [5.4.5].

Experimental research on crop response to elevated CO_2 confirms TAR reviews (medium to high confidence). New results suggest lower responses for forests (medium confidence). Recent reanalyses of free-air carbon dioxide enrichment (FACE) studies indicate that, at 550 ppm CO_2, yields increase under unstressed conditions by 10 to 20% over current concentrations for C3 crops, and by 0 to 10% for C4 crops (medium confidence). Crop model simulations under elevated CO_2 are consistent with these ranges (high confidence) [5.4.1]. Recent FACE results suggest no significant response for mature forest stands and confirm enhanced growth for young tree stands [5.4.1]. Ozone exposure limits CO_2 response in both crops and forests [B5.2].

Coastal systems and low-lying areas

Since the TAR, our understanding of the implications of climate change for coastal systems and low-lying areas (henceforth referred to as 'coasts') has increased substantially, and six important policy-relevant messages emerge.

Coasts are experiencing the adverse consequences of hazards related to climate and sea level (very high confidence). Coasts are highly vulnerable to extreme events, such as storms, which impose substantial costs on coastal societies [6.2.1, 6.2.2, 6.5.2]. Annually, about 120 million people are exposed to tropical cyclone hazards. These killed 250,000 people from 1980 to 2000 [6.5.2]. Throughout the 20th century, the global rise of sea level contributed to increased coastal inundation, erosion and ecosystem losses, but the precise role of sea-level rise is difficult to determine due to considerable regional and local variation due to other factors [6.2.5, 6.4.1]. Late 20th century effects of rising temperature include loss of sea ice, thawing of permafrost and associated coastal retreat at high latitudes, and more frequent coral bleaching and mortality at low latitudes [6.2.5].

Coasts are very likely to be exposed to increasing risks in future decades due to many compounding climate-change factors (very high confidence). Anticipated climate-related changes include: an accelerated rise in sea level of 0.2 to 0.6 m or more by 2100; further rise in sea surface temperatures of 1 to 3°C; more intense tropical and extra-tropical cyclones; generally larger extreme wave and storm surges; altered precipitation/runoff; and ocean acidification [WG1 AR4 Chapter 10; 6.3.2]. These phenomena will vary considerably at regional and local scales, but the impacts are virtually certain to be overwhelmingly negative [6.4, 6.5.3]. Coastal wetland ecosystems, such as salt marshes and mangroves, are very likely threatened where they are sediment-starved or constrained on their landward margin [6.4.1]. The degradation of coastal ecosystems, especially wetlands and coral reefs, has serious implications for the well-being of societies dependent on coastal ecosystems for goods and services [6.4.2, 6.5.3]. Increased flooding and the degradation of freshwater, fisheries and other resources could impact hundreds of millions of people, and socio-economic costs for coasts are virtually certain to escalate as a result of climate change [6.4.2, 6.5.3].

The impact of climate change on coasts is exacerbated by increasing human-induced pressures (very high confidence). Utilisation of the coast increased dramatically during the 20th century and this trend is virtually certain to continue through the 21st century. Under the SRES scenarios, the coastal population could grow from 1.2 billion people (in 1990) to between 1.8 billion and 5.2 billion people by the 2080s, depending on future trends in coastward migration [6.3.1]. Hundreds of millions of people and major assets at risk at the coast are subject to additional stresses by land-use and hydrological changes in catchments, including dams that reduce sediment supply to the coast [6.3]. Three key hotspots of societal vulnerability are: (i) deltas (see Figure TS.8), especially the seven Asian megadeltas with a collective population already exceeding 200 million; (ii) low-lying coastal urban areas, especially those prone to subsidence; and (iii) small islands, especially coral atolls [6.4.3].

Adaptation for the coasts of developing countries is virtually certain to be more challenging than for coasts of developed countries (high confidence). Developing countries already experience the most severe impacts from present coastal hazards [6.5.2]. This is virtually certain to continue under climate change, even allowing for optimum adaptation, with Asia and Africa most exposed [6.4.2, B6.6, F6.4, 6.5.3]. Developing countries have a more limited adaptive capacity due to their development status, with the most vulnerable areas being concentrated in exposed or sensitive settings such as small islands or deltas [6.4.3]. Adaptation in developing countries will be most challenging in these vulnerable 'hotspots' [6.4.3].

Adaptation costs for vulnerable coasts are much less than the costs of inaction (high confidence). Adaptation costs for climate change are virtually certain to be much lower than damage costs without adaptation for most developed coasts, even considering only property losses and human deaths [6.6.2, 6.6.3]. As post-event impacts on coastal businesses, people, housing, public and private social institutions, natural resources and the environment generally go unrecognised in disaster cost accounting, it is virtually certain that the full benefits of adaptation are even larger [6.5.2, 6.6.2]. Without action, the highest sea-level scenarios combined with other climate change (e.g., increased storm intensity) are about as likely as not to make some low-lying islands and other low-lying areas

Figure TS.8. *Relative vulnerability of coastal deltas as indicated by estimates of the population potentially displaced by current sea-level trends to 2050 (extreme >1 million; high 1 million to 50,000; medium 50,000 to 5,000) [B6.3]. Climate change would exacerbate these impacts.*

(e.g., in deltas and megadeltas) uninhabitable by 2100 [6.6.3]. Effective adaptation to climate change can be integrated with wider coastal management, reducing implementation costs among other benefits [6.6.1.3].

The unavoidability of sea-level rise, even in the longer term, frequently conflicts with present-day human development patterns and trends (high confidence).
Sea-level rise has substantial inertia and will continue beyond 2100 for many centuries [WG1 AR4 Chapter 10]. Breakdown of the West Antarctic and/or Greenland ice sheets would make this long-term rise significantly larger. For Greenland, the temperature threshold for breakdown is estimated to be about 1.1 to 3.8°C above today's global average temperature. This is likely to happen by 2100 under the A1B scenario [WG1 AR4 Chapter 10]. This questions both the long-term viability of many coastal settlements and infrastructure (e.g., nuclear power stations) across the globe and the current trend of increasing human use of the coastal zone, including a significant coastward migration. This issue presents a challenge for long-term coastal spatial planning. Stabilisation of climate is likely to reduce the risks of ice sheet breakdown, and reduce but not stop sea-level rise due to thermal expansion [B6.6]. Hence, since the IPCC Third Assessment it has become virtually certain that the most appropriate response to sea-level rise for coastal areas is a combination of adaptation to deal with the inevitable rise, and mitigation to limit the long-term rise to a manageable level [6.6.5, 6.7].

Industry, settlement and society

Virtually all of the world's people live in settlements, and many depend on industry, services and infrastructure for jobs, well-being and mobility. For these people, climate change adds a new challenge in assuring sustainable development for societies across the globe. Impacts associated with this challenge will be determined mainly by trends in human systems in future decades as climate conditions exacerbate or ameliorate stresses associated with non-climate systems [7.1.1, 7.4, 7.6, 7.7].

Inherent uncertainties in predicting the path of technological and institutional change and trends in socio-economic development over a period of many decades limit the potential to project future prospects for industry, settlements and society involving *considerable* climate change from prospects involving relatively little climate change. In many cases, therefore, research to date has tended to focus on *vulnerabilities to impacts* rather than on *projections of impacts* of change, saying more about what could happen than about what is expected to happen [7.4].

Key vulnerabilities of industry, settlements and society are most often related to (i) climate phenomena that exceed thresholds for adaptation, related to the rate and magnitude of climate change, particularly extreme weather events and/or abrupt climate change, and (ii) limited access to resources (financial, human, institutional) to cope, rooted in issues of development context (see Table TS.1) [7.4.1, 7.4.3, 7.6, 7.7].

Findings about the context for assessing vulnerabilities are as follows.

Climate change vulnerabilities of industry, settlement and society are mainly to extreme weather events rather than to gradual climate change, although gradual changes can be associated with thresholds beyond which impacts become significant (high confidence).
The significance of gradual climate change, e.g., increases in the mean temperature, lies mainly in variability and volatility, including changes in the intensity and frequency of extreme events [7.2, 7.4].

Climate driven phenomena	Evidence for current impact/vulnerability	Other processes/stresses	Projected future impact/vulnerability	Zones, groups affected
a) Changes in extremes				
Tropical cyclones, storm surge	Flood and wind casualties and damages; economic losses; transport, tourism; infrastructure (e.g., energy, transport); insurance [7.4.2, 7.4.3, B7.2, 7.5].	Land use/population density in flood-prone areas; flood defences; institutional capacities.	Increased vulnerability in storm-prone coastal areas; possible effects on settlements, health, tourism, economic and transportation systems, buildings and infrastructure.	Coastal areas, settlements, and activities; regions and populations with limited capacities and resources; fixed infrastructure; insurance sector.
Extreme rainfall, riverine floods	Erosion/landslides; land flooding; settlements; transportation systems; infrastructure [7.4.2, regional chapters].	Similar to coastal storms plus drainage infrastructure.	Similar to coastal storms plus drainage infrastructure.	Similar to coastal storms.
Heat- or cold-waves	Effects on human health; social stability; requirements for energy, water and other services (e.g., water or food storage); infrastructure (e.g., energy transportation) [7.2, B7.1, 7.4.2.2, 7.4.2.3].	Building design and internal temperature control; social contexts; institutional capacities.	Increased vulnerabilities in some regions and populations; health effects; changes in energy requirements.	Mid-latitude areas; elderly, very young, and/or very poor populations.
Drought	Water availability; livelihoods, energy generation, migration, transportation in water bodies [7.4.2.2, 7.4.2.3, 7.4.2.5].	Water systems; competing water uses; energy demand; water demand constraints.	Water-resource challenges in affected areas; shifts in locations of population and economic activities; additional investments in water supply.	Semi-arid and arid regions; poor areas and populations; areas with human-induced water scarcity.
b) Changes in means				
Temperature	Energy demands and costs; urban air quality; thawing of permafrost soils; tourism and recreation; retail consumption; livelihoods; loss of meltwater [7.4.2.1, 7.4.2.2, 7.4.2.4, 7.4.2.5].	Demographic and economic changes; land-use changes; technological innovations; air pollution; institutional capacities.	Shifts in energy demand; worsening of air quality; impacts on settlements and livelihoods depending on meltwater; threats to settlements/infrastructure from thawing permafrost soils in some regions.	Very diverse, but greater vulnerabilities in places and populations with more limited capacities and resources for adaptation.
Precipitation	Agricultural livelihoods; saline intrusion; water infrastructures; tourism; energy supplies [7.4.2.1, 7.4.2.2, 7.4.2.3].	Competition from other regions/sectors; water resource allocation.	Depending on the region, vulnerabilities in some areas to effects of precipitation increases (e.g., flooding, but could be positive) and in some areas to decreases (see drought above).	Poor regions and populations.
Sea-level rise	Coastal land uses: flood risk, waterlogging; water infrastructures [7.4.2.3, 7.4.2.4].	Trends in coastal development, settlements and land uses.	Long-term increases in vulnerabilities of low-lying coastal areas.	Same as above.

Table TS.1. *Selected examples of current and projected climate-change impacts on industry, settlement and society and their interaction with other processes [for full text, see 7.4.3, T7.4]. Orange shading indicates very significant in some areas and/or sectors; yellow indicates significant; pale brown indicates that significance is less clearly established.*

Aside from major extreme events, climate change is seldom the main factor in considering stresses on sustainability (very high confidence).
The significance of climate change (positive or negative) lies in its interactions with other sources of change and stress, and its impacts should be considered in such a multi-cause context [7.1.3, 7.2, 7.4].

Vulnerabilities to climate change depend considerably on relatively specific geographical and sectoral contexts (very high confidence).
They are not reliably estimated by large-scale (aggregate) modelling and estimation [7.2, 7.4].

Climate change impacts spread from directly impacted areas and sectors to other areas and sectors through extensive and complex linkages (very high confidence).
In many cases, total impacts are poorly estimated by considering only direct impacts [7.4].

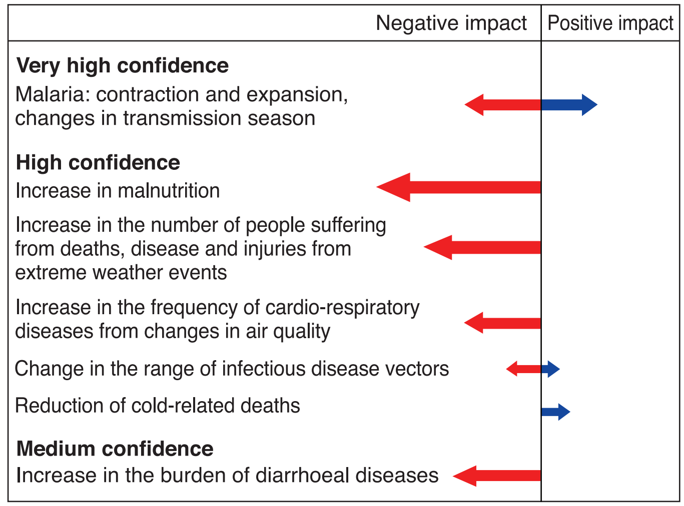


Figure TS.9. *Direction and magnitude of change of selected health impacts of climate change.*

Health

Climate change currently contributes to the global burden of disease and premature deaths (very high confidence).
Human beings are exposed to climate change through changing weather patterns (for example, more intense and frequent extreme events) and indirectly through changes in water, air, food quality and quantity, ecosystems, agriculture and economy. At this early stage the effects are small, but are projected to progressively increase in all countries and regions [8.4.1].

Projected trends in climate-change related exposures of importance to human health will have important consequences (high confidence).
Projected climate-change related exposures are likely to affect the health status of millions of people, particularly those with low adaptive capacity, through:
- increases in malnutrition and consequent disorders, with implications for child growth and development;
- increased deaths, disease and injury due to heatwaves, floods, storms, fires and droughts;
- the increased burden of diarrhoeal disease;
- mixed effects on the range (increases and decreases) and transmission potential of malaria in Africa;
- the increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone related to climate change;
- the altered spatial distribution of some infectious-disease vectors.

This is illustrated in Figure TS.9 [8.2.1, 8.4.1].

Adaptive capacity needs to be improved everywhere (high confidence).
Impacts of recent hurricanes and heatwaves show that even high-income countries are not well prepared to cope with extreme weather events [8.2.1, 8.2.2].

Adverse health impacts will be greatest in low-income countries (high confidence).
Studies in temperate areas (mainly in industrialised countries) have shown that climate change is projected to bring some benefits, such as fewer deaths from cold exposure. Overall it is expected that these benefits will be outweighed by the negative health effects of rising temperatures worldwide, especially in developing countries. The balance of positive and negative health impacts will vary from one location to another, and will alter over time as temperatures continue to rise. Those at greater risk include, in all countries, the urban poor, the elderly and children, traditional societies, subsistence farmers, and coastal populations [8.1.1, 8.4.2, 8.6.1, 8.7].

Current national and international programmes and measures that aim to reduce the burdens of climate-sensitive health determinants and outcomes may need to be revised, reoriented and, in some regions, expanded to address the additional pressures of climate change (medium confidence).
This includes the consideration of climate-change related risks in disease monitoring and surveillance systems, health system planning, and preparedness. Many of the health outcomes are mediated through changes in the environment. Measures implemented in the water, agriculture, food and construction sectors can be designed to benefit human health [8.6, 8.7].

Economic development is an important component of adaptation, but on its own will not insulate the world's population from disease and injury due to climate change (very high confidence).
Critically important will be the manner in which economic growth occurs, the distribution of the benefits of growth, and factors that directly shape the health of populations, such as education, health care, and public health infrastructure [8.3.2].

Box TS.5. The main projected impacts for systems and sectors[16]

Freshwater resources and their management

- Water volumes stored in glaciers and snow cover are very likely to decline, reducing summer and autumn flows in regions where more than one-sixth of the world's population currently live. ** N [3.4.1]
- Runoff and water availability are very likely to increase at higher latitudes and in some wet tropics, including populous areas in East and South-East Asia, and decrease over much of the mid-latitudes and dry tropics, which are presently water-stressed areas. ** D [F3.4]
- Drought-affected areas will probably increase, and extreme precipitation events, which are likely to increase in frequency and intensity, will augment flood risk. Increased frequency and severity of floods and droughts will have implications for sustainable development. ** N [WGI AR4 SPM; 3.4]
- Up to 20% of the world's population live in river basins that are likely to be affected by increased flood hazard by the 2080s in the course of global warming. * N [3.4.3]
- Many semi-arid areas (e.g., Mediterranean Basin, western USA, southern Africa and north-eastern Brazil) will suffer a decrease in water resources due to climate change. *** C [3.4, 3.7]
- The number of people living in severely stressed river basins is projected to increase from 1.4-1.6 billion in 1995 to 4.3-6.9 billion in 2050, for the A2 scenario. ** N [3.5.1]
- Sea-level rise will extend areas of salinisation of groundwater and estuaries, resulting in a decrease in freshwater availability for humans and ecosystems in coastal areas. *** C [3.2, 3.4.2]
- Groundwater recharge will decrease considerably in some already water-stressed regions ** N [3.4.2], where vulnerability is often exacerbated by the rapid increase in population and water demand. *** C [3.5.1]
- Higher water temperatures, increased precipitation intensity and longer periods of low flows exacerbate many forms of water pollution, with impacts on ecosystems, human health, and water system reliability and operating costs. ** N [3.2, 3.4.4, 3.4.5]
- Uncertainties have been evaluated and their interpretation has improved and new methods (e.g., ensemble-based approaches) are being developed for their characterisation *** N [3.4, 3.5]. Nevertheless, quantitative projections of changes in precipitation, river flows and water levels at the river-basin scale remain uncertain. *** D [3.3.1, 3.4]
- Climate change affects the function and operation of existing water infrastructure as well as water management practices *** C [3.6]. Adaptation procedures and risk management practices for the water sector are being developed in some countries and regions that recognise the uncertainty of projected hydrological changes. *** N [3.6]
- The negative impacts of climate change on freshwater systems outweigh the benefits. ** D [3.4, 3.5]
- Areas in which runoff is projected to decline will face a reduction in the value of services provided by water resources *** C [3.4, 3.5]. The beneficial impacts of increased annual runoff in other areas will be tempered by the negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality and flood risks. ** N [3.4, 3.5]

Ecosystems

- The following ecosystems are identified as most vulnerable, and are virtually certain to experience the most severe ecological impacts, including species extinctions and major biome changes. On continents: tundra, boreal forest, mountain and Mediterranean-type ecosystems. Along coasts: mangroves and salt marshes. And in oceans: coral reefs and the sea-ice biomes. *** D [4.4, see also Chapters 1, 5, 6, 14, 15; WGI AR4 Chapters 10, 11]
- Initially positive ecological impacts, such as increased net primary productivity (NPP), will occur in ecosystems identified as least vulnerable: savannas and species-poor deserts. However, these positive effects are contingent on sustained CO_2-fertilisation, and only moderate changes in disturbance regimes (e.g., wildfire) and in extreme events (e.g., drought). • D [4.4.1, 4.4.2, B4.2, 4.4.3, 4.4.10, 4.4.11]
- For global mean temperature increases up to 2°C,[17] some net primary productivity increases are projected at high latitudes (contingent to a large degree on effective migration of woody plants), while an NPP decline (ocean and land) is likely at low latitudes. ** D [4.4.1, 4.4.9, 4.4.10]

[16] In the text of Boxes TS.5 and TS.6, the following conventions are used:

Relationship to the TAR		*Confidence in a statement*	
C	*Confirmation*	***	*Very high confidence*
D	*Development*	**	*High confidence*
R	*Revision*	*	*Medium confidence*
N	*New*	•	*Low confidence*

[17] Temperature thresholds/sensitivities in the Ecosystems section (only) are given relative to pre-industrial climate and are a proxy for climate change including precipitation changes. In other sections temperature changes are relative to 1990 as indicated in the first paragraph of Section TS.4.

- Projected carbon sequestration by poleward taiga expansion • D [4.4.5, F4.3] is as likely as not to be offset by albedo changes, wildfire, and forest declines at taiga's equatorial limit ** N/D [4.4.5, F4.3], and methane losses from tundra. * N [4.4.6]
- Tropical forest sequestration, despite recently observed productivity gains, is very likely to depend on land-use change trends *** D [4.2, 4.3, 4.4.10], but by 2100 is likely to be dominated by climate-change impacts, especially in drier regions. ** D [4.4.5, 4.4.10, F4.3]
- Amazon forests, China's taiga, and much of the Siberian and Canadian tundra are very likely to show major changes with global mean temperatures exceeding 3°C ** D [T4.2, 4.4.1, F4.2, 4.4.10, F4.4]. While forest expansions are projected in North America and Eurasia with <2°C warming [4.4.10, F4.4, T4.3], tropical forests are likely to experience severe impacts, including biodiversity losses. * D [4.4.10, 4.4.11, T4.1]
- For global mean temperature increases of about 1.5 to 3°C, the low-productivity zones in sub-tropical oceans are likely to expand by about 5% (Northern) and about 10% (Southern Hemisphere), but the productive polar sea-ice biomes are very likely to contract by about 40% (Northern) and about 20% (Southern Hemisphere). ** N [4.4.9]
- As sea-ice biomes shrink, dependent polar species, including predators such as penguins, seals and polar bears, are very likely to experience habitat degradation and losses. *** D [4.4.6]
- Loss of corals due to bleaching is very likely to occur over the next 50 years *** C [B4.5, 4.4.9], especially for the Great Barrier Reef, where climate change and direct anthropogenic impacts such as pollution and harvesting are expected to cause annual bleaching (around 2030 to 2050) followed by mass mortality. ** D [B4.4, 4.4.9]
- Accelerated release of carbon from vulnerable carbon stocks, especially peatlands, tundra frozen loess ('yedoma'), permafrost soils, and soils of boreal and tropical forests is virtually certain. *** D/N [F4.1, 4.4.1, 4.4.6, 4.4.8, 4.4.10, 4.4.11]
- An intensification and expansion of wildfires is likely globally, as temperatures increase and dry spells become more frequent and more persistent. ** D/N [4.4.2, 4.4.3, 4.4.4, 4.4.5]
- Greater rainfall variability is likely to compromise inland and coastal wetland species through shifts in the timing, duration and depth of water levels. ** D [4.4.8]
- Surface ocean pH is very likely to decrease further, by as much as 0.5 pH units by 2100, with atmospheric CO_2 increases projected under the A1FI scenario. This is very likely to impair shell or exoskeleton formation by marine organisms requiring calcium carbonate (e.g., corals, crabs, squids, marine snails, clams and oysters). ** N [4.4.9, B4.5]

Food, fibre and forest products

- In mid- to high-latitude regions, moderate warming benefits cereal crops and pasture yields, but even slight warming decreases yields in seasonally dry and tropical regions *. Further warming has increasingly negative impacts in all regions [F5.2]. Short-term adaptations may enable avoidance of a 10 to 15% reduction in yield. */• D [F5.2, 5.4]
- Climate change will increase the number of people at risk of hunger marginally, with respect to overall large reductions due to socio-economic development. ** D [5.6.5, T5.6]
- Projected changes in the frequency and severity of extreme climate events, together with increases in risks of fire, pests, and disease outbreak, will have significant consequences on food and forestry production, and food insecurity, in addition to impacts of projected mean climate. ** D [5.4.1 to 5.4.5]
- Smallholder and subsistence farmers, pastoralists and artisanal fisherfolk will suffer complex, localised impacts of climate change. ** N [5.4.7]
- Global food production potential is likely to increase with increases in global average temperature up to about 3°C, but above this it is very likely to decrease. * D [5.6]
- Globally, forestry production is estimated to change only modestly with climate change in the short and medium term. Production increase will shift from low-latitude regions in the short term, to high-latitude regions in the long term. * D [5.4.5]
- Local extinctions of particular fish species are expected at edges of ranges. ** N [5.4.6]
- Food and forestry trade is projected to increase in response to climate change, with increased food-import dependence of most developing countries. */• N [5.6.1, 5.6.2, 5.4.5]
- Experimental research on crop response to elevated CO_2 confirms TAR conclusions * C. New free-air carbon dioxide enrichment (FACE) results suggest a lower response for forests. * D [5.4.1]

Coastal systems and low-lying areas

- Coasts are very likely to be exposed to increasing risks due to climate change and sea-level rise and the effect will be exacerbated by increasing human-induced pressures on coastal areas. *** D [6.3, 6.4]
- It is likely that corals will experience a major decline due to increased bleaching and mortality due to rising sea-water temperatures. Salt marshes and mangroves will be negatively affected by sea-level rise. *** D [6.4]

- All coastal ecosystems are vulnerable to climate change and sea-level rise, especially corals, salt marshes and mangroves. *** D [6.4.1]
- Corals are vulnerable to thermal stress and it is very likely that projected future increases in sea surface temperature (SST) of about 1 to 3°C in the 21st century will result in more frequent bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals. *** D [B6.1, 6.4.1]
- Coastal wetlands, including salt marshes and mangroves, are sensitive to sea-level rise, with forecast global losses of 33% given a 36 cm rise in sea level from 2000 to 2080. The largest losses are likely to be on the Atlantic and Gulf of Mexico coasts of the Americas, the Mediterranean, the Baltic, and small-island regions. *** D [6.4.1]
- Ocean acidification is an emerging issue with potential for major impacts in coastal areas, but there is little understanding of the details. It is an urgent topic for further research, especially programmes of observation and measurement. ** D [6.2.3, 6.2.5, 6.4.1]
- Coastal flooding in low-lying areas is very likely to become a greater risk than at present due to sea-level rise and more intense coastal storms, unless there is significant adaptation [B6.2, 6.4.2]. Impacts are sensitive to sea-level rise, the socio-economic future, and the degree of adaptation. Without adaptation, more than 100 million people could experience coastal flooding each year by the 2080s due to sea-level rise alone, with the A2 world likely to have the greatest impacts. *** N [F6.2]
- Benefit-cost analysis of responses suggests that it is likely that the potential impacts will be reduced by widespread adaptation. It also suggests that it is likely that impacts and protection costs will fall disproportionately on developing countries. ** C [F6.4, 6.5.3]
- Key human vulnerabilities to climate change and sea-level rise exist where the stresses on natural low-lying coastal systems coincide with low human adaptive capacity and/or high exposure and include: ** D [6.4.2, 6.4.3]
    - deltas, especially Asian megadeltas (e.g., the Ganges-Brahmaputra in Bangladesh and West Bengal);
    - low-lying coastal urban areas, especially areas prone to natural or human-induced subsidence and tropical storm landfall (e.g., New Orleans, Shanghai);
    - small islands, especially low-lying atolls (e.g., the Maldives).
- Regionally, the greatest increase in vulnerability is very likely to be to be in South, South-East and East Asia, and urbanised coastal locations around Africa, and small-island regions. The numbers affected will be largest in the megadeltas of Asia, but small islands face the highest relative increase in risk. ** D [6.4.2]
- Sea-level rise has substantial inertia compared with other climate change factors, and is virtually certain to continue beyond 2100 for many centuries. Stabilisation of climate could reduce, but not stop, sea-level rise. Hence, there is a commitment to adaptation in coastal areas which raises questions about long-term spatial planning and the need to protect versus planned retreat. *** D [B6.6]

Industry, settlement and society

- Benefits and costs of climate change for industry, settlement and society will vary widely by location and scale. Some of the effects in temperate and polar regions will be positive and others elsewhere will be negative. In the aggregate, however, net effects are more likely to be strongly negative under larger or more rapid warming. ** N [7.4, 7.6, 15.3, 15.5]
- Vulnerabilities of industry, infrastructures, settlements and society to climate change are generally greater in certain high-risk locations, particularly coastal and riverine areas, those in areas prone to extreme weather events, and areas whose economies are closely linked with climate-sensitive resources, such as agricultural and forest product industries, water demands and tourism; these vulnerabilities tend to be localised but are often large and growing. For example, rapid urbanisation in most low- and middle-income nations, often in relatively high-risk areas, is placing an increasing proportion of their economies and populations at risk. ** D [7.1, 7.4, 7.5]
- Where extreme weather events become more intense and/or more frequent with climate change, the economic costs of those events will increase, and these increases are likely to be substantial in the areas most directly affected. Experience indicates that costs of major events can range from several percent of annual regional GDP and income in very large regions with very large economies, to more than 25% in smaller areas that are affected by the events. ** N [7.5]
- Some poor communities and households are already under stress from climate variability and climate-related extreme

events; and they can be especially vulnerable to climate change because they tend to be concentrated in relatively high-risk areas, to have limited access to services and other resources for coping, and in some regions to be more dependent on climate-sensitive resources such as local water and food supplies. ** N [7.2, 7.4.5, 7.4.6]

- Growing economic costs from weather-related extreme events are already increasing the need for effective economic and financial risk management. In those regions and locations where risk is rising and private insurance is a major risk management option, pricing signals can provide incentives for adaptation; but protection may also be withdrawn, leaving increased roles for others, including governments. In those regions where private insurance is not widely available, other mechanisms for risk management will be needed. In all situations, poorer groups in the population will need special help in risk management and adaptation. ** D [7.4.2]
- In many areas, climate change is likely to raise social equity concerns and increase pressures on governmental infrastructures and institutional capacities. ** N [7.ES, 7.4.5, 7.6.5]
- Robust and reliable physical infrastructures are especially important to climate-related risk management. Such infrastructures as urban water supply systems are vulnerable, especially in coastal areas, to sea-level rise and reduced regional precipitation; and large population concentrations without infrastructures are more vulnerable to impacts of climate change. ** N [7.4.3 to 7.4.5]

Health

- The projected relative risks attributable to climate change in 2030 show an increase in malnutrition in some Asian countries ** N [8.4.1]. Later in the century, expected trends in warming are projected to decrease the availability of crop yields in seasonally dry and tropical regions [5.4]. This will increase hunger, malnutrition and consequent disorders, including child growth and development, in particular in those regions that are already most vulnerable to food insecurity, notably Africa. ** N [8.4.2]
- By 2030, coastal flooding is projected to result in a large proportional mortality increase; however, this is applied to a low burden of disease so the aggregate impact is small. Overall, a two- to three-fold increase in population at risk of flooding is expected by 2080. ** N [8.4.1]
- Estimates of increases of people at risk of death from heat differ between countries, depending on the place, ageing population, and adaptation measures in place. Overall, significant increases are estimated over this century. ** D [T8.3]
- Mixed projections for malaria are foreseen: globally an estimated additional population at risk between 220 million (A1FI) and 400 million (A2) has been estimated. In Africa, estimates differ from a reduction in transmission in south-east Africa in 2020 and decreases around the Sahel and south-central Africa in 2080, with localised increases in the highlands, to a 16-28% increase in person-months of exposure in 2100 across all scenarios. For the UK, Australia, India and Portugal, some increased risk has been estimated. *** D [T8.2]
- In Canada, a northward expansion of the Lyme-disease vector of approximately 1,000 km is estimated by the 2080s (A2) and a two- to four-fold increase in tick abundance by the 2080s also. In Europe, tick-borne encephalitis is projected to move further north-eastward of its present range but to contract in central and eastern Europe by the 2050s. * N [T8.2]
- By 2030 an increase in the burden of diarrhoeal diseases in low-income regions by approximately 2-5% is estimated ** N [8.4.1]. An annual increase of 5-18% by 2050 was estimated for Aboriginal communities in Australia ** N [T8.2]. An increase in cases of food poisoning has been estimated for the UK for a 1-3°C temperature increase. * N [T8.2]
- In eastern North America under the A2 climate scenario, a 4.5% increase in ozone-related deaths is estimated. A 68% increase in average number of days/summer exceeding the 8-hour regulatory standard is projected to result in a 0.1-0.3% increase in non-accidental mortality and an average 0.3% increase in cardiovascular disease mortality. In the UK, large decreases in days with high particulates and SO_2 and a small decrease in other pollutants have been estimated for 2050 and 2080, but ozone will have increased ** N [T8.4]. The near-term health benefits from reducing air-pollution concentrations (such as for ozone and particulate matter), as a consequence of greenhouse gas reductions, can be substantial. ** D [8.7.1, WGIII AR4]
- By 2085 it is estimated that the risk of dengue from climate change increases to include 3.5 billion people. * N [8.4.1.2]
- Reductions in cold-related deaths due to climate change are projected to be greater than increases in heat-related deaths in the UK. ** D [T8.3]

TS.4.2 Regional impacts, adaptation and vulnerability

A summary of impacts projected for each region is given in Box TS.6.

Africa

Agricultural production in many African countries and regions will likely be severely compromised by climate change and climate variability. This would adversely affect food security and exacerbate malnutrition (very high confidence).
Agricultural yields and dependence on natural resources constitute a large part of local livelihoods in many, but not all, African countries. Agriculture is a major contributor to the current economy of most African countries, averaging 21% and ranging from 10% to 70% of GDP with indications that off-farm income augments the overall contribution of agriculture in some countries [9.2.2, 9.4.4]. Agricultural losses are shown to be possibly severe for several areas (e.g., the Sahel, East Africa and southern Africa) accompanied by changes in length of growing periods impacting mixed rain-fed, arid and semi-arid systems under certain climate projections. In some countries, yields from rain-fed agriculture could be reduced by up to 50% by 2020. At the local level, many people are likely to suffer additional losses to their livelihood when climate change and variability occur together with other stressors (e.g., conflict) [9.2.2, 9.6.1].

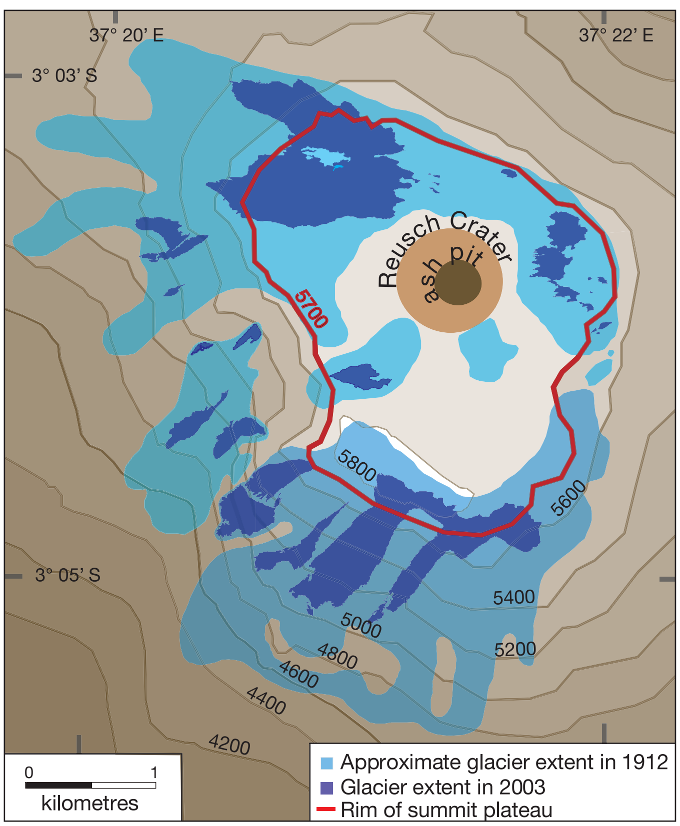


Figure TS.10. *Changes in the Mt. Kilimanjaro ice cap and snow cover over time. Decrease in surface area of Kilimanjaro glaciers from 1912 to 2003. [F9.2]*

Climate change and variability are likely to result in species loss, extinctions and also constrain the 'climate spaces' and ranges of many plants and animals (high confidence).
Changes in a variety of ecosystems are already being detected, particularly in southern African ecosystems, at a faster rate than anticipated as a result of a variety of factors, including the influence of climate, e.g., mountain ecosystems [9.4.5, 4.4.2, 4.4.3, 4.4.8].

In unmanaged environments, multiple, interacting impacts and feedbacks are expected, triggered by changes in climate, but exacerbated by non-climatic factors (high confidence).
Impacts on Kilimanjaro, for example, show that glaciers and snow cover have been retreating as a result of a number of interacting factors (e.g., solar radiation, vegetation changes and human interactions), with a decrease in glacier surface area of approximately 80% between 1912 and 2003 (see Figure TS.10). The loss of 'cloud forests', e.g., through fire, since 1976 has resulted in a 25% annual reduction of water sources derived from fog (equivalent to the annual drinking water supply of 1 million people living around Mt. Kilimanjaro) [9.4.5].

Lack of access to safe water, arising from multiple factors, is a key vulnerability in many parts of Africa. This situation is likely to be further exacerbated by climate change (very high confidence).
By 2020, some assessments project that between 75 and 250 million people are estimated to be exposed to increased water stress due to climate change. If coupled with increased demand, this will adversely affect livelihoods and exacerbate water-related problems. Some assessments, for example, show severe increased water stress and possible increased drought risk for parts of northern and southern Africa and increases in runoff in East Africa. Water access is, however, threatened not only by climate change [9.4.1] but also by complex river-basin management (with several of Africa's major rivers being shared by several countries), and degradation of water resources by abstraction of water and pollution of water sources [9.4.1].

Attributing the contribution of climate change to changes in the risk of malaria remains problematic (high confidence).
Human health, already compromised by a range of factors, could also be further negatively impacted by climate change and climate variability (e.g., in southern Africa and the East African highlands). The debate on climate change attribution and malaria is ongoing and this is an area requiring further research [9.4.3, 8.2.8, 8.4.1].

Africa is one of the most vulnerable continents to climate variability and change because of multiple stresses and low adaptive capacity. The extreme poverty of many Africans, frequent natural disasters such as droughts and floods, and agriculture which is heavily dependent on rainfall, all contribute. Cases of remarkable resilience in the face of multiple stressors have, however, been shown (high confidence).
Africa possesses many examples of coping and adaptation strategies that are used to manage a range of stresses including climate extremes (e.g., droughts and floods). Under possible increases in such stresses, however, these strategies are likely to

be insufficient to adapt to climate variability and change, given the problems of endemic poverty, poor institutional arrangements, poor access to data and information, and growing health burdens [9.2.1, 9.2.2., 9.2.5].

Asia

Observations demonstrate that climate change has affected many sectors in Asia in the past decades (medium confidence).
Evidence of impacts of climate change, variability and extreme events in Asia, as predicted in the Third Assessment, has emerged. The crop yield in most countries of Asia has been observed to be declining, probably partly attributable to rising temperatures. As a likely consequence of warming, the retreat of glaciers and thawing of permafrost in boreal Asia have been unprecedented in recent years. The frequency of occurrence of climate-induced diseases and heat stress in Central, East, South and South-East Asia has increased with rising temperatures and rainfall variability. Observed changes in terrestrial and marine ecosystems have become more pronounced [10.2.3].

Future climate change is expected to affect agriculture through declining production and reductions in arable land area and food supply for fish (medium confidence).
Projected surface warming and shifts in rainfall in most countries of Asia will induce substantial declines in agricultural crop productivity as a consequence of thermal stress and more severe droughts and floods [10.4.1]. The decline in agricultural productivity will be more pronounced in areas already suffering from increasing scarcity of arable land, and will increase the risk of hunger in Asia, particularly in developing countries [10.4.1]. Subsistence farmers are at risk from climate change. Marginal crops such as sorghum and millet could be at the greatest risk, both from a drop in productivity and from a loss of crop genetic diversity [10.4.1]. In response to climate change, it is expected that changes will occur in fish breeding habitats and food supply for fish, and ultimately the abundance of fish populations [10.4.1].

Climate change has the potential to exacerbate water-resource stresses in most regions of Asia (high confidence).
The most serious potential threat arising from climate change in Asia is water scarcity. Freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease due to climate change which, along with population growth and increasing demand arising from higher standards of living, could adversely affect more than a billion people by the 2050s [10.4.2]. Changes in seasonality of runoff due to rapid melting of glaciers and in some areas an increase in winter precipitation could have significant effects on hydropower generation and on crop and livestock production [10.4.2].

Increases in temperature are expected to result in more rapid recession of Himalayan glaciers and the continuation of permafrost thaw across northern Asia (medium confidence).
If current warming rates are maintained, Himalayan glaciers could decay at very rapid rates (Figure TS.11). Accelerated glacier melt would result in increased flows in some river systems for the next two to three decades, resulting in increased flooding, rock avalanches from destabilised slopes, and disruption of water resources. This would be followed by a decrease in flows as the glaciers recede [10.6.2]. Permafrost degradation can result in ground subsidence, alter drainage characteristics and infrastructure stability, and can result in increased emissions of methane [10.4.4].

Asian marine and coastal ecosystems are expected to be affected by sea-level rise and temperature increases (high confidence).
Projected sea-level rise could result in many additional millions of people being flooded each year [10.4.3.1]. Sea-water intrusion could increase the habitat of brackish-water fisheries but significantly damage the aquaculture industry [10.4.1]. Overall, sea-level rise is expected to exacerbate already declining fish productivity in Asia [10.4.1]. Arctic marine fisheries would be greatly influenced by climate change, with some species, such as cod and herring, benefiting at least for modest temperature increases, and others, such as the northern shrimp, suffering declining productivity [10.4.1].

Climate change is expected to exacerbate threats to biodiversity resulting from land-use/cover change and population pressure in most parts of Asia (high confidence).
Increased risk of extinction for many flora and fauna species in Asia is likely as a result of the synergistic effects of climate change and habitat fragmentation [10.4.4]. Threats to the ecological stability of wetlands, mangroves and coral reefs around Asia would also increase [10.4.3, 10.6.1]. The frequency and extent of forest fires in northern Asia is expected to increase in the future due to climate change and extreme weather events that could likely limit forest expansion [10.4.4].

Figure TS.11. *Projected future changes in the northern Asia permafrost boundary under the SRES A2 scenario for 2100. [F10.5]*

Future climate change is likely to continue to adversely affect human health in Asia (high confidence).
Increases in endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected in East, South and South-East Asia, due to projected changes in the hydrological cycle associated with global warming [10.4.5]. Increases in coastal water temperature would exacerbate the abundance and/or toxicity of cholera in South Asia [10.4.5]. Natural habitats of vector-borne and water-borne diseases are reported to be expanding [10.4.5].

Multiple stresses in Asia will be further compounded in the future due to climate change (high confidence).
Exploitation of natural resources associated with rapid urbanisation, industrialisation and economic development in most developing countries of Asia has led to increasing air and water pollution, land degradation, and other environmental problems that have placed enormous pressure on urban infrastructure, human well-being, cultural integrity, and socio-economic settings. It is likely that climate change will intensify these environmental pressures and impinge on sustainable development in many developing countries of Asia, particularly in the South and East [10.5.6].

Australia and New Zealand

The region is already experiencing impacts from recent climate change, and adaptation has started in some sectors and regions (high confidence).
Since 1950 there has been a 0.3 to 0.7°C warming in the region, with more heatwaves, fewer frosts, more rain in north-western Australia and south-western New Zealand, less rain in southern and eastern Australia and north-eastern New Zealand, an increase in the intensity of Australian droughts, and a rise in sea level of 70 mm [11.2.1]. Impacts are now evident in water supply and agriculture, changed natural ecosystems, reduced seasonal snow cover and glacier shrinkage [11.2.2, 11.2.3]. Some adaptation has occurred in sectors such as water, agriculture, horticulture and coasts [11.2.5].

The climate of the 21st century is virtually certain to be warmer, with changes in extreme events (medium to high confidence).
Heatwaves and fires are virtually certain to increase in intensity and frequency (high confidence) [11.3]. Floods, landslides, droughts and storm surges are very likely to become more frequent and intense, and snow and frost are likely to become less frequent (high confidence) [11.3.1]. Large areas of mainland Australia and eastern New Zealand are likely to have less soil moisture, although western New Zealand is likely to receive more rain (medium confidence) [11.3].

Without further adaptation, potential impacts of climate change are likely to be substantial (high confidence).
- As a result of reduced precipitation and increased evaporation, water security problems are very likely to intensify by 2030 in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions [11.4.1].
- Significant loss of biodiversity is projected to occur by 2020 in some ecologically rich sites including the Great Barrier Reef and Queensland Wet Tropics. Other sites at risk include Kakadu Wetlands, south-west Australia, sub-Antarctic islands and the alpine areas of both countries [11.4.2].
- Ongoing coastal development and population growth in areas such as Cairns and south-east Queensland (Australia) and Northland to Bay of Plenty (New Zealand) are projected to exacerbate risks from sea-level rise and increases in the severity and frequency of storms and coastal flooding by 2050 [11.4.5, 11.4.7].
- Risks to major infrastructure are likely to markedly increase. By 2030, design criteria for extreme events are very likely to be exceeded more frequently. These risks include the failure of flood protection and urban drainage/sewerage, increased storm and fire damage, and more heatwaves causing more deaths and more black-outs [11.4.1, 11.4.5, 11.4.7, 11.4.10, 11.4.11].
- Production from agriculture and forestry is projected to decline by 2030 over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits to agriculture and forestry are projected in western and southern areas and close to major rivers due to a longer growing season, less frost and increased rainfall [11.4.3, 11.4.4].

Vulnerability is likely to increase in many sectors, but this depends on adaptive capacity.
- Most human systems have considerable adaptive capacity. The region has well-developed economies, extensive scientific and technical capabilities, disaster-mitigation strategies, and biosecurity measures. However, there are likely to be considerable cost and institutional constraints to the implementation of adaptation options (high confidence) [11.5]. Some Indigenous communities have low adaptive capacity (medium confidence) [11.4.8]. Water security and coastal communities are most vulnerable (high confidence) [11.7].
- Natural systems have limited adaptive capacity. Projected rates of climate change are very likely to exceed rates of evolutionary adaptation in many species (high confidence) [11.5]. Habitat loss and fragmentation are very likely to limit species migration in response to shifting climatic zones (high confidence) [11.2.5, 11.5].
- Vulnerability is likely to rise as a consequence of an increase in extreme events. Economic damage from extreme weather is very likely to increase and provide major challenges for adaptation (high confidence) [11.5].
- Vulnerability is likely to be high by 2050 in a few identified hotspots (see Figure TS.12). In Australia, these include the Great Barrier Reef, eastern Queensland, the south-west, Murray-Darling Basin, the Alps and Kakadu; in New Zealand, these include the Bay of Plenty, Northland, eastern regions and the Southern Alps (medium confidence) [11.7].

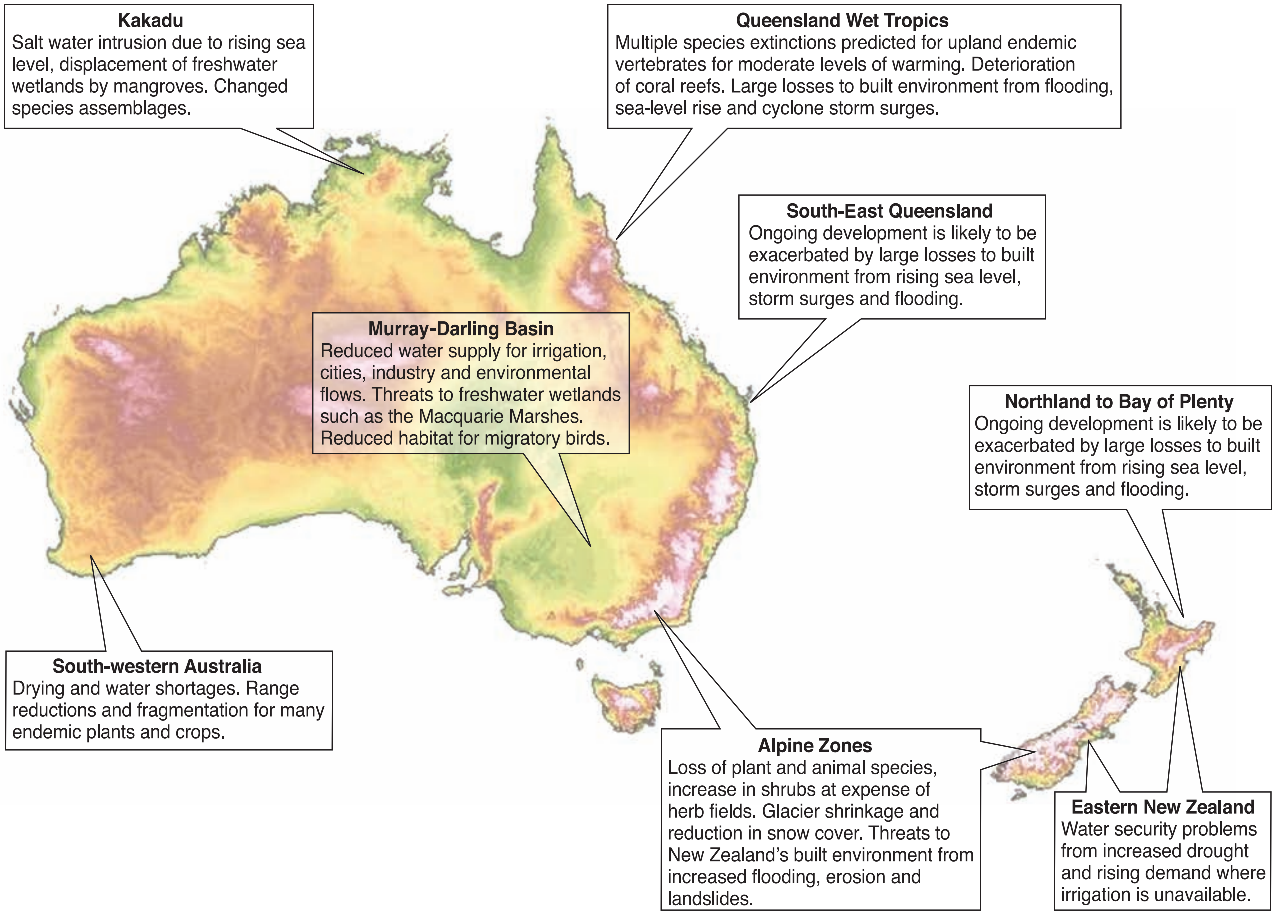


Figure TS.12. *Key hotspots in Australia and New Zealand, based on the following criteria: large impacts, low adaptive capacity, substantial population, economically important, substantial exposed infrastructure, and subject to other major stresses (e.g., continued rapid population growth, ongoing development, ongoing land degradation, ongoing habitat loss and threats from rising sea level). [11.7]*

Europe

For the first time, wide-ranging impacts of changes in current climate have been documented in Europe (very high confidence).

The warming trend and spatially variable changes in rainfall have affected composition and functioning of the cryosphere (retreat of glaciers and extent of permafrost) as well as natural and managed ecosystems (lengthening of growing season, shift of species and human health due to a heatwave of unprecedented magnitude) [12.2.1]. The European heatwave in 2003 (see Figure TS.13) had major impacts on biophysical systems and society (around 35,000 excess deaths were recorded) [12.6.1]. The observed changes are consistent with projections of impacts due to future climate change [12.4].

Climate-related hazards will mostly increase, although changes will vary geographically (very high confidence).

By the 2020s, increases are likely in winter floods in maritime regions and flash floods throughout Europe [12.4.1]. Coastal flooding related to increasing storminess (particularly in the north-east Atlantic) and sea-level rise are likely to threaten an additional 1.5 million people annually by the 2080s; coastal erosion is projected to increase [12.4.2]. Warmer, drier conditions will lead to more frequent and prolonged droughts (by the 2070s, today's 100-year droughts will return every 50 years or less in southern and south-eastern Europe), as well as a longer fire-season and increased fire risk, particularly in the Mediterranean region [12.3.1, 12.4.4]. A higher frequency of catastrophic fires is also expected on drained peatlands in central and eastern Europe [12.4.5]. The frequency of rockfalls will increase due to destabilisation of mountain walls by rising temperatures and melting of permafrost [12.4.3].

Some impacts may be positive, such as reduced cold-related mortality because of increasing winter temperatures. However, on balance, without adaptive measures, health risks due to more frequent heatwaves, especially in southern, central and eastern Europe, flooding and greater exposure to vector- and food-borne diseases are anticipated to increase [12.4.11].

Climate change is likely to magnify regional differences in Europe's natural resources and assets (very high confidence).

Climate-change scenarios indicate significant warming (A2: 2.5 to 5.5°C; B2: 1 to 4°C), greater in winter in the north and in summer in south and central Europe [12.3.1]. Mean annual precipitation is projected to increase in the north and decrease in the south. Seasonal changes, however, will be more pronounced: summer precipitation is projected to decrease by up to 30 to 45%

over the Mediterranean Basin, and also over eastern and central Europe and, to a lesser degree, over northern Europe even as far north as central Scandinavia [12.3.1]. Recruitment and production of marine fisheries in the North Atlantic are likely to increase [12.4.7]. Crop suitability is likely to change throughout Europe, and crop productivity (all other factors remaining unchanged) is likely to increase in northern Europe, and decrease along the Mediterranean and in south-east Europe [12.4.7]. Forests are projected to expand in the north and retreat in the south [12.4.4]. Forest productivity and total biomass are likely to increase in the north and decrease in central and eastern Europe, while tree mortality is likely to accelerate in the south [12.4.4]. Differences in water availability between regions are anticipated to become more pronounced: annual average runoff increasing in north/north-west, and decreasing in south/south-east Europe (summer low flow is projected to decrease by up to 50% in central Europe and by up to 80% in some rivers in southern Europe) [12.4.1, 12.4.5].

Water stress is likely to increase, as well as the number of people living in river basins under high water stress (high confidence).

Water stress is likely to increase over central and southern Europe. The percentage of area under high water stress is likely to increase from 19% to 35% by the 2070s, and the number of people at risk from 16 to 44 million [12.4.1]. The regions most at risk are southern Europe and some parts of central and eastern Europe [12.4.1]. The hydropower potential of Europe is expected to decline on average by 6%, and by 20 to 50% around the Mediterranean by the 2070s [12.4.8.1].

It is anticipated that Europe's natural systems and biodiversity will be substantially affected by climate change (very high confidence). The great majority of organisms and ecosystems are likely to have difficulty in adapting to climate change (high confidence).

Sea-level rise is likely to cause an inland migration of beaches and loss of up to 20% of coastal wetlands [12.4.2.], reducing the habitat availability for several species that breed or forage in low-lying coastal areas [12.4.6]. Small glaciers will disappear and larger glaciers substantially shrink (projected volume reductions of between 30% and 70% by 2050) during the 21st century [12.4.3]. Many permafrost areas in the Arctic are projected to disappear [12.4.5.]. In the Mediterranean, many ephemeral aquatic ecosystems are projected to disappear, and permanent ones shrink and become ephemeral [12.4.5]. The northward expansion of forests is projected to reduce current tundra areas under some scenarios [12.4.4]. Mountain communities face up to a 60% loss of species under high-emissions scenarios by 2080 [12.4.3]. A large percentage of the European flora (one study found up to 50%) is likely to become vulnerable, endangered or committed to extinction by the end of this century [12.4.6]. Options for adaptation are likely to be limited for many organisms and ecosystems. For example, limited dispersal is very likely to reduce the range of most reptiles and amphibians [12.4.6]. Low-lying, geologically subsiding coasts are likely to be unable to adapt to sea-level rise [12.5.2]. There are no obvious climate adaptation options for either tundra or alpine vegetation [12.5.3].

The adaptive capacity of ecosystems can be enhanced by reducing human stresses [12.5.3, 12.5.5]. New sites for conservation may be needed because climate change is very likely to alter conditions of suitability for many species in current sites (with climate change, to meet conservation goals, the current reserve area in the EU would have to be increased by 41%) [12.5.6].

Nearly all European regions are anticipated to be negatively affected by some future impacts of climate change and these will pose challenges to many economic sectors (very high confidence).

In southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability. In northern Europe, climate change is initially projected to bring mixed effects, including some benefits, but as climate change continues, its negative effects are likely to outweigh its benefits [12.4].

Agriculture will have to cope with increasing water demand for irrigation in southern Europe due to climate change (e.g., increased water demand of 2 to 4% for maize cultivation and 6 to 10% for potatoes by 2050), and additional restrictions due to increases in crop-related nitrate leaching [12.5.7]. Winter heating demands are expected to decrease and summer cooling demands

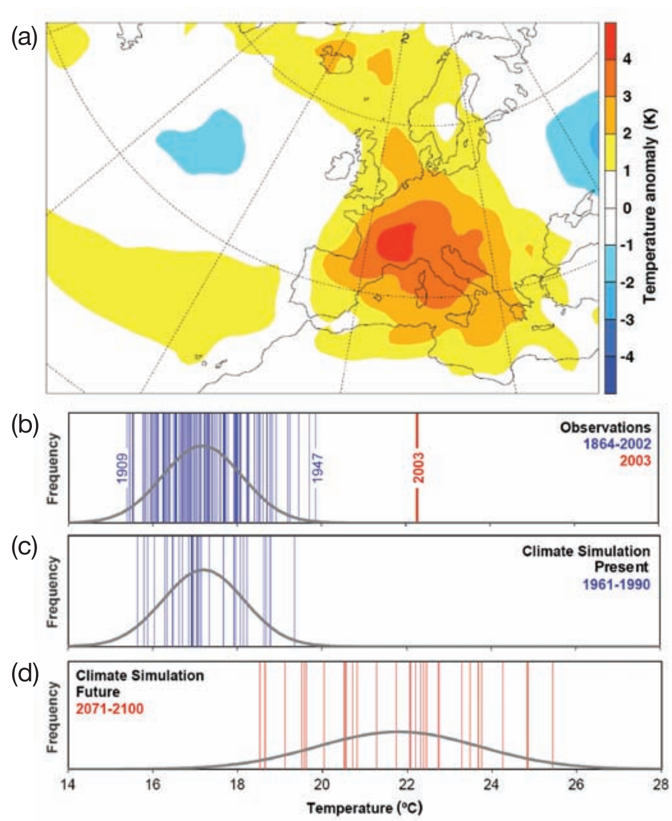


Figure TS.13. *Characteristics of the summer 2003 heatwave: (a) JJA temperature anomaly with respect to 1961-1990; (b-d) June, July, August temperatures for Switzerland; (b) observed during 1864-2003; (c) simulated using a regional climate model for the period 1961-1990; (d) simulated for 2071-2100 under the SRES A2 scenario. The vertical bars in panels (b-d) represent mean summer surface temperature for each year of the time period considered; the fitted Gaussian distribution is indicated in black. Reprinted by permission from Macmillan Publishers Ltd. [Nature] (Schär et al., 2004), copyright 2004, [F12.4].*

to increase due to climate change: around the Mediterranean, 2 to 3 fewer weeks in a year will require heating but an additional 2 to 5 weeks will need cooling by 2050 [12.4.8]. Peak electricity demand is likely to shift in some locations from winter to summer [12.4.8]. Tourism along the Mediterranean is likely to decrease in summer and increase in spring and autumn. Winter tourism in mountain regions is anticipated to face reduced snow cover (the duration of snow cover is expected to decrease by several weeks for each °C of temperature increase in the Alps region) [12.4.9, 12.4.11].

Adaptation to climate change is likely to benefit from experiences gained in reactions to extreme climate events, by specifically implementing proactive climate-change risk management adaptation plans (very high confidence).
Since the TAR, governments have greatly increased the number of actions for coping with extreme climate events. Current thinking about adaptation to extreme climate events has moved away from reactive disaster relief and towards more proactive risk management. A prominent example is the implementation in several countries of early-warning systems for heatwaves (Portugal, Spain, France, UK, Italy, Hungary) [12.6.1]. Other actions have addressed long-term climate change. For example, national action plans have been developed for adapting to climate change [12.5] and more specific plans have been incorporated into European and national policies for agriculture, energy, forestry, transport and other sectors [12.2.3,12.5.2]. Research has also provided new insights into adaptation policies (e.g., studies have shown that crops that become less economically viable under climate change can be profitably replaced by bioenergy crops) [12.5.7].

Although the effectiveness and feasibility of adaptation measures are expected to vary greatly, only a few governments and institutions have systematically and critically examined a portfolio of measures. As an example, some reservoirs used now as a measure for adapting to precipitation fluctuations may become unreliable in regions where long-term precipitation is projected to decrease [12.4.1]. The range of management options to cope with climate change varies largely among forest types, with some types having many more options than others [12.5.5].

Latin America

Climatic variability and extreme events have been severely affecting the Latin America region over recent years (high confidence).
Highly unusual extreme weather events have recently occurred, such as Venezuelan intense rainfall (1999, 2005), flooding in the Argentine Pampas (2000-2002), Amazon drought (2005), hail storms in Bolivia (2002) and the Greater Buenos Aires area (2006), the unprecedented Hurricane Catarina in the South Atlantic (2004), and the record hurricane season of 2005 in the Caribbean Basin [13.2.2]. Historically, climate variability and extremes have had negative impacts on population, increasing mortality and morbidity in affected areas. Recent developments in meteorological forecasting techniques could improve the necessary information for human welfare and security. However, the lack of modern observation equipment and badly-needed upper-air information, the low density of weather stations, the unreliability of their reports, and the lack of monitoring of climate variables hinder the quality of forecasts, with adverse effects on the public, lowering their appreciation of applied meteorological services, as well as their trust in climate records. These shortcomings also affect hydrometeological observing services, with a negative impact on the quality of early warnings and alert advisories (medium confidence) [13.2.5].

During the last few decades, important changes in precipitation and increases in temperature have been observed (high confidence).
Increases in rainfall in south-east Brazil, Paraguay, Uruguay, the Argentine Pampas, and some parts of Bolivia have had impacts on land use and crop yields and have increased flood frequency and intensity. On the other hand, a declining trend in precipitation has been observed in southern Chile, south-west Argentina, southern Peru, and western Central America. Increases in temperature of approximately 1°C in Mesoamerica and South America and of 0.5°C in Brazil have been observed. As a consequence of temperature increases, the trend in glacier retreat reported in the TAR is accelerating (very high confidence). This issue is critical in Bolivia, Peru, Colombia and Ecuador, where water availability has already been compromised either for consumption or hydropower generation [13.2.4]. These problems with supply are expected to increase in the future, becoming chronic if no appropriate adaptation measures are planned and implemented. Over the next decades Andean inter-tropical glaciers are very likely to disappear, affecting water availability and hydropower generation (high confidence) [13.2.4].

Land-use changes have intensified the use of natural resources and exacerbated many of the processes of land degradation (high confidence).
Almost three-quarters of the dryland surface is moderately or severely affected by degradation processes. The combined effects of human action and climate change have brought a decline in natural land cover, which continues to decline at very high rates (high confidence). In particular, rates of deforestation of tropical forests have increased during the last 5 years. There is evidence that biomass-burning aerosols may change regional temperature and precipitation in the southern part of Amazonia (medium confidence). Biomass burning also affects regional air quality, with implications for human health. Land-use and climate changes acting synergistically will increase vegetation fire risk substantially (high confidence) [13.2.3, 13.2.4].

The projected mean warming for Latin America to the end of the 21st century, according to different climate models, ranges from 1 to 4°C for SRES emissions scenario B2 and from 2 to 6°C for scenario A2 (medium confidence).
Most GCM projections indicate rather larger than present (positive and negative) rainfall anomalies for the tropical portions of Latin America and smaller ones for extra-tropical South America. Changes in temperature and precipitation will have especially severe impacts on already vulnerable hotspots,

identified in Figure TS.14. In addition, the frequency of occurrence of weather and climate extremes is likely to increase in the future; as is the frequency and intensity of hurricanes in the Caribbean Basin [13.3.1, 13.3.1].

Under future climate change, there is a risk of significant species extinctions in many areas of tropical Latin America (high confidence).
Gradual replacement of tropical forest by savannas is expected by mid-century in eastern Amazonia and the tropical forests of central and southern Mexico, along with replacement of semi-arid by arid vegetation in parts of north-east Brazil and most of central and northern Mexico, due to increases in temperature and associated decreases in soil water (high confidence) [13.4.1]. By the 2050s, 50% of agricultural lands are very likely to be subjected to desertification and salinisation in some areas (high confidence) [13.4.2]. There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America. Seven out of the world's twenty-five most critical places with high endemic species concentrations are in Latin America, and these areas are undergoing habitat loss. Biological reserves and ecological corridors have been either implemented or planned for the maintenance of biodiversity in natural ecosystems, and these can serve as adaptation measures to help protect ecosystems in the face of climate change [13.2.5].

By the 2020s, the net increase in the number of people experiencing water stress due to climate change is likely to be between 7 and 77 million (medium confidence).
For the second half of the 21st century, the potential water availability reduction and the increasing demand from an increasing regional population would increase these figures to between 60 and 150 million [13.4.3].

Generalised reductions in rice yields by the 2020s, as well as increases in soybean yields in temperate zones, are likely when CO_2 effects are considered (medium confidence).
For other crops (wheat, maize), the projected response to climate change is more erratic, depending on the chosen scenario. Assuming low CO_2 fertilisation effects, the number of additional people at risk of hunger under the A2 scenario is likely to reach 5, 26 and 85 million in 2020, 2050 and 2080, respectively (medium confidence). Livestock and dairy productivity is likely to decline in response to increasing temperatures [13.4.2].

The expected increases in sea-level rise, weather and climatic variability and extremes are very likely to affect coastal areas (high confidence).
During the last 10 to 20 years, the rate of sea-level rise increased from 1 to 2-3 mm/year in south-eastern South America [13.2.4]. In the future, sea-level rise is projected to cause an increased risk of flooding in low-lying areas. Adverse impacts would be observed on (i) low-lying areas (e.g., in El Salvador, Guyana, the coast of the province of Buenos Aires), (ii) buildings and tourism (e.g., in Mexico, Uruguay), (iii) coastal morphology (e.g., in Peru), (iv) mangroves (e.g., in Brazil, Ecuador, Colombia, Venezuela), (v) availability of drinking water on the Pacific coast of Costa Rica, Ecuador and the Rio de la Plata estuary [13.4.4].

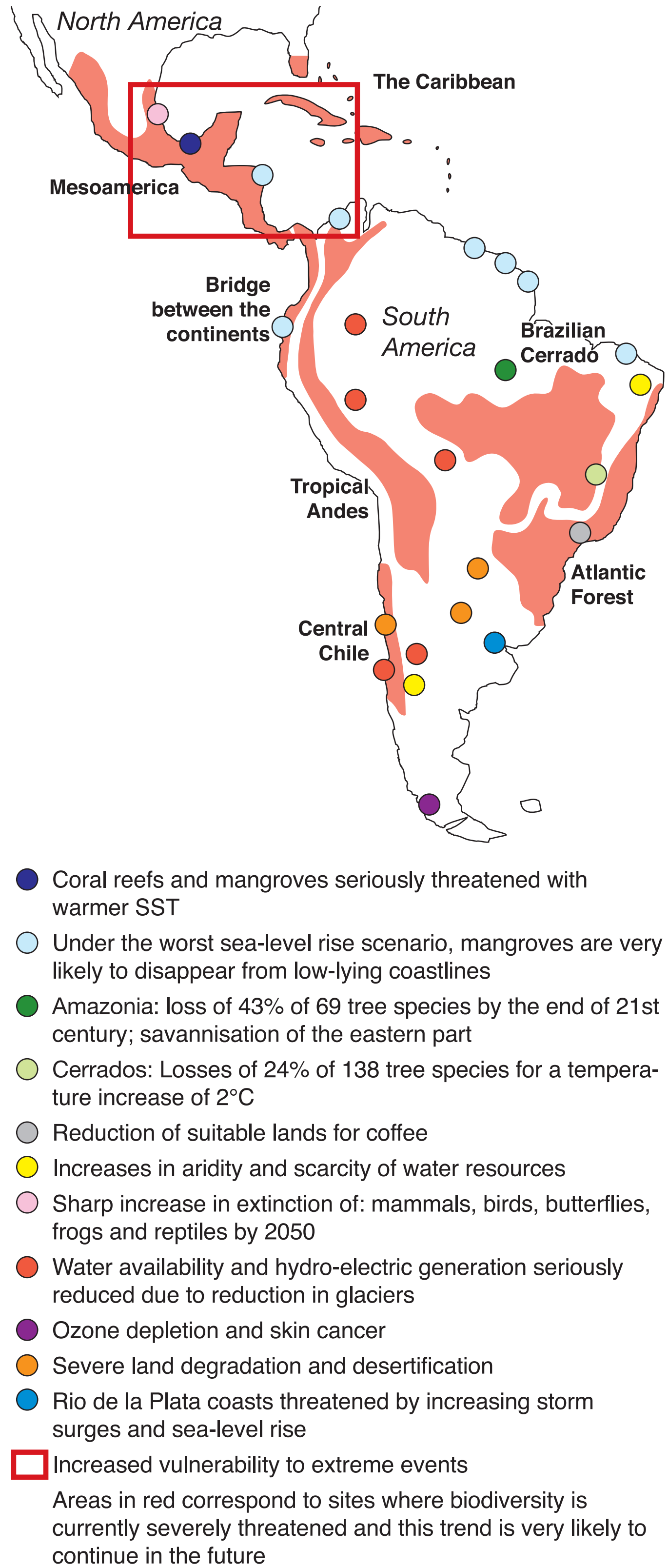


Figure TS.14. *Key hotspots for Latin America, where climate change impacts are expected to be particularly severe. [13.4]*

Future sustainable development plans should include adaptation strategies to enhance the integration of climate change into development policies (high confidence).

Several adaptation measures have been proposed for coastal, agricultural, water and health sectors. However, the effectiveness of these efforts is outweighed by a lack of capacity-building and appropriate political, institutional and technological frameworks, low income, and settlements in vulnerable areas, among others. The present degree of development of observation and monitoring networks necessarily requires improvement, capacity-building, and the strengthening of communication in order to permit the effective operation of environmental observing systems and the reliable dissemination of early warnings. Otherwise, the Latin American countries' sustainable development goals are likely to be seriously compromised, adversely affecting, among other things, their capability to reach the Millennium Development Goals [13.5].

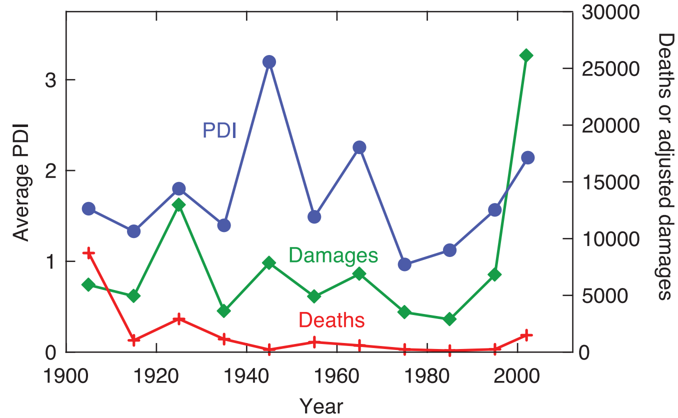


Figure TS.15. *Decadal average (6-year average for 2000-2005) hurricane total dissipated energy (PDI), loss of life, and inflation-adjusted economic damages (in thousands of US$) from hurricanes making landfall in the continental USA since 1900. [F14.1]*

North America

North America has considerable adaptive capacity, which has been deployed effectively at times, but this capacity has not always protected its population from adverse impacts of climate variability and extreme weather events (very high confidence).

Damage and loss of life from Hurricane Katrina in August 2005 illustrate the limitations of existing adaptive capacity to extreme events. Traditions and institutions in North America have encouraged a decentralised response framework where adaptation tends to be reactive, unevenly distributed, and focused on coping with rather than preventing problems. "Mainstreaming" climate change issues into decision making is a key prerequisite for sustainability [14.2.3, 14.2.6, 14.4, 14.5, 14.7].

Emphasis on effective adaptation is critical, because economic damage from extreme weather is likely to continue increasing, with direct and indirect consequences of climate change playing a growing role (very high confidence).

Over the past several decades, economic damage from hurricanes in North America has increased over fourfold (Figure TS.15), due largely to an increase in the value of infrastructure at risk [14.2.6]. Costs to North America include billions of dollars in damaged property and diminished economic productivity, as well as lives disrupted and lost [14.2.6, 14.2.7, 14.2.8]. Hardships from extreme events disproportionately affect those who are socially and economically disadvantaged, especially the poor and indigenous peoples of North America [14.2.6].

Climate change is likely to exacerbate other stresses on infrastructure, and human health and safety in urban centres (very high confidence).

Climate change impacts in urban centres are very likely to be compounded by urban heat islands, air and water pollution, ageing infrastructure, maladapted urban form and building stock, water quality and supply challenges, immigration and population growth, and an ageing population [14.3.2, 14.4.1, 14.4.6].

Coastal communities and habitats are very likely to be increasingly stressed by climate change impacts interacting with development and pollution (very high confidence).

Sea level is rising along much of the coast, and the rate of change is likely to increase in the future, exacerbating the impacts of progressive inundation, storm surge flooding, and shoreline erosion [14.2.3, 14.4.3]. Storm impacts are likely to be more severe, especially along the Gulf and Atlantic coasts [14.4.3]. Salt marshes, other coastal habitats and dependent species are threatened now and increasingly in future decades by sea-level rise, fixed structures blocking landward migration, and changes in vegetation [14.2]. Population growth and rising value of infrastructure in coastal areas increases vulnerability to climate variability and future climate change, with losses projected to increase if the intensity of tropical storms increases. Current adaptation to coastal hazards is uneven and readiness for increased exposure is low [14.2.3, 14.4.3, 14.5].

Warm temperatures and extreme weather already cause adverse human health effects through heat-related mortality, pollution, storm-related fatalities and injuries, and infectious diseases, and are likely, in the absence of effective countermeasures, to increase with climate change (very high confidence).

Depending on progress in health care, infrastructure, technology and access, climate change could increase the risk of heatwave deaths, water-borne diseases and degraded water quality [14.4.1], respiratory illness through exposure to pollen and ozone, and vector-borne infectious diseases (low confidence) [14.2.5, 14.4.5].

Climate change is very likely to constrain North America's already intensively utilised water resources, interacting with other stresses (high confidence).

Diminishing snowpack and increasing evaporation due to rising temperatures are very likely to affect timing and availability of water and intensify competition among uses [B14.2, 14.4.1]. Warming is very likely to place additional stress on groundwater availability, compounding the effects of higher demand from economic development and population growth (medium confidence) [14.4.1]. In the Great Lakes and some major river systems, lower water levels are likely to exacerbate issues of water quality, navigation, hydropower generation, water diversions, and bi-national co-operation [14.4.1, B14.2].

Disturbances such as wildfire and insect outbreaks are increasing and are likely to intensify in a warmer future with drier soils and longer growing seasons, and to interact with changing land use and development affecting the future of wildland ecosystems (high confidence).
Recent climate trends have increased ecosystem net primary production, and this trend is likely to continue for the next few decades [14.2.2]. However, wildfire and insect outbreaks are increasing, a trend that is likely to intensify in a warmer future [14.4.2, B14.1]. Over the course of the 21st century, the tendency for species and ecosystems to shift northward and to higher elevations is likely to rearrange the map of North American ecosystems. Continuing increases in disturbances are likely to limit carbon storage, facilitate invasives, and amplify the potential for changes in ecosystem services [14.4.2, 14.4.4].

Polar Regions

The environmental impacts of climate change show profound regional differences both within and between the polar regions (very high confidence).
The impacts of climate change in the Arctic over the next hundred years are likely to exceed the changes forecast for many other regions. However, the complexity of responses in biological and human systems, and the fact that they are subject to additive multiple stresses, means that the impacts of climate change on these systems remain difficult to predict. Changes on the Antarctic Peninsula, sub-Antarctic islands and Southern Ocean have also been rapid, and in future dramatic impacts are expected. Evidence of ongoing change over the rest of the Antarctic continent is less conclusive and prediction of the likely impacts is thus difficult. For both polar regions, economic impacts are especially difficult to address due to the lack of available information [15.2.1, 15.3.2, 15.3.3].

There is a growing evidence of the impacts of climate change on ecosystems in both polar regions (high confidence).
There has been a measured change in composition and range of plants and animals on the Antarctic Peninsula and on the sub-Antarctic islands. There is a documented increase in the overall greenness of parts of the Arctic, an increase in biological productivity, a change in species ranges (e.g., shifts from tundra to shrublands), some changes in position of the northern limit of trees, and changes in the range and abundance of some animal species. In both the Arctic and Antarctic, research indicates that such changes in biodiversity and vegetation zone relocation will continue. The poleward migration of existing species and competition from invading species is already occurring, and will continue to alter species composition and abundance in terrestrial and aquatic systems. Associated vulnerabilities are related to loss of biodiversity and the spread of animal-transmitted diseases [15.2.2, 15.4.2].

The continuation of hydrological and cryospheric changes will have significant regional impacts on Arctic freshwater, riparian and near-shore marine systems (high confidence).
The combined discharge of Eurasian rivers draining into the Arctic Ocean shows an increase since the 1930s, largely consistent with increased precipitation, although changes to cryospheric processes (snowmelt and permafrost thaw) are also modifying routing and seasonality of flow [15.3.1, 15.4.1].

The retreat of Arctic sea ice over recent decades has led to improved marine access, changes in coastal ecology/biological production, adverse effects on many ice-dependent marine mammals, and increased coastal wave action (high confidence).
Continued loss of sea ice will produce regional opportunities and problems; reductions in freshwater ice will affect lake and river ecology and biological production, and will require changes in water-based transportation. For many stakeholders, economic benefits may accrue, but some activities and livelihoods may be adversely affected [15.ES, 15.4.7, 15.4.3, 15.4.1, 15.4.1].

Around the Antarctic Peninsula, a newly documented decline in krill abundance, together with an increase in salp abundance, has been attributed to a regional reduction in the extent and duration of sea ice (medium confidence).
If there is a further decline in sea ice, a further decline in krill is likely, impacting predators higher up the food chain [15.2.2, 15.6.3].

Warming of areas of the northern polar oceans has had a negative impact on community composition, biomass and distribution of phytoplankton and zooplankton (medium confidence).
The impact of present and future changes on higher predators, fish and fisheries will be regionally specific, with some beneficial and some detrimental effects [15.2.2].

Many Arctic human communities are already adapting to climate change (high confidence).
Indigenous people have exhibited resilience to changes in their local environments for thousands of years. Some indigenous communities are adapting through changes in wildlife management regimes and hunting practices. However, stresses in addition to climate change, together with a migration into small remote communities and increasing involvement in employment economies and sedentary occupations, will challenge adaptive capacity and increase vulnerability. Some traditional ways of life are being threatened and substantial investments are needed to adapt or relocate physical structures and communities [15.4.6, 15.5, 15.7].

A less severe climate in northern regions will produce positive economic benefits for some communities (very high confidence).
The benefits will depend on particular local conditions but will, in places, include reduced heating costs, increased agricultural and forestry opportunities, more navigable northern sea routes and marine access to resources [15.4.2].

The impacts of future climate change in the polar regions will produce feedbacks that will have globally significant consequences over the next hundred years (high confidence).

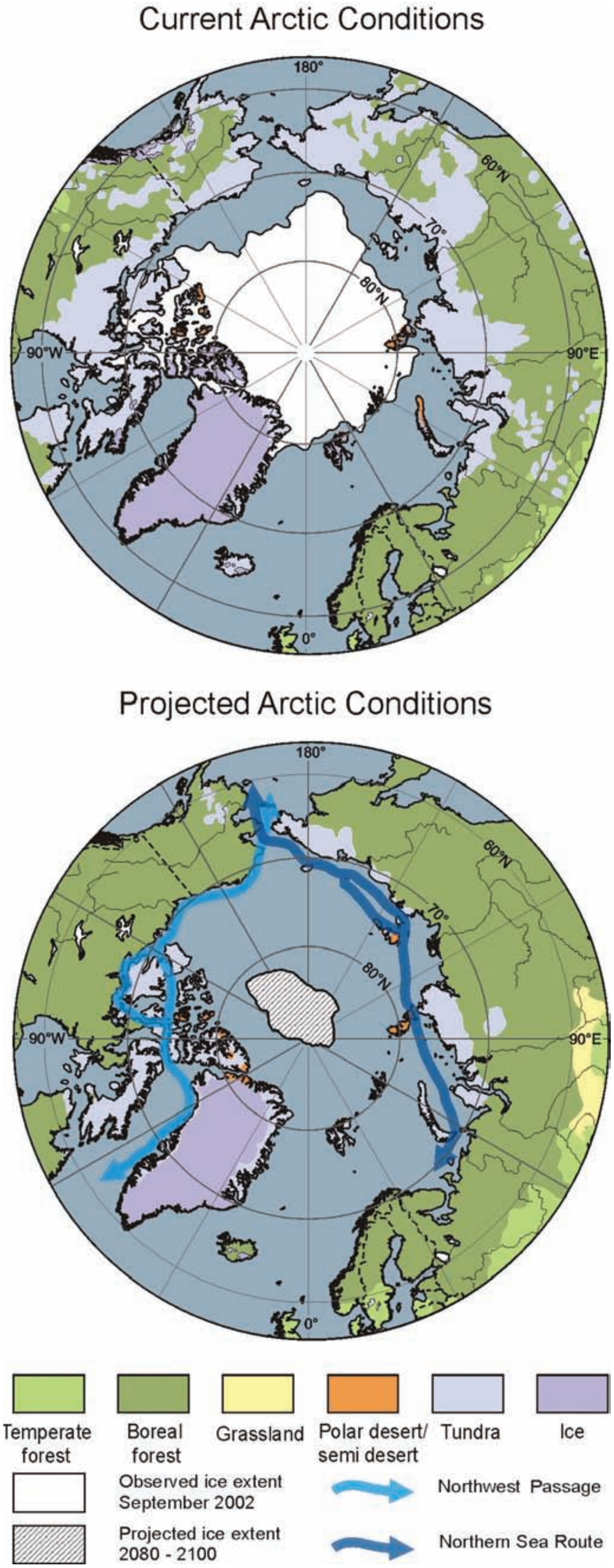


Figure TS.16. *Vegetation of the Arctic and neighbouring regions. Top: present-day, based on floristic surveys. Bottom: modelled for 2090-2100 under the IS92a emissions scenario. [F15.2]*

A continued loss of land-based ice will add to global sea-level rise. A major impact could result from a weakening of the thermohaline circulation due to a net increase in river flow into the Arctic Ocean and the resulting increased flux of freshwater into the North Atlantic. Under CO_2-doubling, total river flow into the Arctic Ocean is likely to increase by up to 20%. Warming will expose more bare ground in the Arctic (Figure TS.16) and on the Antarctic Peninsula, to be colonised by vegetation. Recent models predict a decrease in albedo due to loss of ice and changing vegetation, and that the tundra will be a small sink for carbon, although increased methane emissions from the thawing permafrost could contribute to climate warming [15.4.1, 15.4.2].

Small Islands

Small islands have characteristics which make them especially vulnerable to the effects of climate change, sea-level rise and extreme events (very high confidence).
These include their limited size and proneness to natural hazards and external shocks. They have low adaptive capacity, and adaptation costs are high relative to GDP [16.5].

Sea-level rise is likely to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening the vital infrastructure that supports the socio-economic well-being of island communities (very high confidence).
Some studies suggest that sea-level rise could cause coastal land loss and inundation, while others show that some islands are morphologically resilient and are expected to persist [16.4.2]. In the Caribbean and Pacific Islands, more than 50% of the population live within 1.5 km of the shore. Almost without exception, the air and sea ports, major road arteries, communication networks, utilities and other critical infrastructure in the small islands of the Indian and Pacific Oceans and the Caribbean tend to be restricted to coastal locations (Table TS.2). The threat from sea-level rise is likely to be amplified by changes in tropical cyclones [16.4.5, 16.4.7].

There is strong evidence that under most climate-change scenarios, water resources in small islands are likely to be seriously compromised (very high confidence).
Most small islands have a limited water supply. Many small islands in the Caribbean and Pacific are likely to experience increased water stress as a result of climate change [16.4.1]. Predictions under all SRES scenarios for this region show reduced rainfall in summer, so that it is unlikely that demand will be met during low rainfall periods. Increased rainfall in winter will be unlikely to compensate, due to a lack of storage and high runoff during storms [16.4.1].

Climate change is likely to heavily impact coral reefs, fisheries and other marine-based resources (high confidence).
Fisheries make an important contribution to the GDP of many island states. Changes in the occurrence and intensity of El Niño-Southern Oscillation (ENSO) events are likely to have severe impacts on commercial and artisanal fisheries. Increasing sea surface temperature and sea level, increased turbidity, nutrient loading and chemical pollution, damage from tropical cyclones, and decreases in growth rates due to the effects of higher CO_2-

concentrations on ocean chemistry, are very likely to lead to coral bleaching and mortality [16.4.3].

On some islands, especially those at higher latitudes, warming has already led to the replacement of some local species (high confidence).

Mid- and high-latitude islands are virtually certain to be colonised by non-indigenous invasive species, previously limited by unfavourable temperature conditions (see Table TS.2). Increases in extreme events in the short term are virtually certain to affect the adaptation responses of forests on tropical islands, where regeneration is often slow. In view of their small area, forests on many islands can easily be decimated by violent cyclones or storms. On some high-latitude islands it is likely that forest cover will increase [16.4.4, 15.4.2].

It is very likely that subsistence and commercial agriculture on small islands will be adversely affected by climate change (high confidence).

Sea-level rise, inundation, sea-water intrusion into freshwater lenses, soil salinisation and a decline in water supply will very likely adversely impact coastal agriculture. Away from the coast, changes in extremes (e.g., flooding and drought) are likely to have a negative effect on agricultural production. Appropriate adaptation measures may help to reduce these impacts. In some high-latitude islands, new opportunities may arise for increased agricultural production [16.4.3, 15.4.2].

New studies confirm previous findings that the effects of climate change on tourism are likely to be direct and indirect, and largely negative (high confidence).

Tourism is the major contributor to GDP and employment in many small islands. Sea-level rise and increased sea-water temperature are likely to contribute to accelerated beach erosion, degradation of coral reefs and bleaching (Table TS.2). In addition, loss of cultural heritage from inundation and flooding will reduce the amenity value for coastal users. Whereas a warmer climate could reduce the number of people visiting small islands in low latitudes, it could have the reverse effect in mid- and high-latitude islands. However, water shortages and increased incidence of vector-borne diseases are also likely to deter tourists [16.4.6].

There is growing concern that global climate change is likely to impact human health, mostly in adverse ways (medium confidence).

Many small islands lie in tropical or sub-tropical zones with weather conducive to the transmission of diseases such as malaria, dengue, filariasis, schistosomiasis, and food- and water-borne diseases. Outbreaks of climate-sensitive diseases can be costly in terms of lives and economic impact. Increasing temperatures and decreasing water availability due to climate change are likely to increase the burdens of diarrhoeal and other infectious diseases in some small-island states [16.4.5].

Latitude	Region and system at risk	Impacts and vulnerability
High	Iceland and isolated Arctic islands of Svalbard and the Faroe Islands: Marine ecosystem and plant species	• The imbalance of species loss and replacement leads to an initial loss in diversity. Northward expansion of dwarf-shrub and tree-dominated vegetation into areas rich in rare endemic species results in their loss. • Large reduction in, or even a complete collapse of, the Icelandic capelin stock leads to considerable negative impacts on most commercial fish stocks, whales and seabirds.
High	High-latitude islands (Faroe Islands): Plant species	• Scenario I (temperature increase 2°C): species most affected by warming are restricted to the uppermost parts of mountains. For other species, the effect will mainly be upward migration. • Scenario II (temperature decrease 2°C): species affected by cooling are those at lower altitudes.
Mid	Sub-Antarctic Marion Islands: Ecosystem	• Changes will directly affect the indigenous biota. An even greater threat is that a warmer climate will increase the ease with which the islands can be invaded by alien species.
Mid	Five islands in the Mediterranean Sea: Ecosystems	• Climate change impacts are negligible in many simulated marine ecosystems. • Invasion into island ecosystems becomes an increasing problem. In the longer term, ecosystems will be dominated by exotic plants irrespective of disturbance rates.
Mid	Mediterranean: Migratory birds (pied flycatchers: *Ficedula hypoleuca*)	• Reduction in nestling and fledgling survival rates of pied flycatchers in two of the southernmost European breeding populations.
Mid	Pacific and Mediterranean: Sim weed (*Chromolaena odorata*)	• Pacific Islands at risk of invasion by sim weed. • Mediterranean semi-arid and temperate climates predicted to be unsuitable for invasion.
Low	Pacific small islands: Coastal erosion, water resources and human settlements	• Accelerated coastal erosion, saline intrusion into freshwater lenses and increased flooding from the sea cause large effects on human settlements. • Lower rainfall coupled with accelerated sea-level rise compounds the threat on water resources; a 10% reduction in average rainfall by 2050 is likely to correspond to a 20% reduction in the size of the freshwater lens on Tarawa Atoll, Kiribati.
Low	American Samoa, fifteen other Pacific, Islands: Mangroves	• 50% loss of mangrove area in American Samoa; 12% reduction in mangrove area in fifteen other Pacific Islands.
Low	Caribbean (Bonaire, Netherlands Antilles): Beach erosion and sea-turtle nesting habitats	• On average, up to 38% (±24% standard deviation) of the total current beach could be lost with a 0.5 m rise in sea level, with lower narrower beaches being the most vulnerable, reducing turtle nesting habitat by one-third.
Low	Caribbean (Bonaire, Barbados): Tourism	• The beach-based tourism industry in Barbados and the marine-diving-based ecotourism industry in Bonaire are both negatively affected by climate change through beach erosion in Barbados and coral bleaching in Bonaire.

Table TS.2. *Range of future impacts and vulnerabilities in small islands [B16.1]. These projections are summarised from studies using a range of scenarios including SRES and Third Assessment Report sea-level rise projections.*

Box TS.6. The main projected impacts for regions

Africa

- The impacts of climate change in Africa are likely to be greatest where they co-occur with a range of other stresses (e.g., unequal access to resources [9.4.1]; enhanced food insecurity [9.6]; poor health management systems [9.2.2, 9.4.3]). These stresses, enhanced by climate variability and change, further enhance the vulnerabilities of many people in Africa. ** D [9.4]
- An increase of 5 to 8% (60 to 90 million ha) of arid and semi-arid land in Africa is projected by the 2080s under a range of climate-change scenarios. ** N [9.4.4]
- Declining agricultural yields are likely due to drought and land degradation, especially in marginal areas. Changes in the length of growing period have been noted under various scenarios. In the A1FI SRES scenario, which has an emphasis on globally-integrated economic growth, areas of major change include the coastal systems of southern and eastern Africa. Under both the A1 and B1 scenarios, mixed rain-fed, semi-arid systems are shown to be heavily affected by changes in climate in the Sahel. Mixed rain-fed and highland perennial systems in the Great Lakes region in East Africa and in other parts of East Africa are also heavily affected. In the B1 SRES scenario, which assumes development within a framework of environmental protection, the impacts are, however, generally less, but marginal areas (e.g., the semi-arid systems) become more marginal, with the impacts on coastal systems becoming moderate. ** D [9.4.4]
- Current stress on water in many areas of Africa is likely to be enhanced by climate variability and change. Increases in runoff in East Africa (possibly floods) and decreases in runoff and likely increased drought risk in other areas (e.g., southern Africa) are projected by the 2050s. Current water stresses are not only linked to climate variations, and issues of water governance and water-basin management must also be considered in any future assessments of water in Africa. ** D [9.4.1]
- Any changes in the primary production of large lakes are likely to have important impacts on local food supplies. For example, Lake Tanganyika currently provides 25 to 40% of animal protein intake for the population of the surrounding countries, and climate change is likely to reduce primary production and possible fish yields by roughly 30% [9.4.5, 3.4.7, 5.4.5]. The interaction of human management decisions, including over-fishing, is likely to further compound fish offtakes from lakes. ** D [9.2.2]
- Ecosystems in Africa are likely to experience major shifts and changes in species range and possible extinctions (e.g., fynbos and succulent Karoo biomes in southern Africa). * D [9.4.5]
- Mangroves and coral reefs are projected to be further degraded, with additional consequences for fisheries and tourism.** D [9.4.5]
- Towards the end of the 21st century, projected sea-level rise will affect low-lying coastal areas with large populations. The cost of adaptation will exceed 5 to 10% of GDP. ** D [B9.2, 9.4.6, 9.5.2]

Asia

- A 1 m rise in sea level would lead to a loss of almost half of the mangrove area in the Mekong River delta (2,500 km^2), while approximately 100,000 ha of cultivated land and aquaculture area would become salt marsh. * N [10.4.3]
- Coastal areas, especially heavily populated megadelta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers. For a 1 m rise in sea level, 5,000 km^2 of Red River delta, and 15,000 to 20,000 km^2 of Mekong River delta are projected to be flooded, which could affect 4 million and 3.5 to 5 million people, respectively. * N [10.4.3]
- Tibetan Plateau glaciers of under 4 km in length are projected to disappear with a temperature increase of 3°C and no change in precipitation. ** D [10.4.4]
- If current warming rates are maintained, Himalayan glaciers could decay at very rapid rates, shrinking from the present 500,000 km^2 to 100,000 km^2 by the 2030s. ** D [10.6.2]
- Around 30% of Asian coral reefs are expected to be lost in the next 30 years, compared with 18% globally under the IS92a emissions scenario, but this is due to multiple stresses and not to climate change alone. ** D [10.4.3]
- It is estimated that under the full range of SRES scenarios, 120 million to 1.2 billion and 185 to 981 million people will experience increased water stress by the 2020s and the 2050s, respectively. ** D [10.4.2]
- The per capita availability of freshwater in India is expected to drop from around 1,900 m^3 currently to 1,000 m^3 by 2025 in response to the combined effects of population growth and climate change [10.4.2.3]. More intense rain and more frequent flash floods during the monsoon would result in a higher proportion of runoff and a reduction in the proportion reaching the groundwater. ** N [10.4.2]
- It is projected that crop yields could increase up to 20% in East and South-East Asia, while they could decrease up to 30% in Central and South Asia by the mid-21st century. Taken together and considering the influence of rapid population growth and urbanisation, the risk of hunger is projected to remain very high in several developing countries. * N [10.4.1]
- Agricultural irrigation demand in arid and semi-arid regions of East Asia is expected to increase by 10% for an increase in

temperature of 1°C. ** N [10.4.1]
- The frequency and extent of forest fires in northern Asia are expected to increase in the future due to climate change and extreme weather events that would likely limit forest expansion. * N [10.4.4]

Australia and New Zealand

- The most vulnerable sectors are natural ecosystems, water security and coastal communities. ** C [11.7]
- Many ecosystems are likely to be altered by 2020, even under medium-emissions scenarios [11.4.1]. Among the most vulnerable are the Great Barrier Reef, south-western Australia, Kakadu Wetlands, rain forests and alpine areas [11.4.2]. This is virtually certain to exacerbate existing stresses such as invasive species and habitat loss, increase the probability of species extinctions, and cause a reduction in ecosystem services for tourism, fishing, forestry and water supply. * N [11.4.2]
- Ongoing water security problems are very likely to increase by 2030 in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions, e.g., a 0 to 45% decline in runoff in Victoria by 2030 and a 10 to 25% reduction in river flow in Australia's Murray-Darling Basin by 2050. ** D [11.4.1]
- Ongoing coastal development is very likely to exacerbate risk to lives and property from sea-level rise and storms. By 2050, there is very likely to be loss of high-value land, faster road deterioration, degraded beaches, and loss of items of cultural significance. *** C [11.4.5, 11.4.7, 11.4.8]
- Increased fire danger is likely with climate change; for example, in south-east Australia the frequency of very high and extreme fire danger days is likely to rise 4 to 25% by 2020 and 15 to 70% by 2050. ** D [11.3.1]
- Risks to major infrastructure are likely to increase. Design criteria for extreme events are very likely to be exceeded more frequently by 2030. Risks include failure of floodplain levees and urban drainage systems, and flooding of coastal towns near rivers. ** D [11.4.5, 11.4.7]
- Increased temperatures and demographic change are likely to increase peak energy demand in summer and the associated risk of black-outs. ** D [11.4.10]
- Production from agriculture and forestry by 2030 is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in western and southern areas and close to major rivers due to a longer growing season, less frost and increased rainfall. ** N [11.4]
- In the south and west of New Zealand, growth rates of economically important plantation crops (mainly *Pinus radiata*) are likely to increase with CO_2-fertilisation, warmer winters and wetter conditions. ** D [11.4.4]
- Increased heat-related deaths for people aged over 65 are likely, with an extra 3,200 to 5,200 deaths on average per year by 2050 (allowing for population growth and ageing, but assuming no adaptation). ** D [11.4.11]

Europe

- The probability of an extreme winter precipitation exceeding two standard deviations above normal is expected to increase by up to a factor of five in parts of the UK and northern Europe by the 2080s with a doubling of CO_2. ** D [12.3.1]
- By the 2070s, annual runoff is projected to increase in northern Europe, and decrease by up to 36% in southern Europe, with summer low flows reduced by up to 80% under IS92a. ** D [12.4.1, T12.2]
- The percentage of river-basin area in the severe water stress category (withdrawal/availability higher than 0.4) is expected to increase from 19% today to 34 to 36% by the 2070s. ** D [12.4.1]
- The number of additional people living in water-stressed watersheds in the seventeen western Europe countries is likely to increase from 16 to 44 million based on HadCM3 climate under the A2 and B1 emission scenarios, respectively, by the 2080s. ** D[12.4.1]
- Under A1FI scenarios, by the 2080s an additional 1.6 million people each year are expected to be affected by coastal flooding. ** D [12.4.2]
- By the 2070s, hydropower potential for the whole of Europe is expected to decline by 6%, with strong regional variations from a 20 to 50% decrease in the Mediterranean region to a 15 to 30% increase in northern and eastern Europe. ** D [12.4.8]
- A large percentage of the European flora could become vulnerable, endangered, critically endangered or extinct by the end of the 21st century under a range of SRES scenarios. *** N [12.4.6]
- By 2050, crops are expected to show a northward expansion in area [12.4.7.1]. The greatest increases in climate-related crop yields are expected in northern Europe (e.g., wheat: +2 to +9% by 2020, +8 to +25% by 2050, +10 to +30% by 2080), while the largest reductions are expected in the south (e.g., wheat: +3 to +4% by 2020, –8 to +22% by 2050, –15 to +32% by 2080).*** C [12.4.7]
- Forested area is likely to increase in the north and decrease in the south. A redistribution of tree species is expected, and an elevation of the mountain tree line. Forest-fire risk is virtually certain to greatly increase in southern Europe. ** D [12.4.4]
- Most amphibian (45 to 69%) and reptile (61 to 89%) species are virtually certain to expand their range if dispersal were unlimited. However, if species were unable to disperse, then the range of most species (>97%) would become smaller, especially in the Iberian Peninsula and France. ** N [12.4.6]

- Small Alpine glaciers in different regions will disappear, while larger glaciers will suffer a volume reduction between 30% and 70% by 2050 under a range of emissions scenarios, with concomitant reductions in discharge in spring and summer. *** C [12.4.3]
- Decreased comfort of the Mediterranean region in the summer, and improved comfort in the north and west, could lead to a reduction in Mediterranean summer tourism and an increase in spring and autumn. ** D [12.4.9]
- Rapid shutdown of Meridional Overturning Circulation (MOC), although assigned a low probability, is likely to have widespread severe impacts in Europe, especially in western coastal areas. These include reductions in crop production with associated price increases, increased cold-related deaths, winter transport disruption, population migration to southern Europe and a shift in the economic centre of gravity. * N [12.6.2]

Latin America

- Over the next 15 years, inter-tropical glaciers are very likely to disappear, reducing water availability and hydropower generation in Bolivia, Peru, Colombia and Ecuador. *** C [13.2.4]
- Any future reductions in rainfall in arid and semi-arid regions of Argentina, Chile and Brazil are likely to lead to severe water shortages. ** C [13.4.3]
- By the 2020s between 7 million and 77 million people are likely to suffer from a lack of adequate water supplies, while for the second half of the century the potential water availability reduction and the increasing demand, from an increasing regional population, would increase these figures to between 60 and 150 million. ** D [13.ES, 13.4.3]
- In the future, anthropogenic climate change (including changes in weather extremes) and sea-level rise are very likely to have impacts on ** N [13.4.4]:
  - low-lying areas (e.g., in El Salvador, Guyana, the coast of Buenos Aires Province in Argentina);
  - buildings and tourism (e.g., in Mexico and Uruguay);
  - coastal morphology (e.g., in Peru);
  - mangroves (e.g., in Brazil, Ecuador, Colombia, Venezuela);
  - availability of drinking water in the Pacific coast of Costa Rica and Ecuador.
- Sea surface temperature increases due to climate change are projected to have adverse effects on ** N [13.4.4]:
  - Mesoamerican coral reefs (e.g., Mexico, Belize, Panama);
  - the location of fish stocks in the south-east Pacific (e.g., Peru and Chile).
- Increases of 2°C and decreases in soil water would lead to a replacement of tropical forest by savannas in eastern Amazonia and in the tropical forests of central and southern Mexico, along with replacement of semi-arid by arid vegetation in parts of north-east Brazil and most of central and northern Mexico. ** D [13.4.1]
- In the future, the frequency and intensity of hurricanes in the Caribbean Basin are likely to increase. * D [13.3.1]
- As a result of climate change, rice yields are expected to decline after the year 2020, while increases in temperature and precipitation in south-eastern South America are likely to increase soybean yields if CO_2 effects are considered. * C [13.4.2]
- The number of additional people at risk of hunger under the SRES A2 emissions scenario is likely to attain 5, 26 and 85 million in 2020, 2050 and 2080, respectively, assuming little or no CO_2 effects. * D [13.4.2]
- Cattle productivity is very likely to decline in response to a 4°C increase in temperatures. ** N [13.ES, 13.4.2]
- The Latin American region, concerned with the potential effects of climate variability and change, is trying to implement some adaptation measures such as:
  - the use of climate forecasts in sectors such as fisheries (Peru) and agriculture (Peru, north-eastern Brazil);
  - early-warning systems for flood in the Rio de la Plata Basin based on the 'Centro Operativo de Alerta Hidrológico'.
- The region has also created new institutions to mitigate and prevent impacts from natural hazards, such as the Regional Disaster Information Center for Latin America and the Caribbean, the International Centre for Research on El Niño Phenomenon in Ecuador, and the Permanent Commission of the South Pacific. *** D [13.2.5]

North America

- Population growth, rising property values and continued investment increase coastal vulnerability. Any increase in destructiveness of coastal storms is very likely to lead to dramatic increases in losses from severe weather and storm surge, with the losses exacerbated by sea-level rise. Current adaptation is uneven, and readiness for increased exposure is poor. *** D [14.2.3, 14.4.3]
- Sea-level rise and the associated increase in tidal surge and flooding have the potential to severely affect transportation and infrastructure along the Gulf, Atlantic and northern coasts. A case study of facilities at risk in New York identified surface road and rail lines, bridges, tunnels, marine and airport facilities and transit stations. *** D [14.4.3, 14.4.6, 14.5.1, B14.3]
- Severe heatwaves, characterised by stagnant, warm air masses and consecutive nights with high minimum temperatures, are likely to increase in number, magnitude and duration in cities where they already occur, with potential for adverse health effects. Elderly populations are most at risk. ** D [14.4.5]

- By mid-century, daily average ozone levels are projected to increase by 3.7 ppb across the eastern USA, with the most polluted cities today experiencing the greatest increases. Ozone-related deaths are projected to increase by 4.5% from the 1990s to the 2050s. * D [14.4.5]
- Projected warming in the western mountains by the mid-21st century is very likely to cause large decreases in snowpack, earlier snow melt, more winter rain events, increased peak winter flows and flooding, and reduced summer flows *** D [14.4.1].
- Reduced water supplies coupled with increases in demand are likely to exacerbate competition for over-allocated water resources. *** D [14.2.1, B14.2]
- Climate change in the first several decades of the 21st century is likely to increase forest production, but with high sensitivity to drought, storms, insects and other disturbances. ** D [14.4.2, 14.4.4]
- Moderate climate change in the early decades of the century is projected to increase aggregate yields of rain-fed agriculture by 5 to 20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilised water resources. ** D [14.4]
- By the second half of the 21st century, the greatest impacts on forests are likely to be through changing disturbances from pests, diseases and fire. Warmer summer temperatures are projected to extend the annual window of high fire risk by 10 to 30%, and increase area burned by 74 to 118% in Canada by 2100. *** D [14.4.4, B14.1]
- Present rates of coastal wetland loss are projected to increase with accelerated relative sea-level rise, in part due to structures preventing landward migration. Salt-marsh biodiversity is expected to decrease in north-eastern marshes. ** D [14.4.3]
- Vulnerability to climate change is likely be concentrated in specific groups and regions, including indigenous peoples and others dependent on narrow resource bases, and the poor and elderly in cities. ** D [14.2.6, 14.4.6]
- Continued investment in adaptation in response to historical experience rather than projected future conditions is likely to increase vulnerability of many sectors to climate change [14.5]. Infrastructure development, with its long lead times and investments, would benefit from incorporating climate-change information. *** D [14.5.3, F14.3]

Polar Regions

- By the end of the century, annually averaged Arctic sea-ice extent is projected to show a reduction of 22 to 33%, depending on emissions scenario; and in Antarctica, projections range from a slight increase to a near-complete loss of summer sea ice. ** D [15.3.3]
- Over the next hundred years there will important reductions in thickness and extent of ice from Arctic glaciers and ice caps, and the Greenland ice sheet ***, as a direct response to climate warming; in Antarctica, losses from the Antarctic Peninsula glaciers will continue ***, and observed thinning in part of the West Antarctic ice sheet, which is probably driven by oceanic change, will continue **. These contributions will form a substantial fraction of sea-level rise during this century. *** D [15.3.4, 15.6.3; WGI AR4 Chapters 4, 5]
- Northern Hemisphere permafrost extent is projected to decrease by 20 to 35% by 2050. The depth of seasonal thawing is likely to increase by 15 to 25% in most areas by 2050, and by 50% or more in northernmost locations under the full range of SRES scenarios. ** D [15.3.4]
- In the Arctic, initial permafrost thaw will alter drainage systems, allowing establishment of aquatic communities in areas formerly dominated by terrestrial species ***. Further thawing will increasingly couple surface drainage to the groundwater, further disrupting ecosystems. Coastal erosion will increase. ** D [15.4.1]
- By the end of the century, 10 to 50% of Arctic tundra will be replaced by forest, and around 15 to 25% of polar desert will be replaced by tundra. * D [15.4.2]
- In both polar regions, climate change will lead to decreases in habitat (including sea ice) for migratory birds and mammals [15.2.2, 15.4.1], with major implications for predators such as seals and polar bears ** [15.2, 15.4.3]. Changes in the distribution and abundance of many species can be expected. *** D [15.6.3]
- The climatic barriers that have hitherto protected polar species from competition will be lowered, and the encroachment of alien species into parts of the Arctic and Antarctic are expected. ** D [15.6.3, 15.4.4, 15.4.2]
- Reductions in lake and river ice cover are expected in both polar regions. These will affect lake thermal structures, the quality/quantity of under-ice habitats and, in the Arctic, the timing and severity of ice jamming and related flooding. *** N [15.4.1]
- Projected hydrological changes will influence the productivity and distribution of aquatic species, especially fish. Warming of freshwaters is likely to lead to reductions in fish stock, especially those that prefer colder waters. ** D [15.4.1]
- For Arctic human communities, it is virtually certain that there will be both negative and positive impacts, particularly through changing cryospheric components, on infrastructure and traditional indigenous ways of life. ** D [15.4]
- In Siberia and North America, there may be an increase in agriculture and forestry as the northern limit for these activities shifts by several hundred kilometres by 2050 [15.4.2]. This will benefit some communities and disadvantage others following traditional lifestyles. ** D [15.4.6]

- Large-scale forest fires and outbreaks of tree-killing insects, which are triggered by warm weather, are characteristic of the boreal forest and some forest tundra areas, and are likely to increase. ** N [15.4.2]
- Arctic warming will reduce excess winter mortality, primarily through a reduction in cardiovascular and respiratory deaths and in injuries. *** N [15.4.6]
- Arctic warming will be associated with increased vulnerability to pests and diseases in wildlife, such as tick-borne encephalitis, which can be transmitted to humans. ** N [15.4.6]
- Increases in the frequency and severity of Arctic flooding, erosion, drought and destruction of permafrost, threaten community, public health and industrial infrastructure and water supply. *** N [15.4.6]
- Changes in the frequency, type and timing of precipitation will increase contaminant capture and increase contaminant loading to Arctic freshwater systems. Increased loadings will more than offset the reductions that are expected to accrue from global emissions of contaminants. ** N [15.4.1]
- Arctic human communities are already being required to adapt to climate change. Impacts to food security, personal safety and subsistence activities are being responded to via changes in resource and wildlife management regimes and shifts in personal behaviours (e.g., hunting, travelling). In combination with demographic, socio-economic and lifestyle changes, the resilience of indigenous populations is being severely challenged. *** N [15.4.1, 15.4.2, 15.4.6, 15.6]

Small Islands

- Sea-level rise and increased sea-water temperature are projected to accelerate beach erosion, and cause degradation of natural coastal defences such as mangroves and coral reefs. It is likely that these changes would, in turn, negatively impact the attraction of small islands as premier tourism destinations. According to surveys, it is likely that, in some islands, up to 80% of tourists would be unwilling to return for the same holiday price in the event of coral bleaching and reduced beach area resulting from elevated sea surface temperatures and sea-level rise. ** D [16.4.6]
- Port facilities at Suva, Fiji, and Apia, Samoa, are likely to experience overtopping, damage to wharves and flooding of the hinterland following a 0.5 m rise in sea level combined with waves associated with a 1 in 50-year cyclone. *** D [16.4.7]
- International airports on small islands are mostly sited on or within a few kilometres of the coast, and the main (and often only) road network runs along the coast. Under sea-level rise scenarios, many of them are likely to be at serious risk from inundation, flooding and physical damage associated with coastal inundation and erosion. *** D [16.4.7]
- Coastal erosion on Arctic islands has additional climate sensitivity through the impact of warming on permafrost and massive ground ice, which can lead to accelerated erosion and volume loss, and the potential for higher wave energy. *** D [16.4.2]
- Reduction in average rainfall is very likely to reduce the size of the freshwater lens. A 10% reduction in average rainfall by 2050 is likely to correspond to a 20% reduction in the size of the freshwater lens on Tarawa Atoll, Kiribati. In general, a reduction in physical size resulting from land loss accompanying sea-level rise could reduce the thickness of the freshwater lens on atolls by as much as 29%. *** N [16.4.1]
- Without adaptation, agricultural economic costs from climate change are likely to reach between 2-3% and 17-18% of 2002 GDP by 2050, on high terrain (e.g., Fiji) and low terrain (e.g., Kiribati) islands, respectively, under SRES A2 (1.3°C increase by 2050) and B2 (0.9°C increase by 2050). ** N [16.4.3]
- With climate change, increased numbers of introductions and enhanced colonisation by alien species are likely to occur on mid- and high-latitude islands. These changes are already evident on some islands. For example, in species-poor sub-Antarctic island ecosystems, alien microbes, fungi, plants and animals have been causing a substantial loss of local biodiversity and changes to ecosystem function. ** N [16.4.4]
- Outbreaks of climate-sensitive diseases such as malaria, dengue, filariasis and schistosomiasis can be costly in lives and economic impacts. Increasing temperatures and decreasing water availability due to climate change is likely to increase burdens of diarrhoeal and other infectious diseases in some small-island states. ** D [16.4.5]
- Climate change is expected to have significant impacts on tourism destination selection ** D [16.4.6]. Several small-island countries (e.g., Barbados, Maldives, Seychelles, Tuvalu) have begun to invest in the implementation of adaptation strategies, including desalination, to offset current and projected water shortages. *** D [16.4.1]
- Studies so far conducted on adaptation on islands suggest that adaptation options are likely to be limited and the costs high relative to GDP. Recent work has shown that, in the case of Singapore, coastal protection would be the least-cost strategy to combat sea-level rise under three scenarios, with the cost ranging from US$0.3-5.7 million by 2050 to US$0.9-16.8 million by 2100. ** D [16.5.2]
- Although adaptation choices for small islands may be limited and adaptation costs high, exploratory research indicates that there are some co-benefits which can be generated from pursuing prudent adaptation strategies. For example, the use of waste-to-energy and other renewable energy systems can promote sustainable development, while strengthening resilience to climate change. In fact, many islands have already embarked on initiatives aimed at ensuring that renewables constitute a significant percentage of the energy mix. ** D [16.4.7, 16.6]

TS.4.3 Magnitudes of impact for varying amounts of climate change

Magnitudes of impact can now be estimated more systematically for a range of possible increases in global average temperature.
Since the IPCC Third Assessment, many additional studies, particularly in regions that previously had been little researched, have enabled a more systematic understanding of how the timing and magnitude of impacts is likely to be affected by changes in climate and sea level associated with differing amounts and rates of change in global average temperature.

Examples of this new information are presented in Tables TS.3 and TS.4. Entries have been selected which are judged to be relevant for people and the environment and for which there is at least medium confidence in the assessment. All entries of impact are drawn from chapters of the Assessment, where more detailed information is available. Depending on circumstances, some of these impacts could be associated with 'key vulnerabilities', based on a number of criteria in the literature (magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts). Assessment of potential key vulnerabilities is intended to provide information on rates and levels of climate change to help decision-makers make appropriate responses to the risks of climate change [19.ES, 19.1].

TS.4.4 The impact of altered extremes

Impacts are very likely to increase due to increased frequencies and intensities of extreme weather events.
Since the IPCC Third Assessment, confidence has increased that some weather events and extremes will become more frequent, more widespread or more intense during the 21st century; and more is known about the potential effects of such changes. These are summarised in Table TS.5.

TS.4.5 Especially affected systems, sectors and regions

Some systems, sectors and regions are likely to be especially affected by climate change.
Regarding systems and sectors, these are as follows.

- Some ecosystems especially
  - terrestrial: tundra, boreal forest, mountain, mediterranean-type ecosystems;
  - along coasts: mangroves and salt marshes;
  - in oceans: coral reefs and the sea-ice biomes.

  [4.ES, 4.4, 6.4]
- Low-lying coasts, due to the threat of sea-level rise [6.ES].
- Water resources in mid-latitude and dry low-latitude regions, due to decreases in rainfall and higher rates of evapotranspiration [3.4].
- Agriculture in low-latitude regions, due to reduced water availability [5.4, 5.3].
- Human health, especially in areas with low adaptive capacity [8.3].

Regarding regions, these are as follows.

- The Arctic, because of high rates of projected warming on natural systems [15.3].
- Africa, especially the sub-Saharan region, because of current low adaptive capacity as well as climate change [9.ES, 9.5].
- Small islands, due to high exposure of population and infrastructure to risk of sea-level rise and increased storm surge [16.1, 16.2].
- Asian megadeltas, such as the Ganges-Brahmaputra and the Zhujiang, due to large populations and high exposure to sea-level rise, storm surge and river flooding [T10.9, 10.6].

Within other areas, even those with high incomes, some people can be particularly at risk (such as the poor, young children and the elderly) and also some areas and some activities [7.1, 7.2, 7.4].

TS.4.6 Events with large impacts

Some large-scale climate events have the potential to cause very large impacts, especially after the 21st century.
Very large sea-level rises that would result from widespread deglaciation of Greenland and West Antarctic ice sheets imply major changes in coastlines and ecosystems, and inundation of low-lying areas, with the greatest effects in river deltas. Relocating populations, economic activity and infrastructure would be costly and challenging. There is medium confidence that at least partial deglaciation of the Greenland ice sheet, and possibly the West Antarctic ice sheet, would occur over a period of time ranging from centuries to millennia for a global average temperature increase of 1-4°C (relative to 1990-2000), causing a contribution to sea-level rise of 4-6 m or more. The complete melting of the Greenland ice sheet and the West Antarctic ice sheet would lead to a contribution to sea-level rise of up to 7 m and about 5 m, respectively [WGI AR4 6.4, 10.7; WGII AR4 19.3].

Based on climate model results, it is very unlikely that the Meridional Overturning Circulation (MOC) in the North Atlantic will undergo a large abrupt transition during the 21st century. Slowing of the MOC this century is very likely, but temperatures over the Atlantic and Europe are projected to increase nevertheless, due to global warming. Impacts of large-scale and persistent changes in the MOC are likely to include changes to marine ecosystem productivity, fisheries, ocean CO_2 uptake, oceanic oxygen concentrations and terrestrial vegetation [WGI AR4 10.3, 10.7; WGII AR4 12.6, 19.3].

TS.4.7 Costing the impacts of climate change

Impacts of unmitigated climate change will vary regionally. Aggregated and discounted to the present, they are very likely to impose costs, even though specific estimates are uncertain and should therefore be interpreted very carefully. These costs are very likely to increase over time.

This Assessment (see Tables TS.3 and TS.4) makes it clear that the impacts of future climate change will be mixed across regions. For increases in global mean temperature of less than 1-3°C above 1990 levels, some impacts are projected to produce benefits in some places and some sectors, and produce costs in other places and other sectors. It is, however, projected that some low-latitude and polar regions will experience net costs even for small increases in temperature. It is very likely that all regions will experience either declines in net benefits or increases in net costs for increases in temperature greater than about 2-3°C [9.ES, 9.5, 10.6, T10.9, 15.3, 15.ES]. These observations confirm evidence reported in the Third Assessment that, while developing countries are expected to experience larger percentage losses, global mean losses could be 1-5% of GDP for 4°C of warming [F20.3].

Many estimates of aggregate net economic costs of damages from climate change across the globe (i.e., the social cost of carbon (SCC), expressed in terms of future net benefits and costs that are discounted to the present) are now available. Peer-reviewed estimates of the SCC for 2005 have an average value of US$43 per tonne of carbon (i.e., US$12 per tonne of CO_2) but the range around this mean is large. For example, in a survey of 100 estimates, the values ranged from –US$10 per tonne of carbon (–US$3 per tonne of CO_2) up to US$350 per tonne of carbon (US$95 per tonne of CO_2) [20.6].

The large ranges of SCC are due in large part to differences in assumptions regarding climate sensitivity, response lags, the treatment of risk and equity, economic and non-economic impacts, the inclusion of potentially catastrophic losses, and discount rates. It is very likely that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts. Taken as a whole, the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time [T20.3, 20.6, F20.4].

It is virtually certain that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries, and populations. In some locations and amongst some groups of people with high exposure, high sensitivity, and/or low adaptive capacity, net costs will be significantly larger than the global aggregate [20.6, 20.ES, 7.4].

TS.5 Current knowledge about responding to climate change

TS.5.1 Adaptation

Some adaptation is occurring now, to observed and projected future climate change, but on a very limited basis.

Societies have a long record of adapting to the impacts of weather and climate through a range of practices that include crop diversification, irrigation, water management, disaster risk management and insurance. But climate change poses novel risks which are often outside the range of experience, such as impacts related to drought, heatwaves, accelerated glacier retreat and hurricane intensity [17.2.1].

There is growing evidence since the TAR that adaptation measures that also consider climate change are being implemented, on a limited basis, in both developed and developing countries. These measures are undertaken by a range of public and private actors through policies, investments in infrastructure and technologies, and behavioural change.

Examples of adaptations to observed changes in climate include:

- partial drainage of the Tsho Rolpa glacial lake (Nepal);
- changes in livelihood strategies in response to permafrost melt by the Inuit in Nunavut (Canada);
- increased use of artificial snow-making by the Alpine ski industry (Europe, Australia and North America);
- coastal defences in the Maldives and the Netherlands;
- water management in Australia;
- government responses to heatwaves in, for example, some European countries.

[7.6, 8.2, 8.6, 17.ES, 16.5, 1.5]

However, all of the adaptations documented were imposed by the climate risk and involve real cost and reduction of welfare in the first instance [17.2.3]. These examples also confirm the observations of attributable climate signals in the impacts of change.

A limited but growing set of adaptation measures also explicitly considers scenarios of future climate change. Examples include consideration of sea-level rise in the design of infrastructure such as the Confederation Bridge in Canada and a coastal highway in Micronesia, as well as in shoreline management policies and flood risk measures, for example in Maine (USA) and the Thames Barrier (UK) [17.2.2].

Adaptation measures are seldom undertaken in response to climate change alone.

Many actions that facilitate adaptation to climate change are undertaken to deal with current extreme events such as heatwaves and cyclones. Often, planned adaptation initiatives are also not undertaken as stand-alone measures, but embedded within broader sectoral initiatives such as water-resource planning, coastal defence, and risk reduction strategies [17.2.2, 17.3.3]. Examples include consideration of climate change in the National Water Plan of Bangladesh, and the design of flood protection and cyclone-resistant infrastructure in Tonga [17.2.2].

Adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions.

Past emissions are estimated to involve some unavoidable warming (about a further 0.6°C by the end of the century relative to 1980-1999) even if atmospheric greenhouse gas concentrations remain at 2000 levels (see WGI AR4). There are some impacts for which adaptation is the only available and

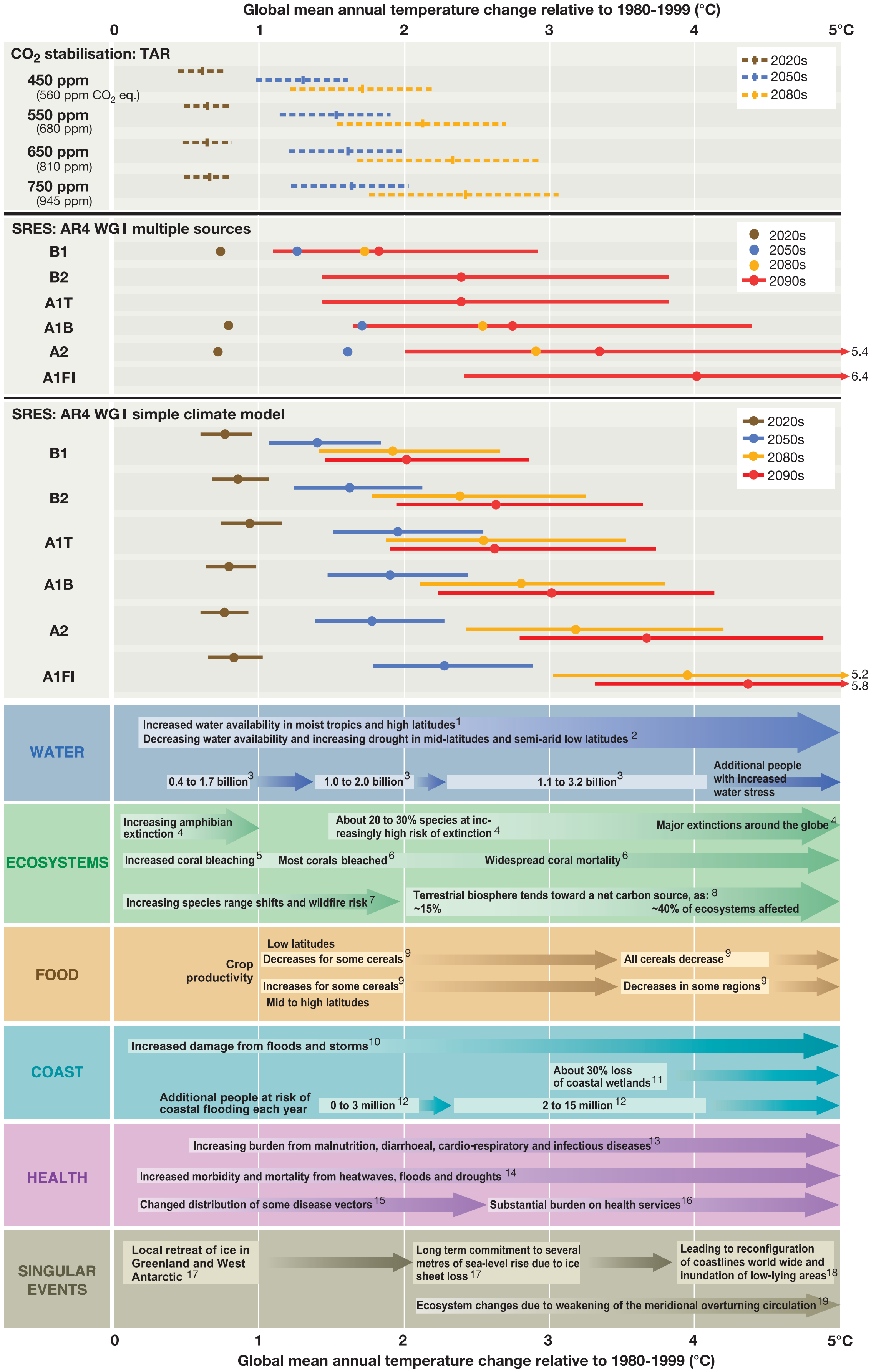


Table TS.3. *Examples of global impacts projected for changes in climate (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century [T20.8]. This is a selection of some estimates currently available. All entries are from published studies in the chapters of the Assessment. (Continues below Table TS.4.)*

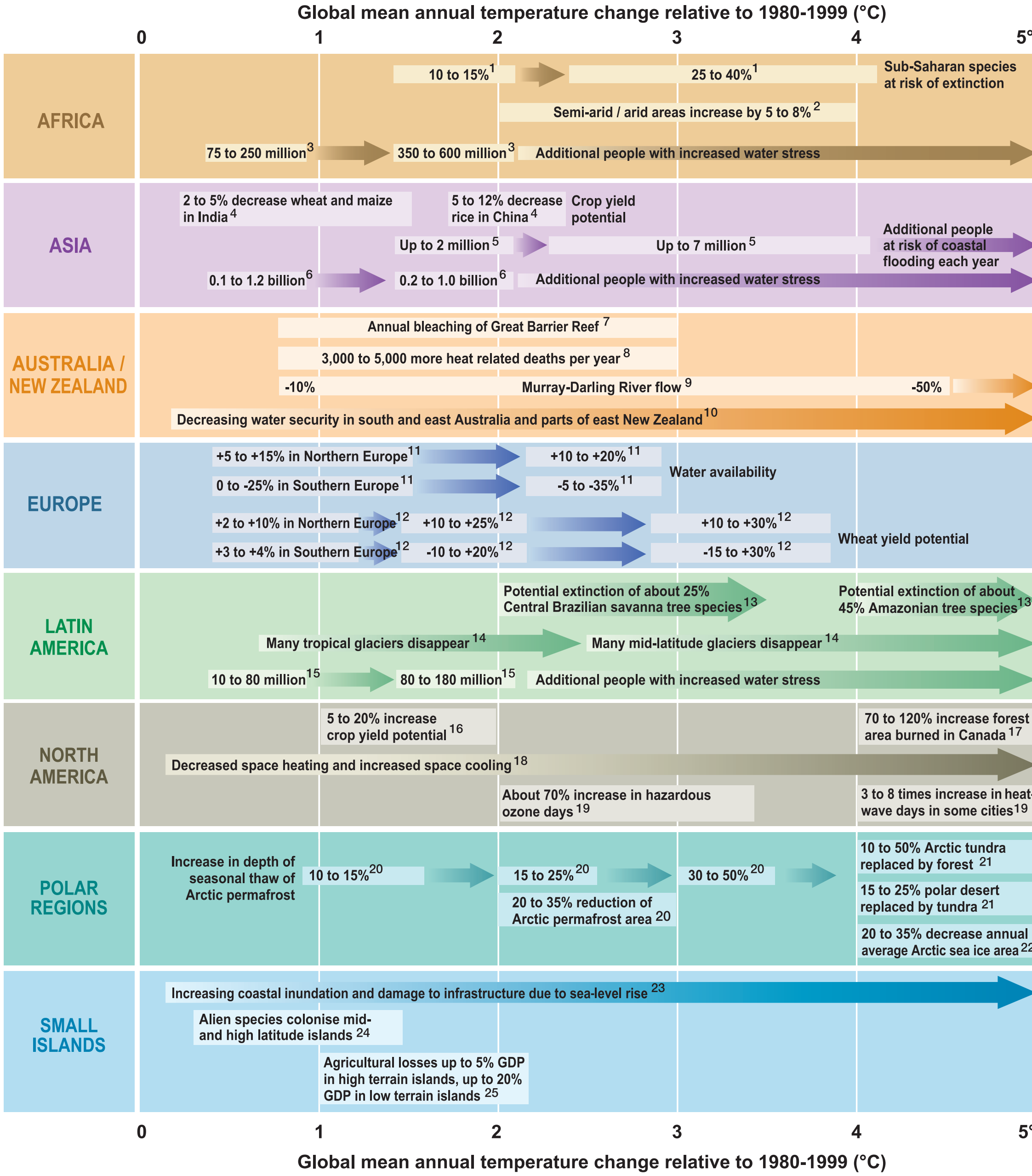


Table TS.4. *Examples of regional impacts [T20.9]. See caption for Table TS.3.*

Table TS.3. (cont.) *Edges of boxes and placing of text indicate the range of temperature change to which the impacts relate. Arrows between boxes indicate increasing levels of impacts between estimations. Other arrows indicate trends in impacts. All entries for water stress and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. For extinctions, 'major' means ~40 to ~70% of assessed species.*

The table also shows global temperature changes for selected time periods, relative to 1980-1999, projected for SRES and stabilisation scenarios. To express the temperature change relative to 1850-1899, add 0.5°C. More detail is provided in Chapter 2 [Box 2.8]. Estimates are for the 2020s, 2050s and 2080s, (the time periods used by the IPCC Data Distribution Centre and therefore in many impact studies) and for the 2090s. SRES-based projections are shown using two different approaches. ***Middle panel:*** *projections from the WGI AR4 SPM based on multiple sources. Best estimates are based on AOGCMs (coloured dots). Uncertainty ranges, available only for the 2090s, are based on models, observational constraints and expert judgement.* ***Lower panel:*** *best estimates and uncertainty ranges based on a simple climate model (SCM), also from WGI AR4 (Chapter 10).* ***Upper panel:*** *best estimates and uncertainty ranges for four CO_2-stabilisation scenarios using an SCM. Results are from the TAR because comparable projections for the 21st century are not available in the AR4. However, estimates of equilibrium warming are reported in the WGI AR4 for CO_2-equivalent stabilisation[18]. Note that equilibrium temperatures would not be reached until decades or centuries after greenhouse gas stabilisation.*

Table TS.3. Sources: 1, 3.4.1; **2,** 3.4.1, 3.4.3; **3,** 3.5.1; **4,** 4.4.11; **5,** 4.4.9, 4.4.11, 6.2.5, 6.4.1; **6,** 4.4.9, 4.4.11, 6.4.1; **7,** 4.2.2, 4.4.1, 4.4.4 to 4.4.6, 4.4.10; **8,** 4.4.1, 4.4.11; **9,** 5.4.2; **10,** 6.3.2, 6.4.1, 6.4.2; **11,** 6.4.1; **12,** 6.4.2; **13,** 8.4, 8.7; **14,** 8.2, 8.4, 8.7; **15,** 8.2, 8.4, 8.7; **16,** 8.6.1; **17,** 19.3.1; **18,** 19.3.1, 19.3.5; **19,** 19.3.5
Table TS.4. Sources: 1, 9.4.5; **2,** 9.4.4; **3,** 9.4.1; **4,** 10.4.1; **5,** 6.4.2; **6,** 10.4.2; **7,** 11.6; **8,** 11.4.12; **9,** 11.4.1, 11.4.12; **10,** 11.4.1, 11.4.12; **11,** 12.4.1; **12,** 12.4.7; **13,** 13.4.1; **14,** 13.2.4; **15,** 13.4.3; **16,** 14.4.4; **17,** 5.4.5, 14.4.4; **18,** 14.4.8; **19,** 14.4.5; **20,** 15.3.4, **21,** 15.4.2; **22,** 15.3.3; **23,** 16.4.7; **24,** 16.4.4; **25,** 16.4.3

[18] Best estimate and likely range of equilibrium warming for seven levels of CO_2-equivalent stabilisation from WGI AR4 are: 350 ppm, 1.0°C [0.6–1.4]; 450 ppm, 2.1°C [1.4–3.1]; 550 ppm, 2.9°C [1.9–4.4]; 650 ppm, 3.6°C [2.4–5.5]; 750 ppm, 4.3°C [2.8–6.4]; 1,000 ppm, 5.5°C [3.7–8.3] and 1,200 ppm, 6.3°C [4.2–9.4].

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems	Water resources	Human health	Industry, settlements and society
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks [5.8.1, 4.4.5]	Effects on water resources relying on snow melt; effects on some water supply [3.4.1, 3.5.1]	Reduced human mortality from decreased cold exposure [8.4.1, T8.3]	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism [7.4.2, 14.4.8, 15.7.1]
Warm spells/ heatwaves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; wildfire danger increase [5.8.1, 5.4.5, 4.4.3, 4.4.4]	Increased water demand; water quality problems, e.g., algal blooms [3.4.2, 3.5.1, 3.4.4]	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated [8.4.2, T8.3, 8.4.1]	Reduction in quality of life for people in warm areas without appropriate housing; impacts on elderly, very young and poor [7.4.2, 8.2.1]
Heavy precipitation events. Frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils [5.4.2]	Adverse effects on quality of surface and groundwater; contamination of water supply; water stress may be relieved [3.4.4]	Increased risk of deaths, injuries, infectious, respiratory and skin diseases [8.2.2, 11.4.11]	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property [T7.4, 7.4.2]
Area affected by drought increases	Likely	Land degradation, lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire [5.8.1, 5.4, 4.4.4]	More widespread water stress [3.5.1]	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases [5.4.7, 8.2.3, 8.2.5]	Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration [T7.4, 7.4, 7.1.3]
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs [5.4.5, 16.4.3]	Power outages cause disruption of public water supply [7.4.2]	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders [8.2.2, 8.4.2, 16.4.5]	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers, potential for population migrations, loss of property [7.4.1, 7.4.2, 7.1.3]
Increased incidence of extreme high sea level (excludes tsunamis)[c]	Likely[d]	Salinisation of irrigation water, estuaries and freshwater systems [3.4.2, 3.4.4, 10.4.2]	Decreased freshwater availability due to salt-water intrusion [3.4.2, 3.4.4]	Increased risk of deaths and injuries by drowning in floods; migration-related health effects [6.4.2, 8.2.2, 8.4.2]	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above [7.4.2]

[a] See WGI AR4 Table 3.7 for further details regarding definitions.
[b] Warming of the most extreme days and nights each year.
[c] Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
[d] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period [WGI AR4 10.6]. The effect of changes in regional weather systems on sea-level extremes has not been assessed.

Table TS.5. *Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid- to late 21st century. These do not take into account any changes or developments in adaptive capacity. Examples of all entries are to be found in chapters in the full Assessment (see sources). The first two columns of this table (shaded yellow) are taken directly from the Working Group I Fourth Assessment (Table SPM.2). The likelihood estimates in column 2 relate to the phenomena listed in column 1. The direction of trend and likelihood of phenomena are for SRES projections of climate change.*

appropriate response. An indication of these impacts can be seen in Tables TS.3 and TS.4.

Many adaptations can be implemented at low cost, but comprehensive estimates of adaptation costs and benefits are currently lacking.

There are a growing number of adaptation cost and benefit-cost estimates at regional and project level for sea-level rise, agriculture, energy demand for heating and cooling, water-resource management, and infrastructure. These studies identify a number of measures that can be implemented at low cost or with high benefit-cost ratios. However, some common adaptations may have social and environmental externalities. Adaptations to heatwaves, for example, have involved increased demand for energy-intensive air-conditioning [17.2.3].

Limited estimates are also available for global adaptation costs related to sea-level rise, and energy expenditures for space heating and cooling. Estimates of global adaptation benefits for the agricultural sector are also available, although such literature does not explicitly consider the costs of adaptation. Comprehensive multi-sectoral estimates of global costs and benefits of adaptation are currently lacking [17.2.3].

Adaptive capacity is uneven across and within societies.

There are individuals and groups within all societies that have insufficient capacity to adapt to climate change. For example, women in subsistence farming communities are disproportionately burdened with the costs of recovery and coping with drought in southern Africa [17.3.2].

The capacity to adapt is dynamic and influenced by economic and natural resources, social networks, entitlements, institutions and governance, human resources, and technology [17.3.3]. For example, research in the Caribbean on hurricane preparedness shows that appropriate legislation is a necessary prior condition to implementing plans for adaptation to future climate change [17.3].

Multiple stresses related to HIV/AIDS, land degradation, trends in economic globalisation, trade barriers and violent conflict affect exposure to climate risks and the capacity to adapt. For example, farming communities in India are exposed to impacts of import competition and lower prices in addition to climate risks; and marine ecosystems over-exploited by globalised fisheries have been shown to be less resilient to climate variability and change (see Box TS.7) [17.3.3].

High adaptive capacity does not necessarily translate into actions that reduce vulnerability. For example, despite a high capacity to adapt to heat stress through relatively inexpensive adaptations, residents in urban areas in some parts of the world, including in European cities, continue to experience high levels of mortality. One example is the 2003 European heatwave-related deaths. Another example is Hurricane Katrina, which hit the Gulf of Mexico Coast and New Orleans in 2005 and caused the deaths of more than 1,000 people, together with very high economic and social costs [17.4.2].

A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to future climate change. There are barriers, limits and costs, but these are not fully understood.

The array of potential adaptive responses available to human societies is very large (see Table TS.6), ranging from purely technological (e.g., sea defences), through behavioural (e.g., altered food and recreational choices), to managerial (e.g., altered farm practices) and to policy (e.g., planning regulations). While most technologies and strategies are known and developed in some countries, the assessed literature does not indicate how effective various options are at fully reducing risks, particularly at higher levels of warming and related impacts, and for vulnerable groups.

Although many early impacts of climate change can be effectively addressed through adaptation, the options for successful adaptation diminish and the associated costs increase with increasing climate change. At present we do not have a clear picture of the limits to adaptation, or the cost, partly because effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political and financial constraints [7.6, 17.2, 17.4]. There are significant barriers to implementing adaptation. These include both the inability of natural systems to adapt to the rate and magnitude of climate change, as well as formidable environmental, economic, informational, social, attitudinal and behavioural constraints. There are also significant knowledge gaps for adaptation as well as impediments to flows of knowledge and information relevant for adaptation decisions [17.4.1, 17.4.2]. For developing countries, availability of resources and building adaptive capacity are particularly important [see Sections 5 and 6 in Chapters 3 to 16; also 17.2, 17.4]. Some examples and reasons are given below.

a. The large number and expansion of potentially hazardous glacial lakes due to rising temperatures in the Himalayas. These far exceed the capacity of countries in the region to manage such risks.
b. If climate change is faster than is anticipated, many developing countries simply cannot cope with more frequent/intense occurrence of extreme weather events, as this will drain resources budgeted for other purposes.
c. Climate change will occur in the life cycle of many infrastructure projects (coastal dykes, bridges, sea ports, etc.). Strengthening of these infrastructures based on new design criteria may take decades to implement. In many cases, retrofitting would not be possible.
d. Due to physical constraints, adaptation measures cannot be implemented in many estuaries and delta areas.

New planning processes are attempting to overcome these barriers at local, regional and national levels in both developing and developed countries. For example, Least Developed Countries are developing National Adaptation Plans of Action (NAPA) and some developed countries have established national adaptation policy frameworks [17.4.1].

TS.5.2 Interrelationships between adaptation and mitigation

Both adaptation and mitigation can help to reduce the risks of climate change to nature and society.
However, their effects vary over time and place. Mitigation will have global benefits but, owing to the lag times in the climate and biophysical systems, these will hardly be noticeable until around the middle of the 21st century [WGI AR4 SPM]. The benefits of adaptation are largely local to regional in scale but they can be immediate, especially if they also address vulnerabilities to current climate conditions [18.1.1, 18.5.2]. Given these differences between adaptation and mitigation, climate policy is not about making a choice between adapting to and mitigating climate change. If key vulnerabilities to climate change are to be addressed, adaptation is necessary because even the most stringent mitigation efforts cannot avoid further climate change in the next few decades. Mitigation is necessary because reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is possible only at very high social, environmental and economic costs [18.4, 18.6].

Many impacts can be avoided, reduced or delayed by mitigation.
A small number of impact assessments have now been completed for scenarios in which future atmospheric concentrations of greenhouse gases are stabilised. Although these studies do not take full account of uncertainties in projected climate under stabilisation – for example, the

	Food, fibre and forestry	Water resources	Human health	Industry, settlement and society
Drying/ Drought	*Crops*: development of new drought-resistant varieties; intercropping; crop residue retention; weed management; irrigation and hydroponic farming; water harvesting *Livestock*: supplementary feeding; change in stocking rate; altered grazing and rotation of pasture *Social*: Improved extension services; debt relief; diversification of income	Leak reduction Water demand management through metering and pricing Soil moisture conservation e.g., through mulching Desalination of sea water Conservation of groundwater through artificial recharge Education for sustainable water use	Grain storage and provision of emergency feeding stations Provision of safe drinking water and sanitation Strengthening of public institutions and health systems Access to international food markets	Improve adaptation capacities, especially for livelihoods Incorporate climate change in development programmes Improved water supply systems and co-ordination between jurisdictions
Increased rainfall/ Flooding	*Crops*: Polders and improved drainage; development and promotion of alternative crops; adjustment of plantation and harvesting schedule; floating agricultural systems *Social*: Improved extension services	Enhanced implementation of protection measures including flood forecasting and warning, regulation through planning legislation and zoning; promotion of insurance; and relocation of vulnerable assets	Structural and non-structural measures. Early-warning systems; disaster preparedness planning; effective post-event emergency relief	Improved flood protection infrastructure "Flood-proof" buildings Change land use in high-risk areas Managed realignment and "Making Space for Water" Flood hazard mapping; flood warnings Empower community institutions
Warming/ Heatwaves	*Crops*: Development of new heat-resistant varieties; altered timing of cropping activities; pest control and surveillance of crops *Livestock*: Housing and shade provision; change to heat-tolerant breeds *Forestry*: Fire management through altered stand layout, landscape planning, dead timber salvaging, clearing undergrowth. Insect control through prescribed burning, non-chemical pest control *Social*: Diversification of income	Water demand management through metering and pricing Education for sustainable water use	International surveillance systems for disease emergence Strengthening of public institutions and health systems National and regional heat warning systems Measures to reduce urban heat island effects through creating green spaces Adjusting clothing and activity levels; increasing fluid intake	Assistance programmes for especially vulnerable groups Improve adaptive capacities Technological change
Wind speed/ Storminess	*Crops*: Development of wind-resistant crops (e.g., vanilla)	Coastal defence design and implementation to protect water supply against contamination	Early-warning systems; disaster preparedness planning; effective post-event emergency relief	Emergency preparedness, including early-warning systems More resilient infrastructure Financial risk management options for both developed and developing regions

Table TS.6. *Examples of current and potential options for adapting to climate change for vulnerable sectors. All entries have been referred to in chapters in the Fourth Assessment. Note that, with respect to ecosystems, generic rather than specific adaptation responses are required. Generic planning strategies would enhance the capacity to adapt naturally. Examples of such strategies are: enhanced wildlife corridors, including wide altitudinal gradients in protected areas. [5.5, 3.5, 6.5, 7.5, T6.5]* sensitivity of climate models to forcing – they nevertheless provide indications of damages avoided or vulnerabilities and risks reduced for different amounts of emissions reduction [2.4, T20.6].

In addition, more quantitative information is now available concerning when, over a range of temperature increases, given amounts of impact may occur. This allows inference of the amounts of global temperature increase that are associated with given impacts. Table TS.3 illustrates the change in global average temperature projected for three periods (2020s, 2050s, 2080s) for several alternative stabilisation pathways and for emissions trends assumed under different SRES scenarios. Reference to Tables TS.3 and TS.4 provides a picture of the impacts which might be avoided for given ranges of temperature change.

A portfolio of adaptation and mitigation measures can diminish the risks associated with climate change.

Even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades, which makes adaptation essential, particularly in addressing near-term impacts. Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt [20.7].

This suggests the value of a portfolio or mix of strategies that includes mitigation, adaptation, technological development (to enhance both adaptation and mitigation) and research (on climate science, impacts, adaptation and mitigation). Such portfolios could combine policies with incentive-based approaches and actions at all levels from the individual citizen through to national governments and international organisations [18.1, 18.5].

These actions include technological, institutional and behavioural options, the introduction of economic and policy instruments to encourage the use of these options, and research and development to reduce uncertainty and to enhance the options' effectiveness and efficiency [18.4.1, 18.4.2]. Many different actors are involved in the implementation of these actions, operating on different spatial and institutional scales. Mitigation primarily involves the energy, transportation, industrial, residential, forestry and agriculture sectors, whereas the actors involved in adaptation represent a large variety of sectoral interests, including agriculture, tourism and recreation, human health, water supply, coastal management, urban planning and nature conservation [18.5, 18.6].

Box TS.7. Adaptive capacity to multiple stressors in India

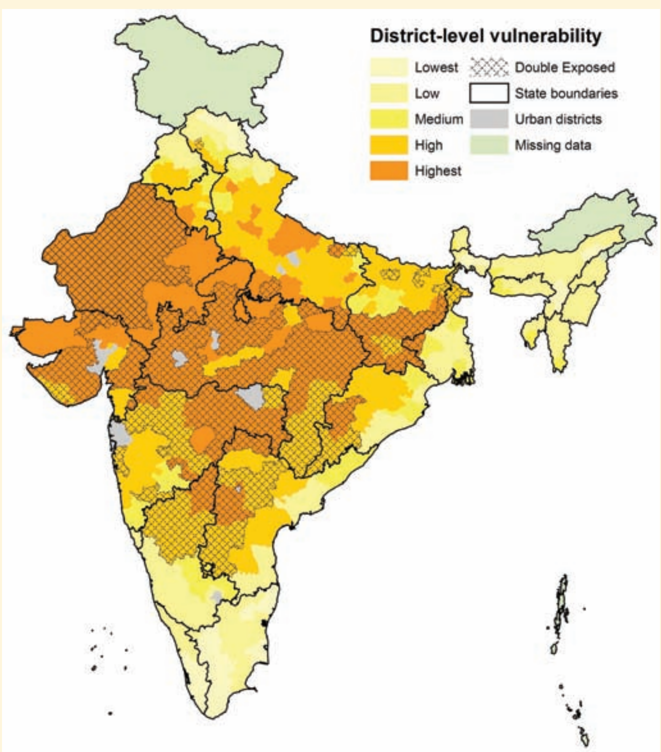


Figure TS.17. *Districts in India that rank highest in terms of (a) vulnerability to climate change and (b) import competition associated with economic globalisation, are considered to be double-exposed (depicted with hatching). From O'Brien et al. (2004) [F17.2].*

The capacity to adapt to climate change is not evenly distributed across or within nations. In India, for example, both climate change and trade liberalisation are changing the context for agricultural production. Some farmers are able to adapt to these changing conditions, including discrete events such as drought and rapid changes in commodity prices, but others are not. Identifying the areas where both processes are likely to have negative outcomes provides a first step in identifying options and constraints in adapting to changing conditions [17.3.2].

Figure TS.17 shows regional vulnerability to climate change, measured as a composite of adaptive capacity and climate sensitivity under exposure to climate change. The superimposed hatching indicates those areas which are doubly exposed through high vulnerability to climate change and high vulnerability to trade liberalisation. The results of this mapping show higher degrees of resilience in districts located along the Indo-Gangetic Plains (except in the state of Bihar), the south and east, and lower resilience in the interior parts of the country, particularly in the states of Bihar, Rajasthan, Madhya Pradesh, Maharashtra, Andhra Pradesh and Karnataka [17.3.2].

One way of increasing adaptive capacity is by introducing the consideration of climate change impacts in development planning [18.7], for example, by:

- including adaptation measures in land-use planning and infrastructure design [17.2];
- including measures to reduce vulnerability in existing disaster risk reduction strategies [17.2, 20.8].

Decisions on adaptation and mitigation are taken at a range of different levels.
These levels include individual households and farmers, private firms and national planning agencies. Effective mitigation requires the participation of the bulk of major greenhouse gas emitters globally, whereas most adaptation takes place at local and national levels. The benefits of mitigation are global, whilst its costs and ancillary benefits arise locally. Both the costs and benefits of adaptation mostly accrue locally [18.1.1, 18.4.2]. Consequently, mitigation is primarily driven by international agreements and the ensuing national public policies, whereas most adaptation is driven by private actions of affected entities and public arrangements of impacted communities [18.1.1, 18.6.1].

Interrelationships between adaptation and mitigation can exist at each level of decision-making.
Adaptation actions can have (often unintended) positive or negative mitigation effects, whilst mitigation actions can have (also often unintended) positive or negative adaptation effects [18.4.2, 18.5.2]. An example of an adaptation action with a negative mitigation effect is the use of air-conditioning (if the required energy is provided by fossil fuels). An example of a mitigation action with a positive adaptation effect could be the afforestation of degraded hill slopes, which would not only sequester carbon but also control soil erosion. Other examples of such synergies between adaptation and mitigation include rural electrification based on renewable energy sources, planting trees in cities to reduce the heat-island effect, and the development of agroforestry systems [18.5.2].

Analysis of the interrelationships between adaptation and mitigation may reveal ways to promote the effective implementation of adaptation and mitigation actions.
Creating synergies between adaptation and mitigation can increase the cost-effectiveness of actions and make them more attractive to potential funders and other decision-makers (see Table TS.7). However, synergies provide no guarantee that resources are used in the most efficient manner when seeking to reduce the risks of climate change. Moreover, essential actions without synergetic effects may be overlooked if the creation of synergies becomes a dominant decision criterion [18.6.1]. Opportunities for synergies exist in some sectors (e.g., agriculture, forestry, buildings and urban infrastructure) but they are rather limited in many other climate-relevant sectors [18.5.2]. A lack of both conceptual and empirical information that explicitly considers both adaptation and mitigation makes it difficult to assess the need for, and potential of synergies in, climate policy [18.7].

Decisions on trade-offs between the immediate localised benefits of adaptation and the longer-term global benefits of mitigation would require information on the actions' costs and benefits over time.
For example, a relevant question would be whether or not investment in adaptation would buy time for mitigation. Global integrated assessment models provide approximate estimates of relative costs and benefits at highly aggregated levels. Intricacies of the interrelationships between adaptation and mitigation become apparent at the more detailed analytical and implementation levels [18.4.2]. These intricacies, including the fact that adaptation and mitigation operate on different spatial, temporal and institutional scales and involve different actors who have different interests and different beliefs, value systems and property rights, present a challenge to the practical implementation of trade-offs beyond the local scale. In particular the notion of an "optimal mix" of adaptation and mitigation is problematic, since it usually assumes that there is a zero-sum budget for adaptation and mitigation and that it would be possible to capture the individual interests of all who will be affected by climate change, now and in the future, into a global aggregate measure of well-being [18.4.2, 18.6.1].

Scale	Adaptation Mitigation	Mitigation Adaptation	Parallel decisions affecting adaptation and mitigation	Adaptation and mitigation trade-offs and synergies
Global/policy	Awareness of limits to adaptation motivates mitigation e.g., policy lobbying by ENGOs	CDM trades provide funds for adaptation through surcharges	Allocation of MEA funds or Special Climate Change Fund	Assessment of costs and benefits in adaptation and mitigation in setting targets for stabilisation
Regional/natural strategy/sectoral planning	Watershed planning (e.g., hydroelectricity) and land cover, affect greenhouse gas emissions	Fossil fuel tax increases the cost of adaptation through higher energy prices	National capacity, e.g., self-assessment, supports adaptation and mitigation in policy integration	Testing project sensitivity to mitigation policy, social cost of carbon and climate impacts
Local/biophysical community and individual actions	Increased use of air-conditioning (homes, offices, transport) raises greenhouse gas emissions	Community carbon sequestration affects livelihoods	Local planning authorities implement criteria related to both adaptation and mitigation in land-use planning	Corporate integrated assessment of exposure to mitigation policy and climate impacts

Table TS.7. *Relationships between adaptation and mitigation [F18.3]. ENGO = Environmental Non-Governmental Organisation; CDM = Clean Development Mechanism; MEA = Millennium Ecosystem Assessment.*

People's capacities to adapt and mitigate are driven by similar sets of factors.
These factors represent a generalised response capacity that can be mobilised in the service of either adaptation or mitigation. Response capacity, in turn, is dependent on the societal development pathway. Enhancing society's response capacity through the pursuit of sustainable development pathways is therefore one way of promoting both adaptation and mitigation [18.3]. This would facilitate the effective implementation of both options, as well as their mainstreaming into sectoral planning and development. If climate policy and sustainable development are to be pursued in an integrated way, then it will be important not simply to evaluate specific policy options that might accomplish both goals, but also to explore the determinants of response capacity that underlie those options as they relate to underlying socio-economic and technological development paths [18.3, 18.6.3].

TS.5.3 Key vulnerabilities

Key vulnerabilities are found in many social, economic, biological and geophysical systems.
Vulnerability to climate change is the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change. The term "vulnerability" may therefore refer to the vulnerable system itself (e.g., low-lying islands or coastal cities), the impact to this system (e.g., flooding of coastal cities and agricultural lands or forced migration), or the mechanism causing these impacts (e.g., disintegration of the West Antarctic ice sheet). Based on a number of criteria in the literature (i.e., magnitude, timing, persistence/reversibility, potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts [19.2]), some of these vulnerabilities might be identified as 'key'. Key impacts and resultant key vulnerabilities are found in many social, economic, biological and geophysical systems [19.1.1].

The identification of potential key vulnerabilities is intended to provide guidance to decision-makers for identifying levels and rates of climate change that may be associated with 'dangerous anthropogenic interference' (DAI) with the climate system, in the terminology of the UNFCCC (United Nations Framework Convention on Climate Change) Article 2 [B19.1]. Ultimately, the determination of DAI cannot be based on scientific arguments alone, but involves other judgements informed by the state of scientific knowledge [19.1.1]. Table TS.8 presents an illustrative and selected list of key vulnerabilities.

Key vulnerabilities may be linked to systemic thresholds where non-linear processes cause a system to shift from one major state to another (such as a hypothetical sudden change in the Asian monsoon or disintegration of the West Antarctic ice sheet or positive feedbacks from ecosystems switching from a sink to a source of CO_2). Other key vulnerabilities can be associated with "normative thresholds" defined by stakeholders or decision-makers (e.g., a magnitude of sea-level rise no longer considered acceptable by low-lying coastal dwellers) [19.1.2].

Increasing levels of climate change will result in impacts associated with an increasing number of key vulnerabilities, and some key vulnerabilities have been associated with observed climate change.
Observed climate change to 2006 has been associated with some impacts that can be linked to key vulnerabilities. Among these are increases in human mortality during extreme weather events, and increasing problems associated with permafrost melting, glacier retreat and sea-level rise [19.3.2, 19.3.3, 19.3.4, 19.3.5, 19.3.6].

Global mean temperature changes of up to 2°C above 1990-2000 levels would exacerbate current key vulnerabilities, such as those listed above (high confidence), and cause others, such as reduced food security in many low-latitude nations (medium confidence). At the same time, some systems such as global agricultural productivity at mid- and high-latitudes, could benefit (medium confidence) [19.3.1, 19.3.2, 19.3.3].

Global mean temperature changes of 2 to 4°C above 1990-2000 levels would result in an increasing number of key impacts at all scales (high confidence), such as widespread loss of biodiversity, decreasing global agricultural productivity and commitment to widespread deglaciation of Greenland (high confidence) and West Antarctic (medium confidence) ice sheets [19.3.1, 19.3.4, 19.3.5].

Global mean temperature changes greater than 4°C above 1990-2000 levels would lead to major increases in vulnerability (very high confidence), exceeding the adaptive capacity of many systems (very high confidence) [19.3.1].

Regions already at high risk from observed climate variability and climate change are more likely to be adversely affected in the near future, due to projected changes in climate and increases in the magnitude and/or frequency of already damaging extreme events [19.3.6, 19.4.1].

The "reasons for concern" identified in the Third Assessment remain a viable framework to consider key vulnerabilities. Recent research has updated some of the findings from the Third Assessment.

Unique and threatened systems

There is new and much stronger evidence of the adverse impacts of observed climate change to date on several unique and threatened systems. Confidence has increased that a 1 to 2°C increase in global mean temperature above 1990 levels poses significant risks to many unique and threatened systems, including many biodiversity hotspots [19.3.7].

Extreme events

There is new evidence that observed climate change has likely already increased the risk of certain extreme events such as heatwaves, and it is more likely than not that warming has contributed to intensification of some tropical cyclones, with increasing levels of adverse impacts as temperatures increase [19.3.7].

Key systems or groups at risk	Prime criteria for 'key vulnerability'	Global average temperature change above 1990 0°C 1°C 2°C 3°C 4°C 5°C
Global social systems		
Food supply	Distribution, magnitude	Productivity decreases for some cereals in low latitudes ** Productivity increases for some cereals in mid/high latitudes ** Cereal productivity decreases in some mid/high latitude regions ** Global production potential increases to around 3°C, decreases above this * **a**
Aggregate market impacts and distribution	Magnitude, distribution	Net benefits in many high latitudes; net costs in many low latitudes * **b** Benefits decrease, while costs increase. Net global cost * **b**
Regional system		
Small islands	Irreversibility, magnitude, distribution, low adaptive capacity	Increasing coastal inundation and damage to infrastructure due to sea-level rise **
Indigenous, poor or isolated communities	Irreversibility, distribution, timing, low adaptive capacity	Some communities already affected ** **c** Climate change and sea-level rise adds to other stresses **. Communities in low-lying coastal and arid areas are especially threatened ** **d**
Global biological systems		
Terrestrial ecosystems and biodiversity	Irreversibility, magnitude, low adaptive capacity, persistence, rate of change, confidence	Many ecosystems already affected *** *c*. 20-30% species at increasingly high risk of extinction * Major extinctions around the globe ** Terrestrial biosphere tends toward a net carbon source **
Marine ecosystems and biodiversity	Irreversibility, magnitude, low adaptive capacity, persistence, rate of change, confidence	Increased coral bleaching ** Most corals bleached ** Widespread coral mortality **
Geophysical systems		
Greenland ice sheet	Magnitude, irreversibility, low adaptive capacity, confidence	Localised deglaciation (already observed due to local warming), extent would increase with temperature *** **e** Commitment to widespread ** or near-total * deglaciation, 2-7 m sea-level rise[19] over centuries to millennia * **e** Near-total deglaciation ** **e**
Meridional Overturning Circulation	Magnitude, persistence, distribution, timing, adaptive capacity, confidence	Variations including regional weakening (already observed but no trend identified) **f** Considerable weakening **. Commitment to large-scale and persistent change including possible cooling in northern high-latitude areas near Greenland and north-west Europe •, highly dependent on rate of climate change.
Risks from extreme events		
Tropical cyclone intensity	Magnitude, timing, distribution	Increase in Cat. 4-5 storms */**, with impacts exacerbated by sea-level rise Further increase in tropical cyclone intensity */**
Drought	Magnitude, timing	Drought already increasing * **g** Increasing frequency / intensity drought in mid-latitude continental areas ** **h** Extreme drought increasing from 1% land area to 30% (A2 scenario) * **i** Mid-latitude regions affected by poleward migration of Annular Modes seriously affected ** **j**

Table TS.8. *Table of selected key vulnerabilities. The key vulnerabilities range from those associated with societal systems, for which the adaptation potential is the greatest, to those associated with biophysical systems, which are likely to have the least adaptive capacity. Adaptation potential for key vulnerabilities resulting from extreme events is associated with the affected systems, most of which are socio-economic. Information is presented where available on how impacts may change at larger increases in global mean temperature (GMT). All increases in GMT are relative to circa 1990. Most impacts are the result of changes in climate, weather and/or sea level, not of temperature alone. In many cases climate change impacts are marginal or synergistic on top of other existing and possibly increasing stresses. Criteria for key vulnerabilities are given in Section TS 5.3. For full details refer to the corresponding text in Chapter 19. Confidence symbol legend: *** very high confidence, ** high confidence, * medium confidence, • low confidence.*
Sources for left hand column are T19.1. Sources for right hand column are T19.1, and are also found in Tables TS.3 and TS.4, with the exception of: ***a****: 5.4.2, 5.6;* ***b****: 20.6, 20.7;* ***c****: 1.3, 11.4.8, 14.2.3, 15.4.5;* ***d****: 3.4, 6.4, 11.4;* ***e****: 19.3.5, T19.1;* ***f****: 19.3.5, 12.6;* ***g****: 1.3.2, 1.3.3, T19.1;* ***h****: WGI 10.3.6.1;* ***i****: WGI AR4 10.3.6.1;* ***j****: WGI AR4 10.3.5.6.*

[19] Range combines results from modelling and analysis of palaeo data.

Distribution of impacts

There is still high confidence that the distribution of climate impacts will be uneven, and that low-latitude, less-developed areas are generally at greatest risk. However, recent work has shown that vulnerability to climate change is also highly variable within individual countries. As a consequence, some population groups in developed countries are also highly vulnerable [19.3.7].

Aggregate impacts

There is some evidence that initial net market benefits from climate change will peak at a lower magnitude and sooner than was assumed in the Third Assessment, and that it is likely there will be higher damages for larger magnitudes of global mean temperature increases than estimated in the Third Assessment. Climate change could adversely affect hundreds of millions of people through increased risk of coastal flooding, reduction in water supplies, increased risk of malnutrition, and increased risk of exposure to climate-dependent diseases [19.3.7].

Large-scale singularities

Since the Third Assessment, the literature offers more specific guidance on possible thresholds for partial or near-complete deglaciation of Greenland and West Antarctic ice sheets. There is medium confidence that at least partial deglaciation of the Greenland ice sheet, and possibly the West Antarctic ice sheet, would occur over a period of time ranging from centuries to millennia for a global average temperature increase of 1-4ºC (relative to 1990-2000), causing a contribution to sea-level rise of 4-6 m or more [WGI AR4 6.4, 10.7.4.3, 10.7.4.4; 19.3.5.2].

TS.5.4 Perspectives on climate change and sustainability

Future vulnerability depends not only on climate change but also on development pathway.
An important advance since the Third Assessment has been the completion of impacts studies for a range of different development pathways, taking into account not only projected climate change but also projected social and economic changes. Most have been based on characterisations of population and income levels drawn from the SRES scenarios [2.4].

These studies show that the projected impacts of climate change can vary greatly due to the development pathway assumed. For example, there may be large differences in regional population, income and technological development under alternative scenarios, which are often a strong determinant of the level of vulnerability to climate change [2.4].

To illustrate, Figure TS.18 shows estimates from a recent study of the number of people projected to be at risk of coastal flooding each year under different assumptions of socio-economic development. This indicates that the projected number of people affected is considerably greater under the A2-type scenario of development (characterised by relatively low per capita income and large population growth) than under other SRES futures [T20.6]. This difference is largely explained, not by differences in changes of climate, but by differences in vulnerability [T6.6].

Vulnerability to climate change can be exacerbated by the presence of other stresses.
Non-climate stresses can increase vulnerability to climate change by reducing resilience and can also reduce adaptive capacity because of resource deployment to competing needs. For example, current stresses on some coral reefs include marine pollution and chemical runoff from agriculture as well as increases in water temperature and ocean acidification. Vulnerable regions face multiple stresses that affect their exposure and sensitivity as well as their capacity to adapt. These stresses arise from, for example, current climate hazards, poverty and unequal access to resources, food insecurity, trends in economic globalisation, conflict, and incidence of disease such as HIV/AIDS [7.4, 8.3, 17.3, 20.3].

Climate change itself can produce its own set of multiple stresses in some locations because the physical manifestations of the impacts of climate change are so diverse [9.4.8]. For example, more variable rainfall implies more frequent droughts and more frequent episodes of intense rainfall, whilst sea-level rise may bring coastal flooding to areas already experiencing more frequent wind storm. In such cases, total vulnerability to climate change is greater than the sum of the vulnerabilities to specific impacts considered one at a time in isolation (very high confidence) [20.7.2].

Climate change will very likely impede nations' abilities to achieve sustainable development pathways, as measured, for example, as long-term progress towards the Millennium Development Goals.
Following the lead of the TAR, this Report has adopted the Bruntland Commission definition of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Over the next half-century, it is very likely that climate

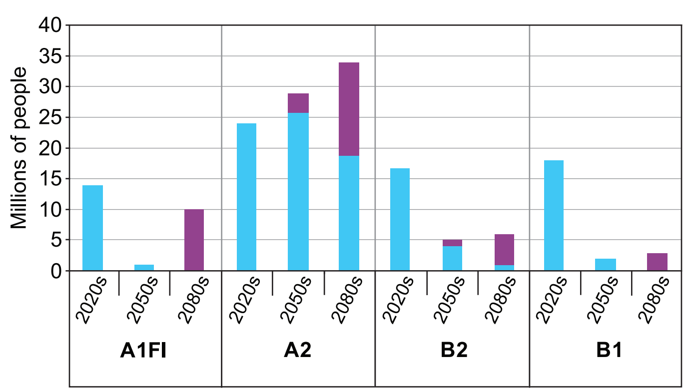


Figure TS.18. *Results from a recent study showing estimated millions of people per annum at risk globally from coastal flooding. Blue bars: numbers at risk without sea-level rise; purple bars: numbers at risk with sea-level rise. [T6.6]* change will make sustainable development more difficult, particularly as measured by their progress toward achieving Millennium Development Goals for the middle of the century. Climate change will erode nations' capacities to achieve the Goals, calibrated in terms of reducing poverty and otherwise improving equity by 2050, particularly in Africa and parts of Asia (very high confidence) [20.7.1].

Even though there are cases where climate-related extreme events have severely interfered with economic development, it is very unlikely that climate change attributed to anthropogenic sources, per se, will be a significant extra impediment to most nations' reaching their 2015 Millennium Development targets. Many other obstacles with more immediate impacts stand in the way [20.7.1].

Sustainable development can reduce vulnerability to climate change by encouraging adaptation, enhancing adaptive capacity and increasing resilience (very high confidence) [20.3.3]. On the other hand, it is very likely that climate change can slow the pace of progress toward sustainable development either directly through increased exposure to adverse impact or indirectly through erosion of the capacity to adapt. This point is clearly demonstrated in the sections of the sectoral and regional chapters of this Report that discuss implications for sustainable development [see Section 7 in Chapters 3 to 8, 20.3, 20.7]. At present, few plans for promoting sustainability have explicitly included either adapting to climate-change impacts, or promoting adaptive capacity [20.3].

Sustainable development can reduce vulnerability to climate change.

Efforts to cope with the impacts of climate change and attempts to promote sustainable development share common goals and determinants including: access to resources (including information and technology), equity in the distribution of resources, stocks of human and social capital, access to risk-sharing mechanisms and abilities of decision-support mechanisms to cope with uncertainty. Nonetheless, some development activities exacerbate climate-related vulnerabilities (very high confidence).

It is very likely that significant synergies can be exploited in bringing climate change to the development community, and critical development issues to the climate-change community [20.3.3, 20.8.2 and 20.8.3]. Effective communication in assessment, appraisal and action are likely to be important tools both in participatory assessment and governance as well as in identifying productive areas for shared learning initiatives [20.3.3, 20.8.2, 20.8.3]. Despite these synergies, few discussions about promoting sustainability have thus far explicitly included adapting to climate impacts, reducing hazard risks and/or promoting adaptive capacity [20.4, 20.5, 20.8.3]. Discussions about promoting development and improving environmental quality have seldom explicitly included adapting to climate impacts and/or promoting adaptive capacity [20.8.3]. Most of the scholars and practitioners of development who recognise that climate change is a significant issue at local, national, regional and/or global levels focus their attention almost exclusively on mitigation [20.4, 20.8.3].

Synergies between adaptation and mitigation measures will be effective through the middle of this century, but even a combination of aggressive mitigation and significant investment in adaptive capacity could be overwhelmed by the end of the century along a likely development scenario.

Tables TS.3 and TS.4 track major worldwide impacts for major sectors against temperature increases measured from the 1980 to 1999 period. With very high confidence, no temperature threshold associated with any subjective judgment of what might constitute "dangerous" climate change can be guaranteed to be avoided by anything but the most stringent of mitigation interventions.

As illustrated in Figure TS.19, it is likely that global mitigation efforts designed to cap effective greenhouse gas concentrations at, for example, 550 ppm would benefit developing countries significantly through the middle of this century, regardless of whether the climate sensitivity turns out to be high or low, and especially when combined with enhanced adaptation. Developed countries would also likely see significant benefits from an adaptation-mitigation intervention portfolio, especially for high climate sensitivities and in sectors and regions that are already showing signs of being vulnerable. By 2100, climate change will likely produce significant vulnerabilities across the globe even if aggressive mitigation were implemented in combination with significantly enhanced adaptive capacity [20.7.3].

TS.6 Advances in knowledge and future research needs

TS 6.1 Advances in knowledge

Since the IPCC Third Assessment, the principal advances in knowledge have been as follows.

- Much improved coverage of the impacts of climate change on developing regions, through studies such as the AIACC project (Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors), although further research is still required, especially in Latin America and Africa [9.ES, 10.ES, 13.ES].
- More studies of adaptation to climate change, with improved understanding of current practice, adaptive capacity, the options, barriers and limits to adaptation [17.ES].
- Much more monitoring of observed effects, and recognition that climate change is having a discernible impact on many natural systems [1.ES, F1.1].
- Some standardisation of the scenarios of future climate change underpinning impact studies, facilitated by centralised data provision through organisations such as the IPCC Data Distribution Centre, thus allowing comparison between sectors and regions [2.2.2].
- Improved understanding of the damages for different levels of global warming, and the link between global warming

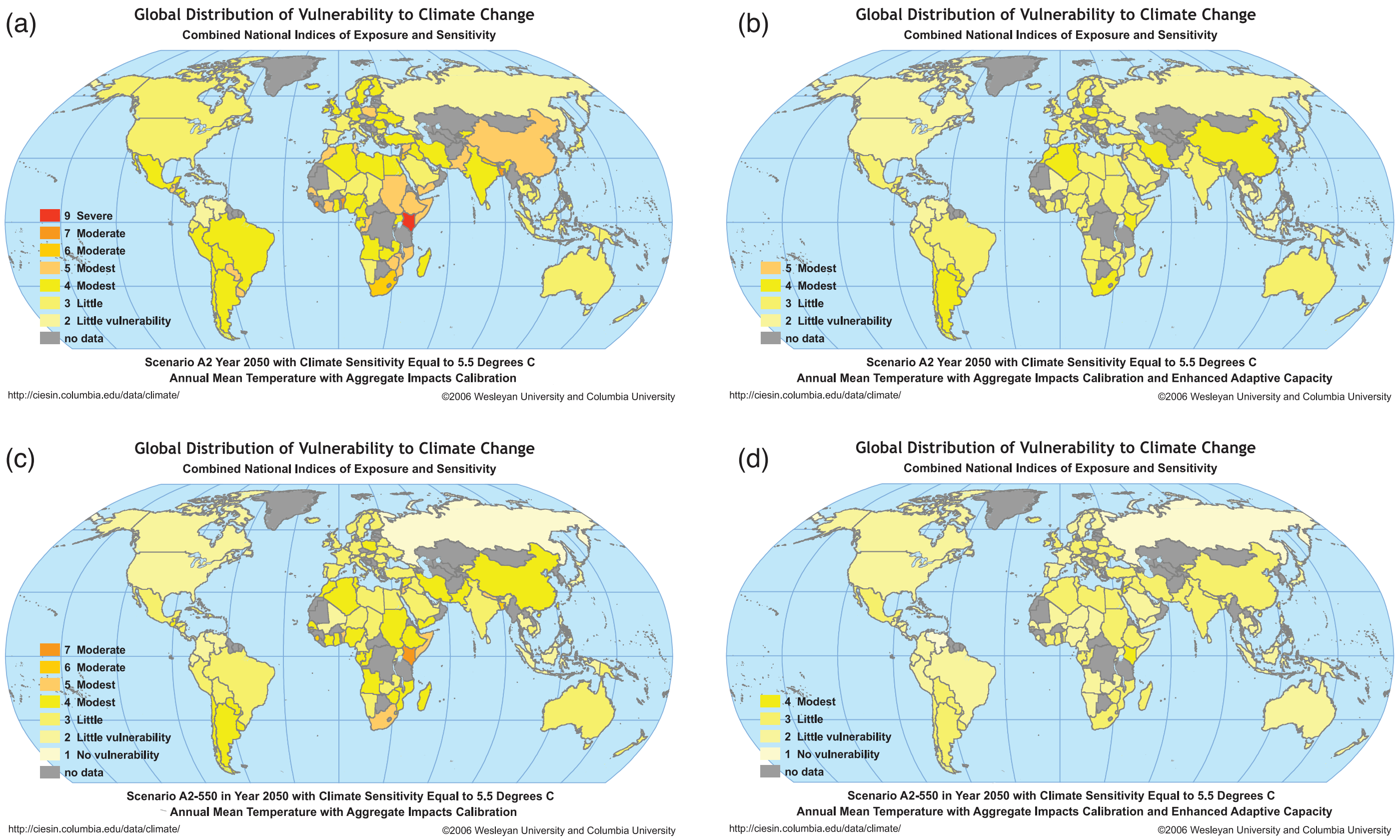


Figure TS.19. *Geographical distribution of vulnerability in 2050 with and without mitigation along an SRES A2 emissions scenario with a climate sensitivity of 5.5°C. Panel (a) portrays vulnerability with a static representation of current adaptive capacity. Panel (b) shows vulnerability with enhanced adaptive capacity worldwide. Panel (c) displays the geographical implications of mitigation designed to cap effective atmospheric concentrations of greenhouse gases at 550 ppm. Panel (d) offers a portrait of the combined complementary effects of mitigation to the same 550 ppmv concentration limit and enhanced adaptive capacity. [F20.6]*

and the probability of stabilising CO_2 at various levels. As a result, we know more about the link between damages and CO_2-stabilisation scenarios [20.7.2, T20.8, T20.9].

However, there has been little advance on:
- impacts under different assumptions about how the world will evolve in future – societies, governance, technology and economic development;
- the costs of climate change, both of the impacts and of response (adaptation and mitigation);
- proximity to thresholds and tipping points;
- impacts resulting from interactions between climate change and other human-induced environmental changes.

TS 6.2 Future research needs

Impacts under different assumptions about future development pathways

Most AR4 studies of future climate change are based on a small number of studies using SRES scenarios, especially the A2 and B2 families [2.3.1]. This has allowed some limited, but incomplete, characterisation of the potential range of futures and their impacts [see Section 4 on key future impacts in all core chapters].

Scenarios are required:
- to describe the future evolution of the world under different and wide-ranging assumptions about how societies, governance, technology, economies will develop in future;
- at the regional and local scales appropriate for impacts analysis;
- which allow adaptation to be incorporated into climate-change impact estimates;
- for abrupt climate change such as the collapse of the North Atlantic Meridional Overturning Circulation, and large sea-level rises due to ice sheet melting [6.8];
- for beyond 2100 (especially for sea-level rise) [6.8, 11.8.1].

Increasingly, climate modellers run model ensembles which allow characterisation of the uncertainty range for each development pathway. Thus, the impacts analyst is faced with very large quantities of data to capture even a small part of the potential range of futures. Tools and techniques to manage these large quantities of data are urgently required [2.3, 2.4].

Damages avoided by different levels of emissions reduction

Very few studies have been carried out to explore the damages avoided, or the impacts postponed, by reducing or stabilising emissions, despite the critical importance of this issue for policy-makers. The few studies which have been performed are reviewed in Chapter 20 of this Report [20.6.2] and show clearly the large reductions in damages which can be achieved by mitigating emissions [T20.4]. Existing research has emphasised the global scale, and studies which are disaggregated to the regional, and even local, scale are urgently required.

Climate-science-related research needs

Two of the most important requirements identified relate to research in climate change science, but have been clearly identified as a hindrance to research in impacts, adaptation and vulnerability.

- The first is that our understanding of the likely future impacts of climate change is hampered by lack of knowledge regarding the nature of future changes, particularly at the regional scale and particularly with respect to precipitation changes and their hydrological consequences on water resources, and changes in extreme events, due in part to the inadequacies of existing climate models at the required spatial scales [T2.5, 3.3.1, 3.4.1, 4.3].
- The second relates to abrupt climate change. Policy-makers require understanding of the impacts of such events as the collapse of the North Atlantic Meridional Overturning Circulation. However, without a better understanding of the likely manifestation of such events at the regional scale, it is not possible to carry out impacts assessments [6.8, 7.6, 8.8, 10.8.3].

Observations, monitoring and attribution

Large-area, long-term field studies are required to evaluate observed impacts of climate change on managed and unmanaged systems and human activities. This will enable improved understanding of where and when impacts become detectable, where the hotspots lie, and why some areas are more vulnerable than others. High-quality observations are essential for full understanding of causes, and for unequivocal attribution of present-day trends to climate change [1.4.3, 4.8].

Timely monitoring of the pace of approaching significant thresholds (such as abrupt climate change thresholds) is required [6.8, 10.8.4].

Multiple stresses, thresholds and vulnerable people and places

It has become clear in the AR4 that the impacts of climate change are most damaging when they occur in the context of multiple stresses arising from the effects, for example, of globalisation, poverty, poor governance and settlement of low-lying coasts. Considerable progress has been made towards understanding which people and which locations may expect to be disproportionately impacted by the negative aspects of climate change. It is important to understand what characteristics enhance vulnerability, what characteristics strengthen the adaptive capacity of some people and places, and what characteristics predispose physical, biological and human systems to irreversible changes as a result of exposure to climate and other stresses [7.1, B7.4, 9.1, 9.ES]. How can systems be managed to minimise the risk of irreversible changes? How close are we to tipping points/thresholds for natural ecosystems such as the Amazon rain forest? What positive feedbacks would emerge if such a tipping point is reached?

Climate change, adaptation and sustainable development

The AR4 recognised that synergies exist between adaptive capacity and sustainable development, and that societies which are pursuing a path of sustainable development are likely to be more resilient to the impacts of climate change. Further research is required to determine the factors which contribute to this synergy, and how policies to enhance adaptive capacity can reinforce sustainable development and vice versa [20.9].

Further understanding of adaptation is likely to require learning-by-doing approaches, where the knowledge base is enhanced through accumulation of practical experience.

The costs of climate change, both the costs of the impacts and of response (adaptation and mitigation)

- Only a small amount of literature on the costs of climate change impacts could be found for assessment [5.6, 6.5.3, 7.5]. Debate still surrounds the topic of how to measure impacts, and which metrics should be used to ensure comparability [2.2.3, 19.3.2.3, 20.9].
- The literature on adaptation costs and benefits is limited and fragmented [17.2.3]. It focuses on sea-level rise and agriculture, with more limited assessments for energy demand, water resources and transport. There is an emphasis on the USA and other OECD countries, with only a few studies for developing countries [17.2.3].

Better understanding of the relative costs of climate change impacts and adaptation allows policy-makers to consider optimal strategies for implementation of adaptation policies, especially the amount and the timing [17.2.3.1].