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"CLIMATE CHANGE 2001: IMPACTS, ADAPTATION AND VULNERABILITY"

TECHNICAL SUMMARY

The Technical Summary (TS), changed to be consistent with the approved SPM, is hereby submitted for acceptance by the Panel. Changes to the rest of the underlying assessment, for consistency with the approved SPM, are listed in IPCC-XVII/Doc. 3d.

TECHNICAL SUMMARY

CLIMATE CHANGE 2001:
IMPACTS, ADAPTATION, AND VULNERABILITY

A Report of Working Group II of the Intergovernmental Panel on Climate Change

This summary was accepted but not approved in detail at the Sixth Session of IPCC Working Group II (Geneva, Switzerland • 13-16 February 2001). "Acceptance" of IPCC reports at a session of the Working Group or Panel signifies that the material has not been subject to line-by-line discussion and agreement, but nevertheless presents a comprehensive, objective, and balanced view of the subject matter.

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1.1. Mandate of the Assessment

The Intergovernmental Panel on Climate Change (IPCC) was established by World Meteorological Organization and United Nations Environmental Programme (UNEP) in 1988 to assess scientific, technical, and socioeconomic information that is relevant in understanding human-induced climate change, its potential impacts, and options for mitigation and adaptation. The IPCC currently is organized into three Working Groups: Working Group I (WGI) addresses observed and projected changes in climate; Working Group II (WGII) addresses vulnerability, impacts, and adaptation related to climate change; and Working Group III (WGIII) addresses options for mitigation of climate change.

This volume—*Climate Change 2001: Impacts, Adaptation, and Vulnerability*—is the WGII contribution to the IPCC's Third Assessment Report (TAR) on scientific, technical, environmental, economic, and social issues associated with the climate system and climate change.[1] WGII's mandate for the TAR is to assess the vulnerability of ecological systems, socioeconomic sectors, and human health to climate change as well as potential impacts of climate change, positive and negative, on these systems. This assessment also examines the feasibility of adaptation to enhance the positive effects of climate change and ameliorate negative effects. This new assessment builds on previous IPCC assessments, reexamining key findings of earlier assessments and emphasizing new information and implications from more recent studies.

1.2. What is Potentially at Stake?

Human activities—primarily burning of fossil fuels and changes in land cover—are modifying the concentration of atmospheric constituents or properties of the surface that absorb or scatter radiant energy. The WGI contribution to the TAR—*Climate Change 2001: The Scientific Basis*—found, "In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations." Future changes in climate are expected to include additional warming, changes in precipitation patterns and amounts, sea-level rise, and changes in the frequency and intensity of some extreme events.

The stakes associated with projected changes in climate are high. Numerous Earth systems that sustain human societies are sensitive to climate and will be impacted by changes in climate (very high confidence). Impacts can be expected in ocean circulation; sea level; the water cycle; carbon and nutrient cycles; air quality; the productivity and structure of natural ecosystems; the productivity of agricultural, grazing, and timber lands; and the geographic distribution, behavior, abundance, and survival of plant and animal species, including vectors and hosts of human disease. Changes in these systems in response to climate change, as well as direct effects of climate change on humans, would affect human welfare, positively and negatively. Human welfare would be impacted through changes in supplies of and demands for water, food, energy, and other tangible goods that are derived from these systems; changes in opportunities for nonconsumptive uses of the environment for recreation and tourism; changes in non-use values of the environment such as cultural and preservation values; changes in incomes; changes in loss of property and lives from extreme climate phenomena; and changes in human health. Climate change impacts will affect the prospects for sustainable development in different parts of the world and may further widen existing inequalities. Impacts will vary in distribution across people, places, and times (very high confidence), raising important questions about equity.

Although the stakes are demonstrably high, the risks associated with climate change are less easily established. Risks are a function of the probability and magnitude of different types of impacts. The WGII report assesses advances in the state of

Box 1. Climate Change
Sensitivity, Adaptability, and Vulnerability

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. Climate-related stimuli encompass all the elements of climate change, including mean climate characteristics, climate variability, and the frequency and magnitude of extremes. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

Adaptive capacity is the ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Vulnerability is the degree to which a system is susceptible to, or 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 variation to which a system is exposed, its sensitivity, and its adaptive capacity.

[1] *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 the definition in Article 1 of the United Nations Framework Convention on Climate Change, where *climate change* refers to a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

knowledge regarding impacts of climate stimuli to which systems may be exposed, the sensitivity of exposed systems to changes in climate stimuli, their adaptive capacity to alleviate or cope with adverse impacts or enhance beneficial ones, and their vulnerability to adverse impacts (see Box 1). Possible impacts include impacts that threaten substantial and irreversible damage to or loss of some systems within the next century; modest impacts to which systems may readily adapt; and impacts that would be beneficial for some systems.

Figure TS-1 illustrates the scope of the WGII assessment and its relation to other parts of the climate change system. Human activities that change the climate expose natural and human systems to an altered set of stresses or stimuli. Systems that are sensitive to these stimuli are affected or impacted by the changes, which can trigger autonomous, or expected, adaptations. These autonomous adaptations will reshape the residual or net impacts of climate change. Policy responses in reaction to impacts already perceived or in anticipation of potential future impacts can take the form of planned adaptations to lessen adverse effects or enhance beneficial ones. Policy responses also can take the form of actions to mitigate climate change through greenhouse gas (GHG) emission reductions and enhancement of sinks. The WGII assessment focuses on the central box of Figure TS-1—exposure, impacts, and vulnerabilities—and the adaptation policy loop.

1.3. *Approach of the Assessment*

The assessment process involves evaluation and synthesis of available information to advance understanding of climate change impacts, adaptation, and vulnerability. The information comes predominately from peer-reviewed published literature. Evidence also is drawn from published, non-peer-reviewed literature and unpublished sources, but only after evaluation of its quality and validity by the authors of this report.

WGII's assessment has been conducted by an international group of experts nominated by governments and scientific bodies and selected by the WGII Bureau of the IPCC for their scientific and technical expertise and to achieve broad geographical balance. These experts come from academia, governments, industry, and scientific and environmental organizations. They participate without compensation from the IPCC, donating substantial time to support the work of the IPCC.

This assessment is structured to examine climate change impacts, adaptations, and vulnerabilities of systems and regions and to provide a global synthesis of cross-system and cross-regional issues. To the extent feasible, given the available literature, climate change is examined in the context of sustainable development and equity. The first section sets the stage for the

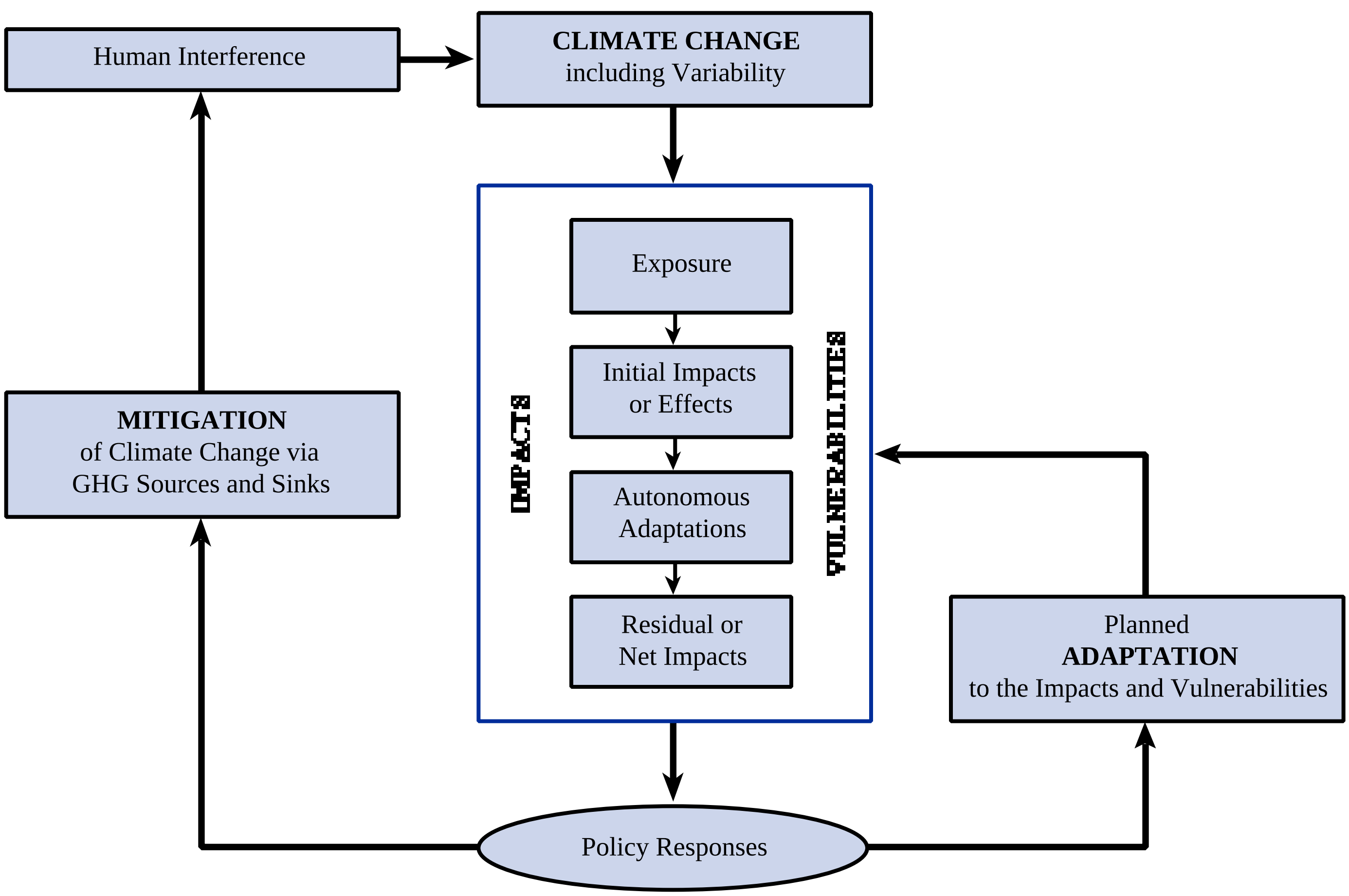


Figure TS-1: Scope of the Working Group II assessment.

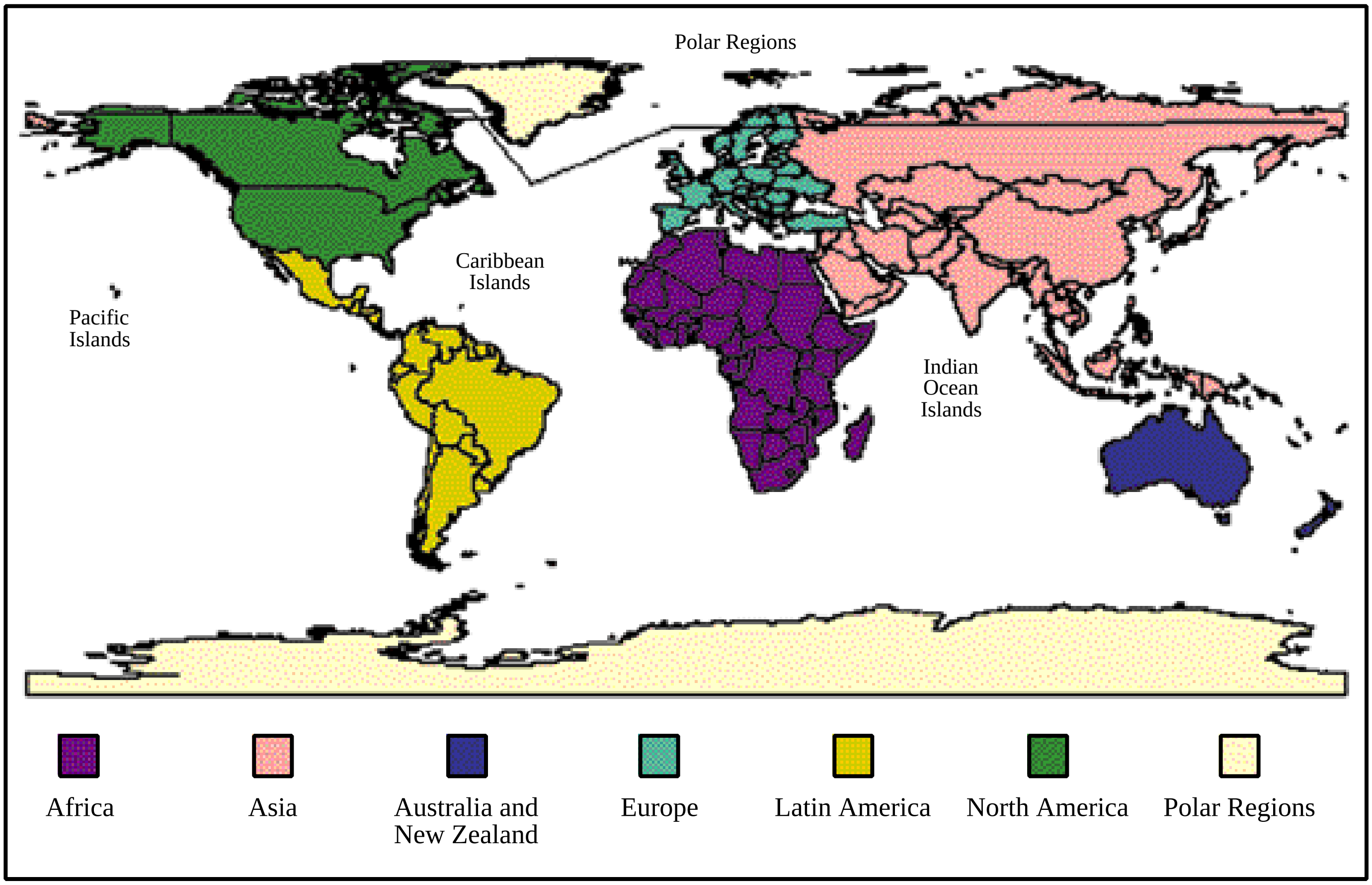


Figure TS-2: Regions for the IPCC Working Group II Third Assessment Report. Note that regions in which small island states are located include the Pacific, Indian, and Atlantic Oceans, and the Caribbean and Mediterranean Seas. The boundary between Europe and Asia runs along the eastern Ural Mountains, River Ural, and Caspian Sea. For the polar regions, the Arctic consists of the area north of the Arctic Circle, including Greenland; the Antarctic consists of the Antarctic continent, together with the Southern Ocean south of ~58°S.

assessment by discussing the context of climate change, methods and tools, and scenarios. Individual chapters assess vulnerabilities of water systems, terrestrial ecosystems (including agriculture and forestry), ocean and coastal systems, human settlements (including energy and industrial sectors), insurance and other financial services, and human health. A chapter is devoted to each of eight major regions of the world: Africa, Asia, Australia and New Zealand, Europe, Latin America, North America, polar regions, and small island states. These regions are shown in Figure TS-2. All of the regions are highly heterogeneous, and climate change impacts, adaptive capacity, and vulnerability will vary in important ways within each of the regions. The final section of the report synthesizes adaptation capacity and its potential to alleviate adverse impacts, enhance beneficial effects, and increase sustainable development and equity and reviews information that is relevant for interpretation of Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) and key provisions of international agreements to address climate change. The report also contains a Summary for Policymakers, which provides a brief synthesis of the conclusions of the report that have particular relevance to those who have responsibility for making climate change response decisions. This Technical Summary provides a more comprehensive summary of the assessment; it references sections of the underlying report in brackets at the end of the paragraphs for readers who would like more information on a particular topic. [1.1]

1.4. Treatment of Uncertainties

Since the SAR, greater emphasis has been placed on developing methods for characterizing and communicating uncertainties. Two approaches to evaluate uncertainties are applied in the WGII assessment. A quantitative approach is adopted to assess confidence levels in instances for which present understanding of relevant processes, system behavior, observations, model simulations, and estimates is sufficient to support broad agreement among authors of the report about Bayesian probabilities associated with selected findings. Amore qualitative approach is used to assess and report the quality or level of scientific understanding that supports a conclusion (see Box 2). These approaches, and the rationale for them, are explained in more detail in *Third Assessment Report: Cross-Cutting Issues Guidance Papers* (http://www.gispri.or.jp), supporting material prepared by the IPCC to increase the use of consistent terms and concepts within and across the Working Group volumes of the TAR. [1.1, 2.6]

2. Methods and Tools of the Assessment

Assessment of climate change impacts, adaptations, and vulnerability draws on a wide range of physical, biological, and social science disciplines and consequently employs an enormous variety of methods and tools. Since the SAR, such methods have improved detection of climate change in biotic and physical systems and produced new substantive findings. In addition, cautious steps have been taken since the SAR to expand the “tool-box” to address more effectively the human dimensions of climate as both causes and consequences of change and to deal more directly with cross-sectoral issues concerning vulnerability, adaptation, and decisionmaking. In particular, a greater number of studies have begun to apply methods and tools for costing and valuing effects, treating uncertainties, integrating effects across sectors and regions, and applying decision analytic frameworks for evaluating adaptive capacity. Overall, these modest methodological developments are encouraging analyses that will build a more solid foundation for understanding how decisions regarding adaptation to future climate change might be taken. [2.8]

2.1. Detecting Responses to Climate Change using Indicator Species or Systems

Since the SAR, methods have been developed and applied to the detection of present impacts of 20th century climate change on abiotic and biotic systems. Assessment of impacts on human and natural systems that already have occurred as a result of recent climate change is an important complement to model projections of future impacts. Such detection is impeded by multiple, often inter-correlated, nonclimatic forces that concurrently affect those systems. Attempts to overcome this problem have involved the use of indicator species (e.g., butterflies, penguins, frogs, and sea anemones) to detect responses to climate change and to infer more general impacts of climate change on natural systems (e.g., in native meadows, coastal Antarctica, tropical cloud forest, and the Pacific rocky intertidal, respectively). An important component of this detection process is the search for systematic patterns of change across many studies that are consistent with expectations, based on observed or predicted changes in climate. Confidence in attribution of these observed changes to climate change increases as studies are replicated across diverse systems and geographic regions. Even though studies now number in the hundreds, some regions and systems remain underrepresented. [2.2]

To investigate possible links between observed changes in regional climate and biological or physical processes in ecosystems, the author team gathered more than 2,500 articles on climate and one of the following entities: animals, plants, glaciers, sea ice, and ice on lakes or streams. To determine if these entities have been influenced by changing climate, only studies meeting at least two of the following criteria were included:

- A trait of these entities (e.g., range boundary, melting date) shows a change over time.
- The trait is correlated with changes in local temperature.
- Local temperature changed over time.

Box 2. Confidence Levels and State of Knowledge

Quantitative Assessment of Confidence Levels

In applying the *quantitative* approach, authors of the report assign a confidence level that represents the degree of belief among the authors in the validity of a conclusion, based on their collective expert judgment of observational evidence, modeling results, and theory that they have examined. Five confidence levels are used. In the tables of the Technical Summary, symbols are substituted for words:

Very High (*****)	95% or greater
High (****)	67–95%
Medium(***)	33–67%
Low (**)	5–33%
Very Low (*)	5% or less

Qualitative Assessment of the State of Knowledge

In applying the *qualitative* approach, authors of the report evaluate the level of scientific understanding in support of a conclusion, based on the amount of supporting evidence and the level of agreement among experts about the interpretation of the evidence. Four qualitative classifications are employed:

- *Well-established*: Models incorporate known processes, observations are consistent with models, or multiple lines of evidence support the finding.
- *Established but incomplete*: Models incorporate most known processes, although some parameterizations may not be well tested; observations are somewhat consistent but incomplete; current empirical estimates are well founded, but the possibility of changes in governing processes over time is considerable; or only one or a few lines of evidence support the finding.
- *Competing explanations*: Different model representations account for different aspects of observations or evidence or incorporate different aspects of key processes, leading to competing explanations.
- *Speculative*: Conceptually plausible ideas that are not adequately represented in the literature or that contain many difficult-to-reduce uncertainties [Box 1-1]

At least two of these three criteria had to exhibit a statistically significant correlation. Only temperature was considered because it is well established in the literature how it influences the entities examined and because temperature trends are more globally homogeneous than other locally varying climatic factors, such as precipitation changes. Selected studies must also have examined at least 10 years of data; more than 90% had a time span of more than 20 years.

These stringent criteria reduced the number of studies used in the analysis to 44 animal and plant studies that cover more than 600 species. Of these species, about 90% (more than 550) show changes in traits over time. Of these 550+ species, about 80% (more than 450) show change in a direction expected given scientific understanding of known mechanisms that relate temperature to each of the species traits. The probability that more than 450 species of 550+ would show changes in the directions expected by random chance is negligible.

Sixteen studies examining glaciers, sea ice, snow cover extent/ snow melt, or ice on lakes or streams included more than 150 sites. Of these 150+ sites, 67% (100+) show changes in traits over time. Of these 100+ sites, about 99% (99+) exhibited trends in a direction expected, given scientific understanding of known mechanisms that relate temperatures to physical processes that govern change in that trait. The probability that 99+ of 100+ sites would show changes in the directions expected by chance alone is negligible. [5.2, 5.4, 19.2]

2.2. Anticipating the Effects of Future Climate Change

Since the SAR, improvements in methods and tools for studying impacts of future changes in climate have included greater emphasis on the use of process-oriented models, transient climate change scenarios, refined socioeconomic baselines, and higher resolution spatial and temporal scales. Country studies and regional assessments in every continent have tested models and tools in a variety of contexts. First-order impact models have been linked to global systems models. Adaptation has been included in many assessments, often for the first time.

Methodological gaps remain concerning scales, data, validation, and integration of adaptation and the human dimensions of climate change. Procedures for assessing regional and local vulnerability and long-term adaptation strategies require high-resolution assessments, methodologies to link scales, and dynamic modeling that uses corresponding and new data sets. Validation at different scales often is lacking. Regional integration across sectors is required to place vulnerability in the context of local and regional development. Methods and tools to assess vulnerability to extreme events have improved but are constrained by low confidence in climate change scenarios and the sensitivity of impact models to major climatic anomalies. Understanding and integrating higher order economic effects and other human dimensions of global change are required. Adaptation models and vulnerability indices to prioritize adaptation options are at early stages of development in many fields. Methods to enable stakeholder participation in assessments need improvement. [2.3]

2.3. Integrated Assessment

Integrated assessment is an interdisciplinary process that combines, interprets, and communicates knowledge from diverse scientific disciplines from the natural and social sciences to investigate and understand causal relationships within and between complicated systems. Methodological approaches employed in such assessments include computer-aided modeling, scenario analyses, simulation gaming and participatory integrated assessment, and qualitative assessments that are based on existing experience and expertise. Since the SAR, significant progress has been made in developing and applying such approaches to integrated assessment, globally and regionally.

However, progress to date, particularly with regard to integrated modeling, has focused largely on mitigation issues at the global or regional scale and only secondarily on issues of impacts, vulnerability, and adaptation. Greater emphasis on the development of methods for assessing vulnerability is required, especially at national and subnational scales where impacts of climate change are felt and responses are implemented. Methods designed to include adaptation and adaptive capacity explicitly in specific applications must be developed. [2.4]

2.4. Costing and Valuation

Methods of economic costing and valuation rely on the notion of opportunity cost of resources used, degraded, or saved. Opportunity cost depends on whether the market is competitive or monopolistic and on whether any externalities are internalized. It also depends on the rate at which the future is discounted, which can vary across countries, over time, and over generations. The impact of uncertainty also can be valued if the probabilities of different possible outcomes are known. Public and nonmarket goods and services can be valued through willingness to pay for them or willingness to accept compensation for lack of them. Impacts on different groups, societies, nations, and species must be assessed. Comparison of alternative distributions of welfare across individuals and groups within a country can be justified if they are made according to internally consistent norms. Comparisons across nations with different societal, ethical, and governmental structures cannot yet be made meaningfully.

Since the SAR, no new fundamental developments in costing and valuation methodology have taken place. Many new applications of existing methods to a widening range of climate change issues have demonstrated, however, the strengths and limitations of some of these methods. Research efforts are required to strengthen methods for multi-objective assessments. Multi-objective assessments are increasingly preferred, but the means by which their underlying metrics might more accurately reflect diverse social, political, economic, and cultural contexts must be developed. In addition, methods for integrating across these multiple metrics are still missing from the methodological repertoire. [2.5]

2.5. Decision Analytic Frameworks

Policymakers who are responsible for devising and implementing adaptive policies should be able to rely on results from one or more of a diverse set of decision analytical frameworks. Commonly used methods include cost-benefit and cost-effectiveness analysis, various types of decision analysis (including multi-objective studies), and participatory techniques such as policy exercises.

Very few cases in which policymakers have used decision analytical frameworks in evaluating adaptation options have been reported. Among the large number of assessments of climate change impacts reviewed in the TAR, only a small fraction include comprehensive and quantitative estimates of adaptation options and their costs, benefits, and uncertainty characteristics. This information is necessary for meaningful applications of any decision analytical method to issues of adaptation. Greater use of such methods in support of adaptation decisions is needed to establish their efficacy and to identify directions for necessary research in the context of vulnerability and adaptation to climate change. [2.7]

3. Scenarios of Future Change

3.1. Scenarios and their Role

A scenario is a coherent, internally consistent, and plausible description of a possible future state of the world. Scenarios are commonly required in climate change impact, adaptation, and vulnerability assessments to provide alternative views of future conditions considered likely to influence a given system or activity. A distinction is made between climate scenarios, which describe the forcing factor of focal interest to the IPCC, and nonclimatic scenarios, which provide the socioeconomic and environmental context within which climate forcing operates. Most assessments of the impacts of future climate change are based on results from impact models that rely on quantitative climate and nonclimatic scenarios as inputs. [3.1.1, Box 3-1]

3.2. Socioeconomic, Land-Use, and Environmental Scenarios

Nonclimatic scenarios describing future socioeconomic, land-use, and environmental changes are important for characterizing the sensitivity of systems to climate change, their vulnerability, and the capacity for adaptation. Such scenarios only recently have been widely adopted in impact assessments alongside climate scenarios.

Socioeconomic scenarios. Socioeconomic scenarios have been used more extensively for projecting GHG emissions than for assessing climate vulnerability and adaptive capacity. Most socioeconomic scenarios identify several different topics or domains, such as population or economic activity, as well as background factors such as the structure of governance, social values, and patterns of technological change. Scenarios make it possible to establish baseline socioeconomic vulnerability, pre-climate change; determine climate change impacts; and assess post-adaptation vulnerability. [3.2]

Land-use and land-cover change scenarios. Land-use change and land-cover change (LUC-LCC) involve several processes that are central to the estimation of climate change and its impacts. First, LUC-LCC influences carbon fluxes and GHG emissions, which directly alter atmospheric composition and radiative forcing properties. Second, LUC-LCC modifies land-surface characteristics and, indirectly, climatic processes. Third, land-cover modification and conversion may alter the properties of ecosystems and their vulnerability to climate change. Finally, several options and strategies for mitigating GHG emissions involve land cover and changed land-use practices. A great diversity of LUC-LCC scenarios have been constructed. Most of these scenarios do not address climate change issues explicitly, however; they focus on other issues—for example, food security and carbon cycling. Large improvements have been made since the SAR in defining current and historic land-use and land-cover patterns, as well as in estimating future scenarios. Integrated assessment models currently are the most appropriate tools for developing LUC-LCC scenarios. [3.3.1, 3.3.2]

Environmental scenarios. Environmental scenarios refer to changes in environmental factors other than climate that will occur in the future regardless of climate change. Because these factors could have important roles in modifying the impacts of future climate change, scenarios are required to portray possible future environmental conditions such as atmospheric composition [e.g., carbon dioxide (CO_2), tropospheric ozone, acidifying compounds, and ultraviolet-B (UV-B) radiation]; water availability, use, and quality; and marine pollution. Apart from the direct effects of CO_2 enrichment, changes in other environmental factors rarely have been considered alongside climate changes in past impact assessments, although their use is increasing with the emergence of integrated assessment methods. [3.4.1]

3.3. Sea-Level Rise Scenarios

Sea-level rise scenarios are required to evaluate a diverse range of threats to human settlements, natural ecosystems, and landscape in the coastal zone. Relative sea-level scenarios (i.e., sea-level rise with reference to movements of the local land surface) are of most interest for impact and adaptation assessments. Tide gauge and wave-height records of 50 years or more are required, along with information on severe weather and coastal processes, to establish baseline levels or trends. Recent techniques of satellite altimetry and geodetic leveling have enhanced and standardized baseline determinations of relative sea level over large areas of the globe. [3.6.2]

Although some components of future sea-level rise can be modeled regionally by using coupled ocean-atmosphere models, the most common method of obtaining scenarios is to apply global mean estimates from simple models. Changes in the occurrence of extreme events such as storm surges and wave setup, which can lead to major coastal impacts, sometimes are investigated by superimposing historically observed events onto a rising mean sea level. More recently, some studies have begun to express future sea-level rise in probabilistic terms, enabling rising levels to be evaluated in terms of the risk of exceeding a critical threshold of impact. [3.6.3, 3.6.4, 3.6.5, 3.6.6]

3.4. Climate Scenarios

Three main types of climate scenarios have been employed in impact assessments: incremental scenarios, analog scenarios, and climate model-based scenarios. Incremental scenarios are simple adjustments of the baseline climate according to anticipated future changes that can offer a valuable aid for testing system sensitivity to climate. However, because they involve arbitrary adjustments, they may not be realistic meteorologically. Analogs of a changed climate from the past record or from other regions may be difficult to identify and are seldom applied, although they sometimes can provide useful insights into impacts of climate conditions outside the present-day range. [3.5.2]

The most common scenarios use outputs from general circulation models (GCMs) and usually are constructed by adjusting a baseline climate (typically based on regional observations of climate over a reference period such as 1961–1990) by the absolute or proportional change between the simulated present and future climates. Most recent impact studies have constructed scenarios on the basis of transient GCM outputs, although some still apply earlier equilibrium results. The great majority of scenarios represent changes in mean climate; some recent scenarios, however, also have incorporated changes in variability and extreme weather events, which can lead to important impacts for some systems. Regional detail is obtained from the coarse-scale outputs of GCMs by using three main methods: simple interpolation, statistical downscaling, and high-resolution dynamical modeling. The simple method, which reproduces the GCM pattern of change, is the most widely applied in scenario development. In contrast, the statistical and modeling approaches can produce local climate changes that are different from large-scale GCM estimates. More research is needed to evaluate the value added to impact studies of such regionalization exercises. One reason for this caution is the large uncertainty of GCM projections, which requires further quantification through model intercomparisons, new model simulations, and pattern scaling methods. [3.5.2, 3.5.4, 3.5.5]

3.5. Scenarios of the 21st Century

In 2000, the IPCC completed a *Special Report on Emissions Scenarios* (SRES) to replace the earlier set of six IS92 scenarios developed for the IPCC in 1992. These newer scenarios consider the period 1990 to 2100 and include a range of socioeconomic assumptions (e.g., global population and gross domestic product). Their implications for other aspects of global change also have been calculated; some of these implications are summarized for 2050 and 2100 in Table TS-1. For example, mean ground-level ozone concentrations in July over the industrialized

***Table TS-1**: The SRES scenarios and their implications for atmospheric composition, climate, and sea level. Values of population, GDP, and per capita income ratio (a measure of regional equity) are those applied in integrated assessment models used to estimate emissions (based on Tables 3-2 and 3-9).*

Date	Global Population (billions)[a]	Global GDP (10^{12} US$ yr^{-1})[b]	Per Capita Income Ratio[c]	Ground-Level O_3 Concentration (ppm)[d]	CO_2 Concentration (ppm)[e]	Global Temperature Change (°C)[f]	Global Sea-Level Rise (cm)[g]
1990	5.3	21	16.1	—	354	0	0
2000	6.1–6.2	25–28	12.3–14.2	40	367	0.2	2
2050	8.4–11.3	59–187	2.4–8.2	~60	463–623	0.8–2.6	5–32
2100	7.0–15.1	197–550	1.4–6.3	>70	478–1099	1.4–5.8	9–88

[a] Values for 2000 show range across the six illustrative SRES emissions scenarios; values for 2050 and 2100 show range across all 40 SRES scenarios.
[b] See footnote a; gross domestic product (trillion 1990 US$ yr^{-1}).
[c] See footnote a; ratio of developed countries and economies-in-transition (Annex I) to developing countries (non-Annex I).
[d] Model estimates for industrialized continents of northern hemisphere assuming emissions for 2000, 2060, and 2100 from the A1F and A2 illustrative SRES emissions scenarios at high end of the SRES range (Chapter 4, TAR WG I).
[e] Observed 1999 value (Chapter 3, WG I TAR); values for 1990, 2050, and 2100 are from simple model runs across the range of 35 fully quantified SRES emissions scenarios and accounting for uncertainties in carbon cycle feedbacks related to climate sensitivity (data from S.C.B. Raper, Chapter 9, WG I TAR). Note that the ranges for 2050 and 2100 differ from those presented by TAR WGI (Appendix II), which were ranges across the six illustrative SRES emissions scenarios from simulations using two different carbon cycle models.
[f] Change in global mean annual temperature relative to 1990 averaged across simple climate model runs emulating results of seven AOGCMs with an average climate sensitivity of 2.8°C for the range of 35 fully quantified SRES emissions scenarios (Chapter 9, WG I TAR).
[g] Based on global mean temperature changes but also accounting for uncertainties in model parameters for land ice, permafrost, and sediment deposition (Chapter 11, WG I TAR).

continents of the northern hemisphere are projected to rise from about 40 ppb in 2000 to more than 70 ppb in 2100 under the highest illustrative SRES emissions scenarios; by comparison, the clean-air standard is below 80 ppb. Peak levels of ozone in local smog events could be many times higher. Estimates of CO_2 concentration range from 478 ppm to1099 ppm by 2100, given the range of SRES emissions and uncertainties about the carbon cycle (Table TS-1). This range of implied radiative forcing gives rise to an estimated global warming from 1990 to 2100 of 1.4–5.8°C, assuming a range of climate sensitivities. This range is higher than the 0.7–3.5°C of the SAR because of higher levels of radiative forcing in the SRES scenarios than in the IS92a-f scenarios—primarily as a result of lower sulfate aerosol emissions, especially after 2050. The equivalent range of estimates of global sea-level rise (for this range of global temperature change in combination with a range of ice melt sensitivities) to 2100 is 9–88 cm (compared to 15–95 cm in the SAR). [3.2.4.1, 3.4.4, 3.8.1, 3.8.2]

In terms of *mean changes in regional climate*, results from GCMs that have been run assuming the new SRES emissions scenarios display many similarities with previous runs. The WGI contribution to the TAR concludes that rates of warming are expected to be greater than the global average over most land areas and will be most pronounced at high latitudes in winter. As warming proceeds, northern hemisphere snow cover and sea-ice extent will be reduced. Models indicate warming below the global average in the north Atlantic and circumpolar southern ocean regions, as well as in southern and southeast Asia and southern South America in June-August. Globally, there will be increases in average water vapor and precipitation. Regionally, December-February precipitation is expected to increase over the northern extratropics, Antarctica, and tropical Africa. Models also agree on a decrease in precipitation over Central America and little change in southeast Asia. Precipitation in June-August is estimated to increase in high northern latitudes, Antarctica, and south Asia; it is expected to change little in southeast Asia and to decrease in central America, Australia, southern Africa, and the Mediterranean region.

Changes in the frequency and intensity of extreme climate events also can be expected. Based on the conclusions of the WGI report and the likelihood scale employed therein, under GHG forcing to 2100, it is very likely that daytime maximum and minimum temperatures will increase, accompanied by an increased frequency of hot days (see Table TS-2). It also is very likely that heat waves will become more frequent, and the number of cold waves and frost days (in applicable regions) will decline. Increases in high-intensity precipitation events are likely at many locations; Asian summer monsoon precipitation variability also is likely to increase. The frequency of summer drought will increase in many interior continental locations, and droughts—as well as floods—associated with El Niño events are likely to intensify. Peak wind intensity and mean and peak precipitation intensities of tropical cyclones are likely to increase. The direction of changes in the average intensity of mid-latitude storms cannot be determined with current climate models. [Table 3-10]

3.6. How can We Improve Scenarios and their Use?

Some features of scenario development and application that are now well established and tested include continued development of global and regional databases for defining baseline conditions, widespread use of incremental scenarios to explore system sensitivity prior to application of model-based scenarios, improved availability and wider application of estimates of long-term mean global changes on the basis of projections produced by specialized international organizations or the use of simple models, and a growing volume of accessible information that enables construction of regional scenarios for some aspects of global change. [3.9.1]

There also are numerous shortcomings of current scenario development, many of which are being actively investigated. These investigations include efforts to properly represent socioeconomic, land-use, and environmental changes in scenarios; to obtain scenarios at higher resolution (in time and space); and to incorporate changes in variability as well as mean conditions in scenarios. Increasing attention is required on construction of scenarios that address policy-related issues such as stabilization of GHG concentrations or adaptation, as well as improving the representation of uncertainties in projections, possibly within a risk assessment framework. [3.9.2]

4. Natural and Human Systems

Natural and human systems are expected to be exposed to climatic variations such as changes in the average, range, and variability of temperature and precipitation, as well as the frequency and severity of weather events. Systems also would be exposed to indirect effects from climate change such as sea-level rise, soil moisture changes, changes in land and water condition, changes in the frequency of fire and pest infestation, and changes in the distribution of infectious disease vectors and hosts. The sensitivity of a system to these exposures depends on system characteristics and includes the potential for adverse and beneficial effects. The potential for a system to sustain adverse impacts is moderated by adaptive capacity. The capacity to adapt human management of systems is determined by access to resources, information and technology, the skill and knowledge to use them, and the stability and effectiveness of cultural, economic, social, and governance institutions that facilitate or constrain how human systems respond.

4.1. Water Resources

There are apparent trends in streamflow volumes—increases and decreases—in many regions. However, confidence that these trends are a result of climate change is low because of factors such as the variability of hydrological behavior over time, the brevity of instrumental records, and the response of river flows to stimuli other than climate change. *In contrast, there is high confidence that observations of widespread accelerated glacier retreat and shifts in the timing of streamflow*

Table TS-2*: Examples of impacts resulting from projected changes in extreme climate events.*

Projected Changes during the 21st Century in Extreme Climate Phenomena and their Likelihood[a]	**Representative Examples of Projected Impacts**[b] *(all high confidence of occurrence in some areas*[c]*)*
Simple Extremes	
Higher maximum temperatures; more hot days and heat waves[d] over nearly all land areas (*Very Likely*[a])	• Increased incidence of death and serious illness in older age groups and urban poor • Increased heat stress in livestock and wildlife • Shift in tourist destinations • Increased risk of damage to a number of crops • Increased electric cooling demand and reduced energy supply reliability
Higher (increasing) minimum temperatures; fewer cold days, frost days, and cold waves[d] over nearly all land areas (*Very Likely*[a])	• Decreased cold-related human morbidity and mortality • Decreased risk of damage to a number of crops, and increased risk to others • Extended range and activity of some pest and disease vectors • Reduced heating energy demand
More intense precipitation events (*Very Likely*[a] over many areas)	• Increased flood, landslide, avalanche, and mudslide damage • Increased soil erosion • Increased flood runoff could increase recharge of some floodplain aquifers • Increased pressure on government and private flood insurance systems and disaster relief
Complex Extremes	
Increased summer drying over most mid-latitude continental interiors and associated risk of drought (*Likely*[a])	• Decreased crop yields • Increased damage to building foundations caused by ground shrinkage • Decreased water resource quantity and quality • Increased risk of forest fire
Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities (*Likely*[a] over some areas)[e]	• Increased risks to human life, risk of infectious disease epidemics, and many other risks • Increased coastal erosion and damage to coastal buildings and infrastructure • Increased damage to coastal ecosystems such as coral reefs and mangroves
Intensified droughts and floods associated with El Niño events in many different regions (*Likely*[a]) (see also under droughts and intense precipitation events)	• Decreased agricultural and rangeland productivity in drought- and flood-prone regions • Decreased hydro-power potential in drought-prone regions
Increased Asian summer monsoon precipitation variability (*Likely*[a])	• Increased flood and drought magnitude and damages in temperate and tropical Asia
Increased intensity of mid-latitude storms (little agreement between current models)[d]	• Increased risks to human life and health • Increased property and infrastructure losses • Increased damage to coastal ecosystems

[a] Likelihood refers to judgmental estimates of confidence used by TAR WGI: *very likely* (90–99% chance); *likely* (66–90% chance). Unless otherwise stated, information on climate phenomena is taken from the Summary for Policymakers, TAR WGI.
[b] These impacts can be lessened by appropriate response measures.
[c] Based on information from chapters in this report; high confidence refers to probabilities between 67 and 95% as described in Footnote 6 of TAR WGII, Summary for Policymakers.
[d] Information from TAR WGI, Technical Summary, Section F.5.
[e] Changes in regional distribution of tropical cyclones are possible but have not been established.

from spring toward winter in many areas are associated with observed increases in temperature. High confidence in these findings exists because these changes are driven by rising temperature and are unaffected by factors that influence streamflow volumes. Glacier retreat will continue, and many small glaciers may disappear (high confidence). The rate of retreat will depend on the rate of temperature rise. [4.3.6.1, 4.3.11]

The effect of climate change on streamflow and groundwater recharge varies regionally and among scenarios, largely following projected changes in precipitation. In some parts of the world, the direction of change is consistent between scenarios, although the magnitude is not. In other parts of the world, the direction of change is uncertain. Possible streamflow changes under two climate change scenarios are shown in Figure TS-3.

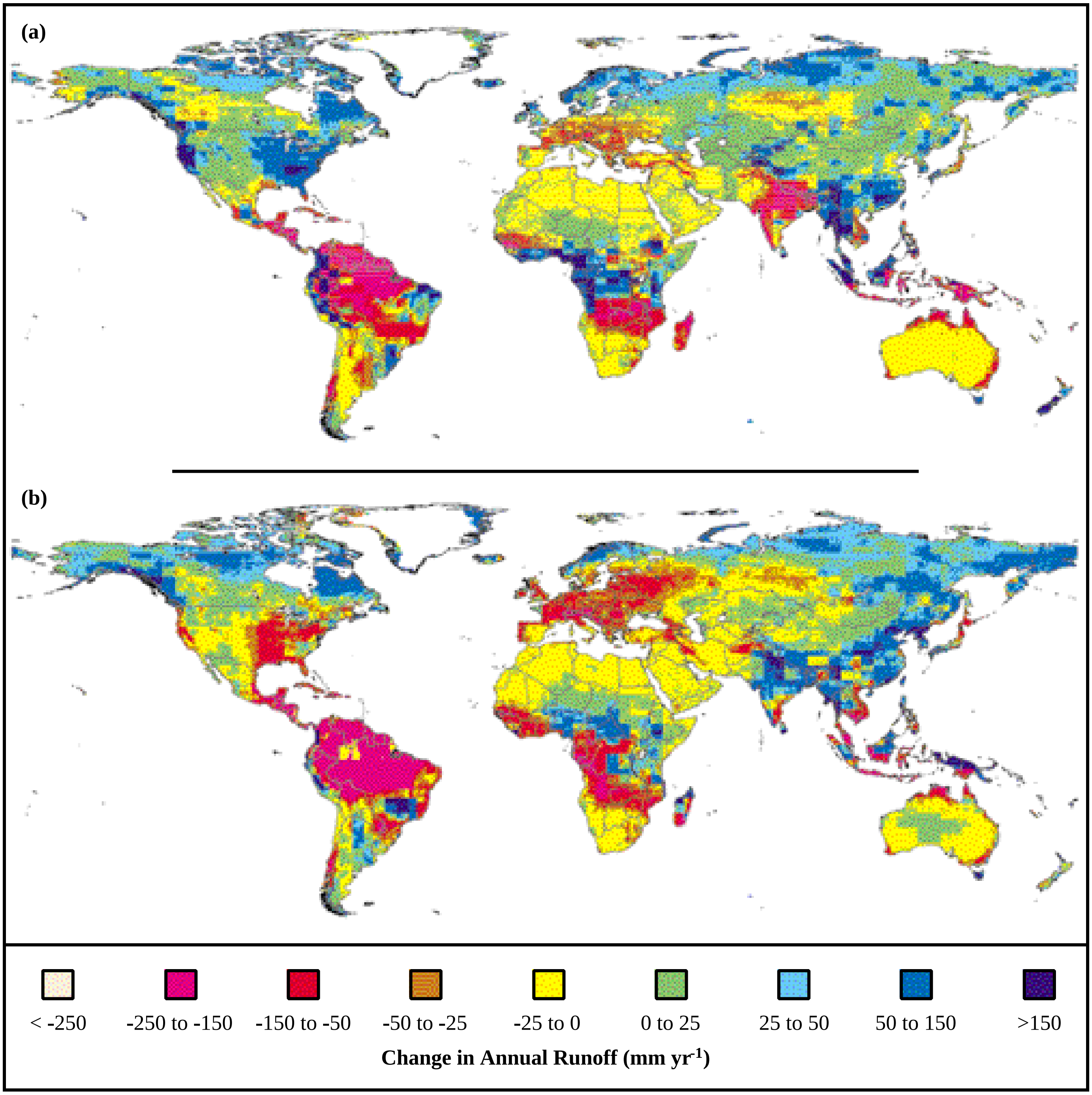


Figure TS-3: The pattern of changes in runoff largely follows the pattern of simulated changes in precipitation, which varies between climate models. The modeled increases in runoff shown in both maps [(a) HadCM2 ensemble mean and (b) HadCM3; see Section 4.3.6.2 of Chapter 4 for discussion of models and scenarios used] for high latitudes and southeast Asia, and decreases in central Asia, the area around the Mediterranean, southern Africa, and Australia are broadly consistent—in terms of direction of change—across most climate models. In other parts of the world, changes in precipitation and runoff vary between climate change scenarios.

Confidence in the projected direction and magnitude of change in streamflow and groundwater recharge is largely dependent on confidence in the projected changes in precipitation. The mapped increase in streamflow in high latitudes and southeast Asia and the decrease in streamflow in central Asia, the area around the Mediterranean, and southern Africa are broadly consistent across climate models. Changes in other areas vary between climate models. [4.3.5, 4.3.6.2]

Peak streamflow will move from spring to winter in many areas where snowfall currently is an important component of the water balance (high confidence). Higher temperatures mean that a greater proportion of winter precipitation falls as rain rather than snow and therefore is not stored on the land surface until it melts in spring. In particularly cold areas, an increase in temperature would still mean that winter precipitation falls as snow, so there would be little change in streamflow timing in these regions. The greatest changes therefore are likely to be in "marginal" zones—including central and eastern Europe and the southern Rocky Mountain chain—where a small temperature rise reduces snowfall substantially. [4.3.6.2]

Water quality generally would be degraded by higher water temperatures (high confidence). The effect of temperature on water quality would be modified by changes in flow volume, which may either exacerbate or lessen the effect of temperature, depending on the direction of change in flow volume. Other things being equal, increasing water temperature alters the rate of operation of biogeochemical processes (some degrading, some cleaning) and, most important, lowers the dissolved oxygen concentration of water. In rivers this effect may be offset to an extent by increased streamflow—which would dilute chemical concentrations further—or enhanced by lower streamflow, which would increase concentrations. In lakes, changes in mixing may offset or exaggerate the effects of increased temperature. [4.3.10]

Flood magnitude and frequency are likely to increase in most regions, and low flows are likely to decrease in many regions. The general direction of change in extreme flows and flow variability is broadly consistent among climate change scenarios, although confidence in the potential magnitude of change in any catchment is low. The general increase in flood magnitude and frequency is a consequence of a projected general increase in the frequency of heavy precipitation events, although the effect of a given change in precipitation depends on catchment characteristics. Changes in low flows are a function of changes in precipitation and evaporation. Evaporation generally is projected to increase, which may lead to lower low flows even where precipitation increases or shows little change. [4.3.8, 4.3.9]

Approximately 1.7 billion people, one-third of the world's population, presently live in countries that are water-stressed (i.e., using more than 20% of their renewable water supply—a commonly used indicator of water stress). This number is projected to increase to about 5 billion by 2025, depending on the rate of population growth. Projected climate change could further decrease streamflow and groundwater recharge in many of these water-stressed countries—for example, in central Asia, southern Africa, and countries around the Mediterranean Sea—but may increase it in some others.

Demand for water generally is increasing, as a result of population growth and economic development, but is falling in some countries. Climate change may decrease water availability in some water-stressed regions and increase it in others. Climate change is unlikely to have a large effect on municipal and industrial demands but may substantially affect irrigation withdrawals. In the municipal and industrial sectors, it is likely that nonclimatic drivers will continue to have very substantial effects on demand for water. Irrigation withdrawals, however, are more climatically determined, but whether they increase or decrease in a given area depends on the change in precipitation: Higher temperatures, hence crop evaporative demand, would mean that the general tendency would be toward an increase in irrigation demands. [4.4.2, 4.4.3, 4.5.2]

The impact of climate change on water resources depends not only on changes in the volume, timing, and quality of streamflow and recharge but also on system characteristics, changing pressures on the system, how management of the system evolves, and what adaptations to climate change are implemented. Nonclimatic changes may have a greater impact on water resources than climate change. Water resources systems are evolving continually to meet changing management challenges. Many of the increased pressures will increase vulnerability to climate change, but many management changes will reduce vulnerability. Unmanaged systems are likely to be most vulnerable to climate change. By definition, these systems have no management structures in place to buffer the effects of hydrological variability. [4.5.2]

Climate change challenges existing water resources management practices by adding uncertainty. Integrated water resources management will enhance the potential for adaptation to change. The historic basis for designing and operating infrastructure no longer holds with climate change because it cannot be assumed that the future hydrological regime will be the same as that of the past. The key challenge, therefore, is incorporating uncertainty into water resources planning and management. Integrated water resources management is an increasingly used means of reconciling different and changing water uses and demands, and it appears to offer greater flexibility than conventional water resources management. Improved ability to forecast streamflow weeks or months ahead also would significantly enhance water management and its ability to cope with a changing hydrological variability. [4.6]

Adaptive capacity (specifically, the ability to implement integrated water resources management), however, is very unevenly distributed across the world. In practice, it may be very difficult to change water management practices in a country where, for example, management institutions and market-like processes are not well developed. The challenge, therefore, is to develop ways to introduce integrated water management practices into specific institutional settings—which is necessary even in the absence of climate change to improve the effectiveness of water management. [4.6.4]

4.2. Agriculture and Food Security

The response of crop yields to climate change varies widely, depending on the species, cultivar, soil conditions, treatment of CO_2 direct effects, and other locational factors. It is established with medium confidence that a few degrees of projected warming will lead to general increases in temperate crop yields, with some regional variation (Table 5-4). At larger amounts of projected warming, most temperate crop yield responses become generally negative. Autonomous agronomic adaptation ameliorates temperate crop yield loss and improves gain in most cases (Figure TS-4). In the tropics, where some crops are near their maximum temperature tolerance and where dryland agriculture predominates, yields would decrease generally with even minimal changes in temperature; where there is a large decrease in rainfall, crop yields would be even more adversely affected (medium confidence). With autonomous agronomic adaptation, it is established with medium confidence that crop yields in the tropics tend to be less adversely affected by climate change than without adaptation, but they still tend to remain below baseline levels. Extreme events also will affect crop yields. Higher minimum temperatures will be beneficial to some crops, especially in temperate regions, and detrimental to other crops, especially in low latitudes (high confidence). Higher maximum temperatures will be generally detrimental to numerous crops (high confidence). [5.3.3]

Important advances in research since the SAR on the direct effects of CO_2 on crops suggest that beneficial effects may be greater under certain stressful conditions, including warmer temperatures and drought. Although these effects are well established for a few crops under experimental conditions, knowledge of them is incomplete for suboptimal conditions of actual farms. Research on agricultural adaptation to climate change also has made important advances. Inexpensive, farm-level (autonomous) agronomic adaptations such as altering of planting dates and cultivar selections have been simulated in crop models extensively. More expensive, directed adaptations—such as changing land-use allocations and developing and using irrigation infrastructure—have been examined in a small but growing number of linked crop-economic models, integrated assessment models, and econometric models.

Degradation of soil and water resources is one of the major future challenges for global agriculture. It is established with high confidence that those processes are likely to be intensified by adverse changes in temperature and precipitation. Land use and management have been shown to have a greater impact on soil conditions than the indirect effect of climate change; thus, adaptation has the potential to significantly mitigate these impacts. A critical research need is to assess whether resource degradation will significantly increase the risks faced

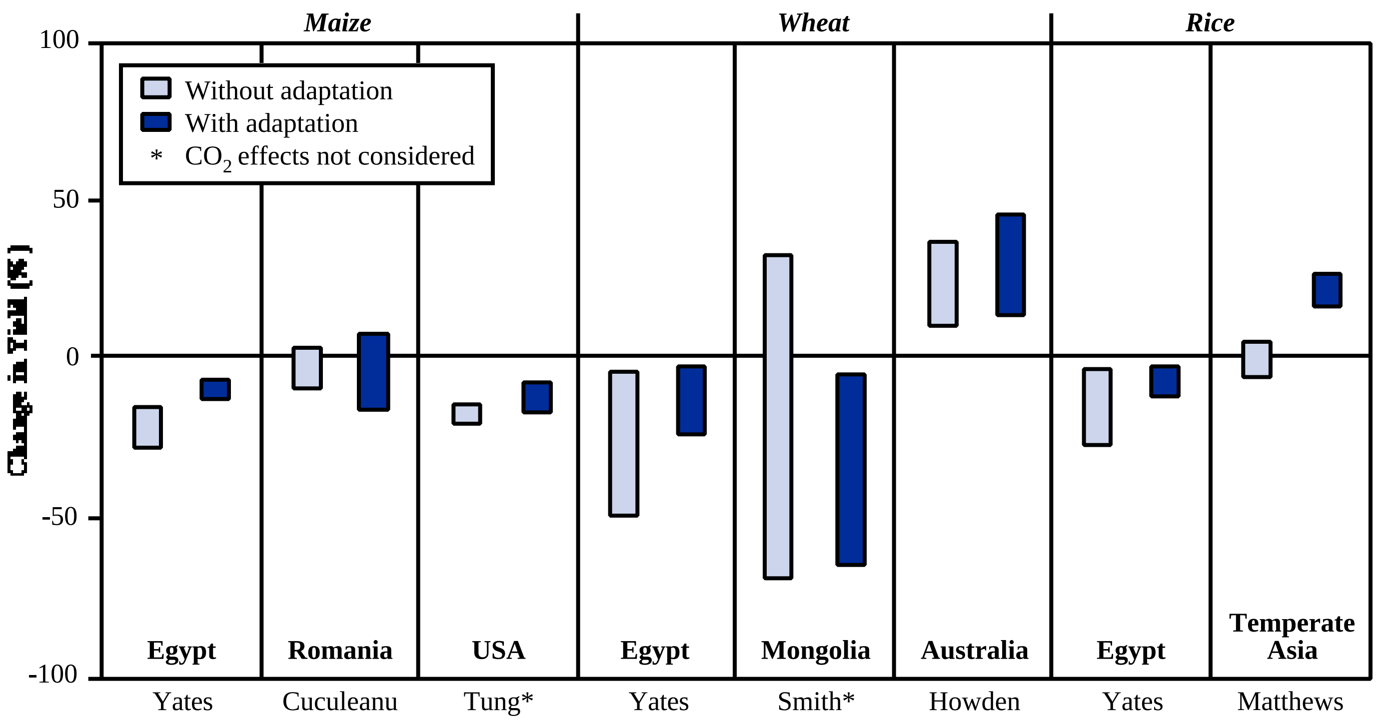


Figure TS-4: Ranges of percentage changes in crop yields (expressed in vertical extent of vertical bars only) spanning selected climate change scenarios—with and without agronomic adaptation—from paired studies listed in Table 5-4. Each pair of ranges is differentiated by geographic location and crop. Pairs of vertical bars represent the range of percentage changes with and without adaptation. Endpoints of each range represent collective high and low percentage change values derived from all climate scenarios used in the study. The horizontal extent of the bars is not meaningful. On the x-axis, the last name of the lead author is listed as it appears in Table 5-4; full source information is provided in the Chapter 5 reference list.

by vulnerable agricultural and rural populations [5.3.2, 5.3.4, 5.3.6].

In the absence of climate change, most global and regional studies project declining real prices for agricultural commodities. Confidence in these projections declines farther into the future. *The impacts of climate change on agriculture are estimated to result in small percentage changes in global income, with positive changes in more developed regions and smaller or negative changes in developing regions (low to medium confidence).* The effectiveness of adaptation (agronomic and economic) in ameliorating the impacts of climate change will vary regionally and depend a great deal on regional resource endowments, including stable and effective institutions. [5.3.1, 5.3.5]

Most studies indicate that mean annual temperature increases of 2.5°C or greater would prompt food prices to increase (low confidence) as a result of slowing in the expansion of global food capacity relative to growth in global food demand. At lesser amounts of warming than 2.5ºC, global impact assessment models cannot distinguish the climate change signal from other sources of change. Some recent aggregated studies have estimated economic impacts on vulnerable populations such as smallholder producers and poor urban consumers. These studies indicate that climate change will lower the incomes of vulnerable populations and increase the absolute number of people at risk of hunger (low confidence). [5.3.5, 5.3.6]

Without autonomous adaptation, increases in extreme events are likely to increase heat stress-related livestock deaths, although winter warming may reduce neonatal deaths at temperate latitudes (established but incomplete). Strategies to adapt livestock to physiological stresses of warming are considered effective; however, adaptation research is hindered by the lack of experimentation and simulation. [5.3.3]

Confidence in specific numerical estimates of climate change impacts on production, income, and prices obtained from large, aggregated, integrated assessment models is considered to be low because there are several remaining uncertainties. The models are highly sensitive to some parameters that have been subjected to sensitivity analysis, yet sensitivity to a large number of other parameters has not been reported. Other uncertainties include the magnitude and persistence of effects of rising atmospheric CO_2 on crop yield under realistic farming conditions; potential changes in crop and animal pest losses; spatial variability in crop responses to climate change; and the effects of changes in climate variability and extreme events on crops and livestock. [Box 5-3]

4.3. Terrestrial and Freshwater Ecosystems

Ecosystems are subject to many pressures, such as land-use changes, deposition of nutrients and pollutants, harvesting, grazing by livestock, introduction of exotic species, and natural climate variability. Climate change constitutes an additional pressure that could change or endanger these systems. The impact of climate change on these systems will be influenced by land and water management adaptation and interactions with other pressures. Adaptive capacity is greater for more intensively managed lands and waters and in production of marketed goods (e.g., timber production in plantations) than in less intensively managed lands and nonmarket values of those lands and waters. [5.1, 5.2]

Populations of many species already are threatened and are expected to be placed at greater risk by the synergy between the stresses of changing climate, rendering portions of current habitat unsuitable, and land-use change that fragments habitats. Without adaptation, some species that currently are classified as "critically endangered" will become extinct, and the majority of those labeled "endangered or vulnerable" will become much rarer in the 21st century (high confidence). This may have the greatest impact on the lowest income human societies, which rely on wildlife for subsistence living. In addition, there is high confidence that loss or reduction of species would impact the services provided by wildlife through roles within an ecosystem (e.g., pollination, natural pest control), recreation (e.g., sport hunting, wildlife viewing), and cultural and religious practices of indigenous people. Possible adaptation methods to reduce risks to species could include establishment of refuges, parks, and reserves with corridors to allow migration of species, as well as use of captive breeding and translocation. However, these options may have limitations of cost. [5.4]

There are now substantial observational and experimental studies demonstrating the link between change in regional climate and biological or physical processes in ecosystems. These include a lengthening of vegetative growing season by 1.2 to 3.6 days per decade in the high northern latitudes (one factor leading to community composition changes); warming of lakes and rivers as a result of shortening duration of ice cover; upward range shifts in alpine herbs; and increased mortality and range contraction of wildlife as a result of heat stress. Others include changes in population sizes, body sizes, and migration times (see TS 2.1 and 7.1, Figure TS-11, and Table TS-16 for additional information). [5.2.1]

Vegetation distribution models since the SAR suggest that mass ecosystem or biome movement is most unlikely to occur because of different climatic tolerance of the species involved, different migration abilities, and the effects of invading species. Species composition and dominance will change, resulting in ecosystem types that may be quite different from those we see today. These changes will lag the changes in climate by years to decades to centuries (high confidence). The effects of changes in disturbances such as fire, blowdown, or pest attacks on vegetation have not been included in these studies. [5.2]

Recent modeling studies continue to show potential for significant disruption of ecosystems under climate change (high confidence). Further development of simple correlative models that were available at the time of the SAR point to areas where ecosystem disruption and the potential for ecosystem migration are high. Observational data and newer dynamic vegetation models linked to transient climate models are refining the projections. However, the precise outcomes depend on processes that are too subtle to be fully captured by current models. [5.2]

Increasing CO_2 concentration would increase net primary productivity (plant growth, litterfall, and mortality) in most systems, whereas increasing temperature may have positive or negative effects (high confidence). Experiments on tree species grown under elevated CO_2 over several years show continued and consistent stimulation of photosynthesis and little evidence of long-term loss of sensitivity to CO_2. However, changes in net ecosystem productivity (which includes plant growth, litterfall, mortality, litter decomposition, and soil carbon dynamics) and net biome productivity (which includes those effects plus the effects of fire or other disturbances) are less likely to be positive and may be generally negative. Research reported since the SAR confirms the view that the largest and earliest impacts induced by climate change are likely to occur in boreal forests, through changes in weather-related disturbance regimes and nutrient cycling. [5.6.1.1, 5.6.3.1]

Terrestrial ecosystems appear to be storing increasing amounts of carbon. At the time of the SAR, this was attributed largely to increasing plant productivity because of the interaction among elevated CO_2 concentration, increasing temperatures, and soil moisture changes. Recent results confirm that productivity gains are occurring but suggest that they are smaller under field conditions than plant-pot experiments indicate (*medium confidence*). Hence, the terrestrial uptake may be caused more by change in uses and management of land than by the direct effects of elevated CO_2 and climate. The degree to which terrestrial ecosystems continue to be net sinks for carbon is uncertain because of the complex interactions between the aforementioned factors (e.g., arctic terrestrial ecosystems and wetlands may act as sources and sinks) (*medium confidence*).

In arid or semi-arid areas (e.g., rangelands, dry forests/ woodlands) where climate change is likely to decrease available soil moisture, productivity is expected to decrease. Increased CO_2 concentrations may counteract some of these losses. However, many of these areas are affected by El Niño/La Niña, other climatic extremes, and disturbances such as fire. Changes in the frequencies of these events and disturbances could lead to loss of productivity thus potential land degradation, potential loss of stored carbon, or decrease in the rate of carbon uptake (medium confidence). [5.5]

Some wetlands will be replaced by forests or heathlands, and those overlying permafrost are likely to be disrupted as a result of thawing of permafrost (high confidence). The initial net effect of warming on carbon stores in high-latitude ecosystems is likely to be negative because decomposition initially may respond more rapidly than production. In these systems, changes in albedo and energy absorption during winter are likely to act as a positive feedback to regional warming as a result of earlier melting of snow and, over decades to centuries, poleward movement of the treeline. [5.8, 5.9]

Most wetland processes are dependent on catchment-level hydrology; thus, adaptations for projected climate change may be practically impossible. Arctic and subarctic ombrotrophic bog communities on permafrost, as well as more southern depressional wetlands with small catchment areas, are likely to be most vulnerable to climate change. The increasing speed of peatland conversion and drainage in southeast Asia is likely to place these areas at a greatly increased risk of fires and affect the viability of tropical wetlands. [5.8]

Opportunities for adapting to expected changes in high-latitude and alpine ecosystems are limited because these systems will respond most strongly to globally induced changes in climate. Careful management of wildlife resources could minimize climatic impacts on indigenous peoples. Many high-latitude regions depend strongly on one or a few resources, such as timber, oil, reindeer, or wages from fighting fires. Economic diversification would reduce the impacts of large changes in the availability or economic value of particular goods and services. High levels of endemism in many alpine floras and their inability to migrate upward means that these species are very vulnerable. [5.9]

Contrary to the SAR, global timber market studies that include adaptations through land and product management suggest that climate change would increase global timber supply (medium confidence). At the regional and global scales, the extent and nature of adaptation will depend primarily on wood and non-wood product prices, the relative value of substitutes, the cost of management, and technology. On specific sites, changes in forest growth and productivity will constrain—and could limit—choices regarding adaptation strategies (high confidence). In markets, prices will mediate adaptation through land and product management. Adaptation in managed forests will include salvaging dead and dying timber, replanting new species that are better suited to the new climate, planting genetically modified species, and intensifying or decreasing management. Consumers will benefit from lower timber prices; producers may gain or lose, depending on regional changes in timber productivity and potential dieback effects. [5.6]

Climate change will lead to poleward movement of the southern and northern boundaries of fish distributions, loss of habitat for cold- and coolwater fish, and gain in habitat for warmwater fish (high confidence). As a class of ecosystems, inland waters are vulnerable to climatic change and other pressures owing to their small size and position downstream from many human activities (high confidence). The most vulnerable elements include reduction and loss of lake and river ice (very high confidence), loss of habitat for coldwater fish (very high confidence), increases in extinctions and invasions of exotics (high confidence), and potential exacerbation of existing pollution problems such as eutrophication, toxics, acid rain, and UV-B radiation (medium confidence). [5.7]

4.4. Coastal Zones and Marine Ecosystems

Global climate change will result in increases in sea-surface temperature (SST) and sea level; decreases in sea-ice cover;

and changes in salinity, wave climate, and ocean circulation. Some of these changes already are taking place. Changes in oceans are expected to have important feedback effects on global climate and on the climate of the immediate coastal area (see TAR WGI). They also would have profound impacts on the biological production of oceans, including fish production. For instance, changes in global water circulation and vertical mixing will affect the distribution of biogenic elements and the efficiency of CO_2 uptake by the ocean; changes in upwelling rates would have major impacts on coastal fish production and coastal climates. [6.3]

If warm events associated with El Niños increase in frequency, plankton biomass and fish larvae abundance would decline and adversely impact fish, marine mammals, seabirds, and ocean biodiversity (high confidence). In addition to El Niño-Southern Oscillation (ENSO) variability, the persistence of multi-year climate-ocean regimes and switches from one regime to another have been recognized since the SAR. Changes in recruitment patterns of fish populations have been linked to such switches. Fluctuations in fish abundance are increasingly regarded as biological responses to medium-term climate fluctuations in addition to overfishing and other anthropogenic factors. Similarly, survival of marine mammals and seabirds also is affected by interannual and longer term variability in several oceanographic and atmospheric properties and processes, especially in high latitudes. [6.3.4]

Growing recognition of the role of the climate-ocean system in the management of fish stocks is leading to new adaptive strategies that are based on the determination of acceptable removable percentages of fish and stock resilience. Another consequence of the recognition of climate-related changes in the distribution of marine fish populations suggests that the sustainability of many nations' fisheries will depend on adaptations that increase flexibility in bilateral and multilateral fishing agreements, coupled with international stock assessments and management plans. Creating sustainable fisheries also depends on understanding synergies between climate-related impacts on fisheries and factors such harvest pressure and habitat conditions. [6.3.4, 6.6.4]

Adaptation by expansion of marine aquaculture may partly compensate for potential reductions in ocean fish catch. Marine aquaculture production has more than doubled since 1990, and in 1997 represented approximately 30% of total commercial fish and shellfish production for human consumption. However, future aquaculture productivity may be limited by ocean stocks of herring, anchovies, and other species that are used to provide fishmeal and fish oils to feed cultured species, which may be negatively impacted by climate change. Decreases in dissolved oxygen levels associated with increased seawater temperatures and enrichment of organic matter creates conditions for the spread of diseases in wild and aquaculture fisheries, as well as outbreaks of algal blooms in coastal areas. Pollution and habitat destruction that can accompany aquaculture also may place limits on its expansion and on the survival success of wild stocks. [6.3.5]

Many coastal areas already are experiencing increased levels of sea flooding, accelerated coastal erosion, and seawater intrusion into freshwater sources; these processes will be exacerbated by climate change and sea-level rise. Sea-level rise in particular has contributed to erosion of sandy and gravel beaches and barriers; loss of coastal dunes and wetlands; and drainage problems in many low-lying, mid-latitude coastal areas. Highly diverse and productive coastal ecosystems, coastal settlements, and island states will continue to be exposed to pressures whose impacts are expected to be largely negative and potentially disastrous in some instances. [6.4]

Low-latitude tropical and subtropical coastlines, particularly in areas where there is significant human population pressure, are highly susceptible to climate change impacts. These impacts will exacerbate many present-day problems. For instance, human activities have increased land subsidence in many deltaic regions by increasing subsurface water withdrawals, draining wetland soils, and reducing or cutting off riverine sediment loads. Problems of inundation, salinization of potable groundwater, and coastal erosion will all be accelerated with global sea-level rise superimposed on local submergence. Especially at risk are large delta regions of Asia and small islands whose vulnerability was recognized more than a decade ago and continues to increase. [6.4.3, 6.5.3]

High-latitude (polar) coastlines also are susceptible to climate warming impacts, although these impacts have been less studied. Except on rock-dominated or rapidly emerging coasts, a combination of accelerated sea-level rise, more energetic wave climate with reduced sea-ice cover, and increased ground temperatures that promote thaw of permafrost and ground ice (with consequent volume loss in coastal landforms) will have severe impacts on settlements and infrastructure and will result in rapid coastal retreat. [6.4.6]

Coastal ecosystems such as coral reefs and atolls, salt marshes and mangrove forests, and submergered aquatic vegetation will be impacted by sea-level rise, warming SSTs, and any changes in storm frequency and intensity. Impacts of sea-level rise on mangroves and salt marshes will depend on the rate of rise relative to vertical accretion and space for horizontal migration, which can be limited by human development in coastal areas. Healthy coral reefs are likely to be able to keep up with sea-level rise, but this is less certain for reefs degraded by coral bleaching, UV-B radiation, pollution, and other stresses. Episodes of coral bleaching over the past 20 years have been associated with several causes, including increased ocean temperatures. Future sea-surface warming would increase stress on coral reefs and result in increased frequency of marine diseases (high confidence). Changes in ocean chemistry resulting from higher CO_2 levels may have a negative impact on coral reef development and health, which would have a detrimental effect on coastal fisheries and on social and economic uses of reef resources. [6.4.4, 6.4.5]

Few studies have examined potential changes in prevailing ocean wave heights and directions and storm waves and surges as a consequence of climate change. Such changes can be expected to have serious impacts on natural and human-modified coasts because they will be superimposed on a higher sea level than at present.

Vulnerabilities have been documented for a variety of coastal settings, initially by using a common methodology developed in the early 1990s. These and subsequent studies have confirmed the spatial and temporal variability of coastal vulnerability at national and regional levels. Within the common methodology, three coastal adaptation strategies have been identified: protect, accommodate, and retreat. Since the SAR, adaptation strategies for coastal zones have shifted in emphasis away from hard protection structures (e.g., seawalls, groins) toward soft protection measures (e.g., beach nourishment), managed retreat, and enhanced resilience of biophysical and socioeconomic systems, including the use of flood insurance to spread financial risk. [6.6.1, 6.6.2]

Integrated assessments of coastal zones and marine ecosystems and better understanding of their interaction with human development and multi-year climate variability could lead to improvements in sustainable development and management. Adaptation options for coastal and marine management are most effective when they are incorporated with policies in other areas, such as disaster mitigation plans and land-use plans.

4.5. Human Settlements, Energy, and Industry

Human settlements are integrators of many of the climate impacts initially felt in other sectors and differ from each other in geographic location, size, economic circumstances, and political and institutional capacity. As a consequence, it is difficult to make blanket statements concerning the importance of climate or climate change that will not have numerous exceptions. However, classifying human settlements by considering pathways by which climate may affect them, size or other obvious physical considerations, and adaptive capacities (wealth, education of the populace, technological and institutional capacity) helps to explain some of the differences in expected impacts. [7.2]

Human settlements are affected by climate in one of three major ways:

1) Economic sectors that support the settlement are affected because of changes in productive capacity (e.g., in agriculture or fisheries) or changes in market demand for goods and services produced there (including demand from people living nearby and from tourism). The importance of this impact depends in part on whether the settlement is rural—which generally means that it is dependent on one or two resource-based industries—or urban, in which case there usually (but not always) is a broader array of alternative resources. It also depends on the adaptive capacity of the settlement. [7.1]
2) Some aspects of physical infrastructure (including energy transmission and distribution systems), buildings, urban services (including transportation systems), and specific industries (such as agroindustry, tourism, and construction) may be directly affected. For example, buildings and infrastructure in deltaic areas may be affected by coastal and river flooding; urban energy demand may increase or decrease as a result of changed balances in space heating and space cooling; and coastal and mountain tourism may be affected by changed seasonal temperature and precipitation patterns and sea-level rise. Concentration of population and infrastructure in urban areas can mean higher numbers of persons and higher value of physical capital at risk, although there also are many economies of scale and proximity in ensuring well-managed infrastructure and service provision. When these factors are combined with other prevention measures, risks can be reduced considerably. However, some larger urban centers in Africa, Asia, Latin America, and the Caribbean, as well as smaller settlements (including villages and small urban centers), often have less wealth, political power, and institutional capacity to reduce risks in this way. [7.1]
3) Population may be directly affected through extreme weather, changes in health status, or migration. Extreme weather episodes may lead to changes in deaths, injuries, or illness. For example, health status may improve as a result of reduced cold stress or deteriorate as a result of increased heat stress and disease. Population movements caused by climate changes may affect the size and characteristics of settlement populations, which in turn changes the demand for urban services. The problems are somewhat different in the largest population centers (e.g., those of more than 1 million population) and mid-sized to small-sized regional centers. The former are more likely to be destinations for migrants from rural areas and smaller settlements and cross-border areas, but larger settlements generally have much greater command over national resource. Thus, smaller settlements actually may be more vulnerable. Informal settlements surrounding large and medium-size cities in the developing world remain a cause for concern because they exhibit several current health and environmental hazards that could be exacerbated by global warming and have limited command over resources. [7.1]

Table TS-3 classifies several types of climate-caused environmental changes discussed in the climate and human settlement literatures. The table features three general types of settlements, each based on the one of the three major mechanisms by which climate affects settlements. The impacts correspond to the mechanism of the effect. Thus, a given settlement may be affected positively by effects of climate change on its resource base (e.g., more agricultural production) and negatively by effects on its infrastructure (e.g., more frequent flooding of its

***Table TS-3**: Impacts of climate change on human settlements, by impact type and settlement type (impact mechanism).*[a,b]

Impact Type	Type of Settlement, Importance Rating, and Reference												Confidence[c]
	Resource-Dependent (Effects on Resources)				*Coastal-Riverine-Steeplands (Effects on Buildings and Infrastructure)*				*Urban 1+ M (Effects on Populations)*		*Urban <1 M (Effects on Populations)*		
	Urban, High Capacity	Urban, Low Capacity	Rural, High Capacity	Rural, Low Capacity	Urban, High Capacity	Urban, Low Capacity	Rural, High Capacity	Rural, Low Capacity	High Capacity	Low Capacity	High Capacity	Low Capacity	
Flooding, landslides	**L–M**	**M–H**	**L–M**	**M–H**	**L–M**	**M–H**	**M–H**	**M–H**	**M**	**M–H**	**M**	**M–H**	*****
Tropical cyclone	**L–M**	**M–H**	**L–M**	**M–H**	**L–M**	**M–H**	**M**	**M–H**	**L–M**	**M**	**L**	**L–M**	***
Water quality	L–M	M	L–M	M–H	**L–M**	**M–H**	*L–M*	*M–H*	L–M	M–H	L–M	M–H	***
Sea-level rise	**L–M**	**M–H**	**L–M**	**M–H**	**M**	**M–H**	*M*	**M–H**	**L**	**L–M**	*L*	**L–M**	***** (** for resource-dependent)
Heat/cold waves	*L–M*	*M–H*	*L–M*	*M–H*	*L–M*	L–M	**L–M**	L	**L–M**	**M–H**	**L–M**	**M–H**	*** (***** for urban)
Water shortage	**L**	*L–M*	**M**	**M–H**	*L*	*L–M*	*L–M*	*M–H*	*L*	*M*	**L–M**	*M*	*** (** for urban)
Fires	*L–M*	*L–M*	**L–M**	*M–H*	*L–M*	*L–M*	*L–M*	*L–M*	**L–M**	**L–M**	*L–M*	*M*	* (*** for urban)
Hail, windstorm	**L–M**	**L–M**	**L–M**	**M–H**	*L–M*	*L–M*	*L–M*	*M*	**L–M**	**L–M**	**L–M**	**L–M**	**
Agriculture/ forestry/fisheries productivity	**L–M**	**L–M**	*L–M*	*M–H*	L	L	L	L	*L*	*L–M*	*L–M*	*M*	***
Air pollution	**L–M**	*L–M*	L	L	—	—	—	—	**L–M**	**M–H**	**L–M**	**M–H**	***
Permafrost melting	L	L	**L–M**	*L–M*	L	L	**L**	L	—	—	*L–M*	*L–M*	*****
Heat islands	L	L	—	—	L	L	—	—	**M**	**L–M**	**L–M**	**L–M**	***

[a] Values in cells in the table were assigned by authors on the basis of direct evidence in the literature or inference from impacts shown in other cells. Typeface indicates source of rating: Boldface indicates direct evidence or study; italic indicates direct inference from similar impacts; regular typeface indicates logical conclusion from settlement type, but cannot be directly corroborated from a study or inferred from similar impacts.
[b] Impacts ratings: Low (L) = impacts are barely discernible or easily overcome; moderate (M) = impacts are clearly noticeable, although not disruptive, and may require significant expense or difficulty in adapting; high (H) = impacts are clearly disruptive and may not be overcome or adaptation is so costly that it is disruptive (impacts generally based on $2xCO_2$ scenarios or studies describing impact of current weather events, but have been placed in context of the IPCC transient scenarios for mid- to late 21st century). Note that "Urban 1+ M" and "Urban <1 M" refer to populations above and below 1 million, respectively.
[c] See Section 1.4 of Technical Summary for key to confidence-level rankings.

water works and overload of its electrical system). Different types of settlements may experience these effects in different relative intensities (e.g., noncoastal settlements do not directly experience impacts through sea-level rise); the impacts are ranked from overall highest to lowest importance. Most settlement effects literature is based on $2xCO_2$ scenarios or studies describing the impact of current weather events (analogs) but has been placed in context of the IPCC transient scenarios. [7.1]

Climate change has the potential to create local and regional conditions that involve water deficits and surpluses, sometimes seasonally in the same geographic locations. *The most widespread serious potential impacts are flooding, landslides, mudslides, and avalanches driven by projected increases in rainfall intensity and sea-level rise.* A growing literature suggests that a very wide variety of settlements in nearly every climate zone may be affected (established but incomplete). Riverine and coastal settlements are believed to be particularly at risk, but urban flooding could be a problem anywhere storm drains, water supply, and waste management systems are not designed with enough capacity or sophistication (including conventional hardening and more advanced system design) to avoid being overwhelmed. The next most serious threats are tropical cyclones (hurricanes or typhoons), which may increase in peak intensity in a warmer world. Tropical cyclones combine the effects of heavy rainfall, high winds, and storm surge in coastal areas and can be disruptive far inland, but they are not as universal in location as floods and landslides. Tens of millions of people live in the settlements potentially flooded. For example, estimates of the mean annual number of people who would be flooded by coastal storm surges increase several-fold (by 75 million to 200 million people, depending on adaptive responses) for mid-range scenarios of a 40-cm sea-level rise by the 2080s relative to scenarios with no sea-level rise. Potential damages to infrastructure in coastal areas from sea-level rise have been estimated to be tens of billions of dollars for individual countries such as Egypt, Poland, and Vietnam. In the middle of Table TS-3 are effects such as heat or cold waves, which can be disruptive to the resource base (e.g., agriculture), human health, and demand for heating and cooling energy. Environmental impacts such as reduced air and water quality also are included. Windstorms, water shortages, and fire also are expected to be moderately important in many regions. At the lower end are effects such as permafrost melting and heat island effects—which, although important locally, may not apply to as wide a variety of settlements or hold less importance once adaptation is taken into account. [7.2, 7.3]

Global warming is expected to result in increases in energy demand for spacing cooling and in decreased energy use for space heating. Increases in heat waves add to cooling energy demand, and decreases in cold waves reduce heating energy demand. The projected net effect on annual energy consumption is scenario- and location-specific. Adapting human settlements, energy systems, and industry to climate change provides challenges for the design and operation of settlements (in some cases) during more severe weather and opportunities to take advantage (in other cases) of more benign weather. For instance, transmission systems of electric systems are known to be adversely affected by extreme events such as tropical cyclones, tornadoes, and ice storms. The existence of local capacity to limit environmental hazards or their health consequences in any settlement generally implies local capacity to adapt to climate change, unless adaptation implies particularly expensive infrastructure investment. Adaptation to warmer climate will require local tuning of settlements to a changing environment, not just warmer temperatures. Urban experts are unanimous that successful environmental adaptation cannot occur without locally based, technically and institutionally competent, and politically supported leadership that have good access to national-level resources. [7.2, 7.3, 7.4, 7.5]

Possible adaptation options involve planning of settlements and their infrastructure, placement of industrial facilities, and making similar long-lived decisions to reduce the adverse effects of events that are of low (but increasing) probability and high (and perhaps rising) consequences. Many specific conventional and advanced techniques can contribute to better environmental planning and management, including market-based tools for pollution control, demand management and waste reduction, mixed-use zoning and transport planning (with appropriate provision for pedestrians and cyclists), environmental impact assessments, capacity studies, strategic environmental plans, environmental audit procedures, and state-of-the-environment reports. Many cities have used a combination of these strategies in developing "Local Agenda 21s." Many Local Agenda 21s deal with a list of urban problems that could closely interact with climate change in the future. [7.2, 7.5]

4.6. Insurance and Other Financial Services

The financial services sector—broadly defined as private and public institutions that offer insurance and disaster relief, banking, and asset management services—is a unique indicator of potential socioeconomic impacts of climate change because it is sensitive to climate change and it integrates effects on other sectors. The sector is a key agent of adaptation (e.g., through support of building codes and, to a limited extent, land-use planning), and financial services represent risk-spreading mechanisms through which the costs of weather-related events are distributed among other sectors and throughout society. However, insurance, whether provided by public or private entities, also can encourage complacency and maladaptation by fostering development in at-risk areas such as U.S. floodplains or coastal zones. The effects of climate change on the financial services sector are likely to manifest primarily through changes in spatial distribution, frequencies, and intensities of extreme weather events (Table TS-4). [8.1, 8.2, 15.2.7]

The costs of extreme weather events have exhibited a rapid upward trend in recent decades. Yearly global economic losses from large events increased from US$3.9 billion yr^{-1} in the 1950s to US$40 billion yr^{-1} in the 1990s (all 1999 US$, uncorrected for purchasing power parity). Approximately one-quarter of

***Table TS-4**: Extreme climate-related phenomena and their effects on the insurance industry: observed changes and projected changes during 21st century (after Table 3-10; see also Table 8-1).*

Changes in Extreme Climate Phenomena	Observed Changes (*Likelihood*)	Projected Changes (*Likelihood*)	Type of Event Relevant to Insurance Sector	Relevant Time Scale	Sensitive Sectors/Activities	Sensitive Insurance Branches
Temperature Extremes						
Higher maximum temperatures, more hot days and heat waves[b] over nearly all land areas	Likely[a] (mixed trends for heat waves in several regions)	Very likely[a]	Heat wave	Daily-weekly maximum	Electric reliability, human settlements	Health, life, property, business interruption
			Heat wave, droughts	Monthly-seasonal maximum	Forests (tree health), natural resources, agriculture, water resources, electricity demand and reliability, industry, health, tourism	Health, crop, business interruption
Higher (increasing) minimum temperatures, fewer cold days, frost days, and cold waves[b] over nearly all land areas	Very likely[a] (cold waves not treated by WGI)	Very likely[a]	Frost, frost heave	Daily-monthly minimum	Agriculture, energy demand, health, transport, human settlements	Health, crop, property, business interruption, vehicle
Rainfall/Precipitation Extremes						
More intense precipitation events	Likely[a] over many Northern Hemisphere mid- to high-latitude land areas	Very likely[a] over many areas	Flash flood	Hourly-daily maximum	Human settlements	Property, flood, vehicle, business interruption, life, health
			Flood, inundation, mudslide	Weekly-monthly maximum	Agriculture, forests, transport, water quality, human settlements, tourism	Property, flood, crop, marine, business interruption
Increased summer drying and associated risk of drought	Likely[a] in a few areas	Likely[a] over most mid-latitude continental interiors (lack of consistent projections in other areas)	Summer drought, land subsidence, wildfire	Monthly-seasonal minimum	Forests (tree health), natural resources, agriculture, water resources, (hydro)energy supply, human settlements	Crop, property, health

the losses occurred in developing countries. The insured portion of these losses rose from a negligible level to US$9.2 billion annually during the same period. Including events of all sizes doubles these loss totals (see Figure TS–5). The costs of weather events have risen rapidly, despite significant and increasing efforts at fortifying infrastructure and enhancing disaster preparedness. These efforts dampen to an unknown degree the observed rise in loss costs, although the literature attempting to separate natural from human driving forces has not quantified this effect. As a measure of increasing insurance industry vulnerability, the ratio of global property/casualty insurance premiums to weather-related losses—an important indicator of adaptive capacity—fell by a factor of three between 1985 and 1999. [8.3]

Part of the observed upward trend in historical disaster losses is linked to socioeconomic factors—such as population growth, increased wealth, and urbanization in vulnerable areas—and

Table TS-4 (continued)

Changes in Extreme Climate Phenomena	Observed Changes (Likelihood)	Projected Changes (Likelihood)	Type of Event Relevant to Insurance Sector	Relevant Time Scale	Sensitive Sectors/Activities	Sensitive Insurance Branches
Rainfall/Precipitation Extremes (continued)						
Increased intensity of mid-latitude storms[c]	Medium likelihood[a] of increase in Northern Hemisphere, decrease in Southern Hemisphere	Little agreement among current models	Snowstorm, ice storm, avalanche	Hourly-weekly	Forests, agriculture, energy distribution and reliability, human settlements, mortality, tourism	Property, crop, vehicle, aviation, life, business interruption
			Hailstorm	Hourly	Agriculture, property	Crop, vehicle, property, aviation
Intensified droughts and floods associated with El Niño events in many different regions (see also droughts and extreme precipitation events)	Inconclusive information	Likely[a]	Drought and floods	Various	Forests (tree health), natural resources, agriculture, water resources, (hydro)energy supply, human settlements	Property, flood, vehicle, crop, marine, business interruption, life, health
Wind Extremes						
Increased intensity of mid-latitude storms[b]	No compelling evidence for change	Little agreement among current models	Mid-latitude windstorm	Hourly-daily	Forests, electricity distribution and reliability, human settlements	Property, vehicle, aviation, marine, business interruption, life
			Tornadoes	Hourly	Forests, electricity distribution and reliability, human settlements	Property, vehicle, aviation, marine, business interruption
Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities[c]	Wind extremes not observed in the few analyses available; insufficient data for precipitation	Likely[a] over some areas	Tropical storms, including cyclones, hurricanes, and typhoons	Hourly-weekly	Forests, electricity distribution and reliability, human settlements, agriculture	Property, vehicle, aviation, marine, business interruption, life

part is linked to climatic factors such as observed changes in precipitation, flooding, and drought events. Precise attribution is complex, and there are differences in the balance of these two causes by region and by type of event. Many of the observed trends in weather-related losses are consistent with what would be expected under climate change. Notably, the growth rate in human-induced and non-weather-related losses has been far lower than that of weather-related events. [8.2.2]

Recent history has shown that weather-related losses can stress insurance companies to the point of impaired profitability, consumer price increases, withdrawal of coverage, and elevated demand for publicly funded compensation and relief. Increased uncertainty will increase the vulnerability of the insurance and government sectors and complicate adaptation and disaster relief efforts under climate change. [8.3, 15.2.7]

Table TS-4 (continued)

Changes in Extreme Climate Phenomena	Observed Changes (Likelihood)	Projected Changes (Likelihood)	Type of Event Relevant to Insurance Sector	Relevant Time Scale	Sensitive Sectors/Activities	Sensitive Insurance Branches
Other Extremes						
Refer to entries above for higher temperatures, increased tropical and mid-latitude storms	Refer to relevant entries above	Refer to relevant entries above	Lightning	Instant-aneous	Electricity distribution and reliability, human settlements, wildfire	Life, property, vehicle, aviation, marine, business interruption
Refer to entries above for increased tropical cyclones, Asian summer monsoon, and intensity of mid-latitude storms	Refer to relevant entries above	Refer to relevant entries above	Tidal surge (associated with onshore gales), coastal inundation	Daily	Coastal zone infrastructure, agriculture and industry, tourism	Life, marine, property, crop
Increased Asian summer monsoon precipitation variability	Not treated by WGI	Likely[a]	Flood and drought	Seasonal	Agriculture, human settlements	Crop, property, health, life

[a] Likelihood refers to judgmental estimates of confidence used by Working Group I: *very likely* (90–99% chance); *likely* (66–90% chance). Unless otherwise stated, information on climate phenomena is taken from Working Group I's Summary for Policymakers and Technical Summary. These likelihoods refer to observed and projected changes in extreme climate phenomena and likelihood shown in first three columns of table.
[b] Information from Working Group I, Technical Summary, Section F.5.
[c] Changes in regional distribution of tropical cyclones are possible but have not been established.

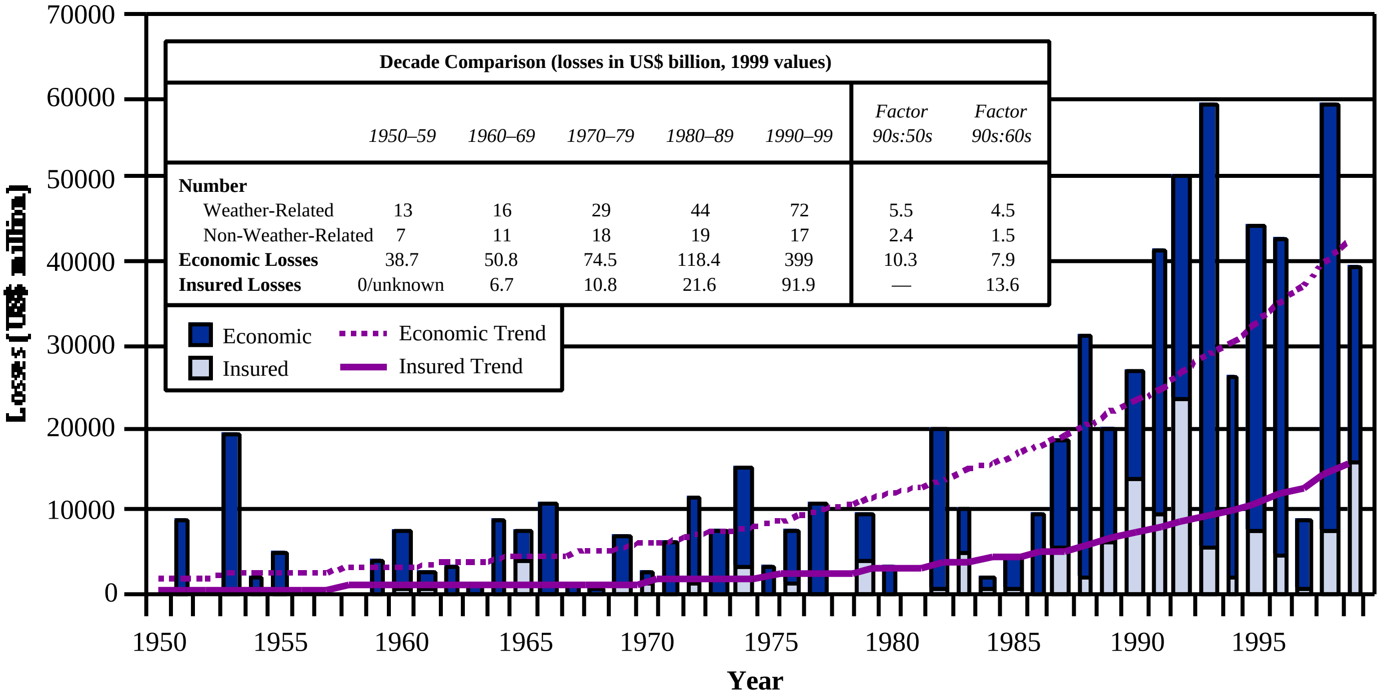
The financial services sector as a whole is expected to be able to cope with the impacts of future climate change, although the historic record shows that low-probability, high-impact events or multiple closely spaced events severely affect parts of the sector, especially if adaptive capacity happens to be simultaneously depleted by nonclimate factors (e.g., adverse market conditions that can deplete insurer loss reserves by eroding the value of securities and other insurer assets). There is high confidence that climate change and anticipated changes in weather-related events that are perceived to be linked to climate change would increase actuarial uncertainty in risk assessment and thus in the functioning of insurance markets. Such developments would place upward pressure on premiums and/or could cause certain risks to be reclassified as uninsurable, with subsequent withdrawal of coverage. This, in turn, would place increased pressure on government-based insurance and relief systems, which already are showing strain in many regions and are attempting to limit their exposures (e.g., by raising deductibles and/or placing caps on maximum claims payable).

Trends toward increasing firm size, diversification, and integration of insurance with other financial services, as well as improved tools to transfer risk, all potentially contribute to robustness. However, the property/casualty insurance and reinsurance segments have greater sensitivity, and individual companies already have experienced catastrophe-related bankruptcies triggered by weather events. Under some conditions and in some regions, the banking industry as a provider of loans also may be vulnerable to climate change. In many cases, however, the banking sector transfers risk back to insurers, who often purchase their debt products. [8.3, 8.4, 15.2.7]

Adaptation[2] to climate change presents complex challenges, as well as opportunities, for the financial services sector. Regulatory involvement in pricing, tax treatment of reserves, and the (in)ability of firms to withdraw from at-risk markets are examples of factors that influence the resilience of the sector. Management of climate-related risk varies by country and region. Usually it is a mixture of commercial and public arrangements and self-insurance. In the face of climate change, the relative role of each can be expected to change. Some potential response options offer co-benefits that support sustainable development and climate change mitigation objectives (e.g., energy-efficiency measures that also make buildings more resilient to natural disasters, in addition to helping the sector adapt to climate changes). [8.3.4, 8.4.2]

The effects of climate change are expected to be greatest in developing countries (especially those that rely on primary production as a major source of income) in terms of loss of life,

[2] The term "mitigation" often is used in the insurance and financial services sectors in much the same way as the term "adaptation" is used in the climate research and policy communities.



Decade Comparison (losses in US$ billion, 1999 values)

	1950–59	1960–69	1970–79	1980–89	1990–99	Factor 90s:50s	Factor 90s:60s
Number							
Weather-Related	13	16	29	44	72	5.5	4.5
Non-Weather-Related	7	11	18	19	17	2.4	1.5
Economic Losses	38.7	50.8	74.5	118.4	399	10.3	7.9
Insured Losses	0/unknown	6.7	10.8	21.6	91.9	—	13.6

Figure TS-5: The costs of catastrophic weather events have exhibited a rapid upward trend in recent decades. Yearly economic losses from large events increased 10.3-fold from US$4 billion yr^{-1} in the 1950s to US$40 billion yr^{-1} in the 1990s (all in 1999 US$). The insured portion of these losses rose from a negligible level to US$9.2 billion annually during the same period, and the ratio of premiums to catastrophe losses fell by two-thirds. Notably, costs are larger by a factor of 2 when losses from ordinary, noncatastrophic weather-related events are included. The numbers generally include "captive" self-insurers but not the less-formal types of self-insurance.

effects on investment, and effects on the economy. Damages from natural disasters have been as high as half of the gross domestic product (GDP) in one case. Weather disasters set back development, particularly when funds are redirected from development projects to disaster-recovery efforts. [8.5]

Equity issues and development constraints would arise if weather-related risks become uninsurable, insurance prices increase, or the availability of insurance or financing becomes limited. Thus, increased uncertainty could constrain development. Conversely, more extensive penetration of or access to insurance and disaster preparedness/recovery resources would increase the ability of developing countries to adapt to climate change. More widespread introduction of microfinancing schemes and development banking also could be an effective mechanism to help developing countries and communities adapt. [8.3]

This assessment of financial services has identified some areas of improved knowledge and has corroborated and further augmented conclusions reached in the SAR. It also has highlighted many areas where greater understanding is needed—in particular, better analysis of economic losses to determine their causation, assessment of financial resources involved in dealing with climate change damage and adaptation, evaluation of alternative methods to generate such resources, deeper investigation of the sector's vulnerability and resilience to a range of extreme weather event scenarios, and more research into how the sector (private and public elements) could innovate to meet the potential increase in demand for adaptation funding in developed and developing countries, to spread and reduce risks from climate change. [8.7]

4.7. Human Health

Global climate change will have diverse impacts on human health—some positive, most negative. Changes in the frequencies of extreme heat and cold, the frequencies of floods and droughts, and the profile of local air pollution and aeroallergens would affect population health directly. Other health impacts would result from the impacts of climate change on ecological and social systems. These impacts would include changes in infectious disease occurrence, local food production and undernutrition, and various health consequences of population displacement and economic disruption.

There is little published evidence that changes in population health status actually have occurred in response to observed trends in climate over recent decades. A recurring difficulty in identifying such impacts is that the causation of most human health disorders is multifactorial, and the "background" socioeconomic, demographic, and environmental context changes significantly over time.

Studies of the health impacts associated with interannual climate variability (particularly those related to the El Niño *cycle) have provided new evidence of human health sensitivity to climate, particularly for mosquito-borne diseases.* The combination of existing research-based knowledge, resultant theoretical understandings, and the output of predictive modeling leads to several conclusions about the future impacts of climate change on human population health.

If heat waves increase in frequency and intensity, the risk of death and serious illness would increase, principally in older age groups and the urban poor (high confidence). The effects of an increase in heat waves often would be exacerbated by increased humidity and urban air pollution. The greatest increases in thermal stress are forecast for mid- to high-latitude (temperate) cities, especially in populations with nonadapted architecture and limited air conditioning. Modeling of heat wave impacts in urban populations, allowing for acclimatization, suggests that a number of U.S. cities would experience, on average, several hundred extra deaths each summer. Although the impact of climate change on thermal stress-related mortality in developing country cities may be significant, there has been little research in such populations. Warmer winters and fewer cold spells will decrease cold-related mortality in many temperate countries (high confidence). Limited evidence indicates that in at least some temperate countries, reduced winter deaths would outnumber increased summer deaths (medium confidence). [9.4]

Any increases in the frequency and intensity of extreme events such as storms, floods, droughts, and cyclones would adversely impact human health through a variety of pathways. These natural hazards can cause direct loss of life and injury and can affect health indirectly through loss of shelter, population displacement, contamination of water supplies, loss of food production (leading to hunger and malnutrition), increased risk of infectious disease epidemics (including diarrhoeal and respiratory disease), and damage to infrastructure for provision of health services (very high confidence). If cyclones were to increase regionally, devastating impacts often would occur, particularly in densely settled populations with inadequate resources. Over recent years, major climate-related disasters have had major adverse effects on human health, including floods in China, Bangladesh, Europe, Venezuela, and Mozambique, as well as Hurricane Mitch, which devastated Central America. [9.5]

Climate change will decrease air quality in urban areas with air pollution problems (medium confidence). An increase in temperature (and, in some models, ultraviolet radiation) increases the formation of ground-level ozone, a pollutant with well-established adverse effects on respiratory health. Effects of climate change on other air pollutants are less well established. [9.6]

Higher temperatures, changes in precipitation, and changes in climate variability would alter the geographic ranges and seasonality of transmission of vector-borne infectious diseases—extending the range and season for some infectious diseases and contracting them for others. Vector-borne infectious diseases are transmitted by blood-feeding organisms such as mosquitoes and ticks. Such organisms depend on the complex interaction of climate and other ecological factors for survival. Currently, 40% of the world population lives in areas with malaria. In areas with limited or deteriorating public health infrastructure, increased temperatures will tend to expand the geographic range of malaria transmission to higher altitudes (high to medium confidence) and higher latitudes (medium to low confidence). Higher temperatures, in combination with conducive patterns of rainfall and surface water, will extend the transmission season in some locations (high confidence). Changes in climate, including changes in climate variability, would affect many other vector-borne infections (such as dengue, leishmansiasis, various types of mosquito-borne encephalitis, Lyme disease, and tick-borne encephalitis) at the margins of their current distributions (medium/high confidence). For some vector-borne diseases in some locations, climate change will decrease transmission via reductions in rainfall or temperatures that are too high for transmission (medium confidence). A range of mathematical models indicate, with high consistency, that climate change scenarios over the coming century would cause a small net increase in the proportion of the world's population living in regions of potential transmission of malaria and dengue (medium to high confidence). A change in climatic conditions will increase the incidence of various types of water- and food-borne infectious diseases. [9.7]

Climate change may cause changes in the marine environment that would alter risks of biotoxin poisoning from human consumption of fish and shellfish. Biotoxins associated with warmer waters, such as ciguatera in tropical waters, could extend their range to higher latitudes (low confidence). Higher SSTs also would increase the occurrence of toxic algal blooms (medium confidence), which have complex relationships with human poisoning and are ecologically and economically damaging. Changes in surface water quantity and quality will affect the incidence of diarrhoeal diseases (medium confidence). [9.8]

Changes in food supply resulting from climate change could affect the nutrition and health of the poor in some regions of the world. Studies of climate change impacts on food production indicate that, globally, impacts could be positive or negative, but the risk of reduced food yields is greatest in developing countries—where 790 million people are estimated to be undernourished at present. Populations in isolated areas with poor access to markets will be particularly vulnerable to local decreases or disruptions in food supply. Undernourishment is a fundamental cause of stunted physical and intellectual development in children, low productivity in adults, and susceptibility to infectious disease. Climate change would increase the number of undernourished people in the developing world (medium confidence), particularly in the tropics. [9.9, 5.3]

In some settings, the impacts of climate change may cause social disruption, economic decline, and population displacement that would affect human health. Health impacts associated with population displacement resulting from natural disasters

Table TS-5*: Options for adaptation to reduce health impacts of climate change.*

Health Outcome	Legislative	Technical	Educational-Advisory	Cultural and Behavioral
Thermal stress	– Building guidelines	– Housing, public buildings, urban planning to reduce heat island effects, air conditioning	– Early warning systems	– Clothing, siesta
Extreme weather events	– Planning laws – Building guidelines – Forced migration – Economic incentives for building	– Urban planning – Storm shelters	– Early warning systems	– Use of storm shelters
Air quality	– Emission controls – Traffic restrictions	– Improved public transport, catalytic converters, smoke stacks	– Pollution warnings	– Carpooling
Vector-borne diseases		– Vector control – Vaccination, impregnated bednets – Sustainable surveillance, prevention and control programs	– Health education	– Water storage practices
Water-borne diseases	– Watershed protection laws – Water quality regulation	– Genetic/molecular screening of pathogens – Improved water treatment (e.g., filters) – Improved sanitation (e.g., latrines)	– Boil water alerts	– Washing hands and other hygiene behavior – Use of pit latrines

or environmental degradation are substantial (high confidence). [9.10]

For each anticipated adverse health impact there is a range of social, institutional, technological, and behavioral adaptation options to lessen that impact (see Table TS-5). Overall, the adverse health impacts of climate change will be greatest in vulnerable lower income populations, predominately within tropical/subtropical countries. There is a basic and general need for public health infrastructure (programs, services, surveillance systems) to be strengthened and maintained. The ability of affected communities to adapt to risks to health also depends on social, environmental, political, and economic circumstances. [9.11]

5. Regional Analysis

The vulnerability of human populations and natural systems to climate change differs substantially across regions and across populations within regions. Regional differences in baseline climate and expected climate change give rise to different exposures to climate stimuli across regions. The natural and social systems of different regions have varied characteristics, resources, and institutions and are subject to varied pressures that give rise to differences in sensitivity and adaptive capacity. From these differences emerge different key concerns for each of the major regions of the world. Even within regions, however, impacts, adaptive capacity, and vulnerability will vary. Because available studies have not employed a common set of climate scenarios and methods and because of uncertainties regarding the sensitivities and adaptability of natural and social systems, assessment of regional vulnerabilities is necessarily qualitative.

5.1. Africa

Africa is highly vulnerable to climate change. Impacts of particular concern to Africa are related to water resources, food production, human health, desertification, and coastal zones, especially in relation to extreme events. A synergy of land-use and climate change will exacerbate desertification. Selected key impacts in Africa are highlighted in Figure TS-6.

5.1.1. Water Resources

Water resources are a key area of vulnerability in Africa, affecting water supply for household use, agriculture, and industry. In shared river basins, regional cooperation protocols minimize adverse impacts and potential for conflicts. Trends in regional per capita water availability in Africa over the past half century show that water availability has diminished by 75%. Although the past 2 decades have experienced reductions in river flows, especially in sub-Saharan West Africa, the trend mainly reflects the impact of population growth—which, for most countries, quadrupled in the same period. Population growth and degradation of water quality are significant threats to water security in many parts of Africa, and the combination of continued population increases and global warming impacts is likely to accentuate water scarcity in subhumid regions of Africa.

Africa is the continent with the lowest conversion factor of precipitation to runoff, averaging 15%. Although the equatorial region and coastal areas of eastern and southern Africa are humid, the rest of the continent is dry subhumid to arid. The dominant impact of global warming will be a reduction in soil moisture in subhumid zones and a reduction in runoff. Current trends in major river basins indicate decreasing runoff of about 17% over the past decade.

Most of Africa has invested significantly in hydroelectric power facilities to underpin economic development. Reservoir storage shows marked sensitivity to variations in runoff and periods of drought. Lake storage and major dams have reached critical levels, threatening industrial activity. Model results and some reservoirs and lakes indicate that global warming will increase the frequency of such low storage as a result of flooding or drought conditions that are related to ENSO. [10.2.1]

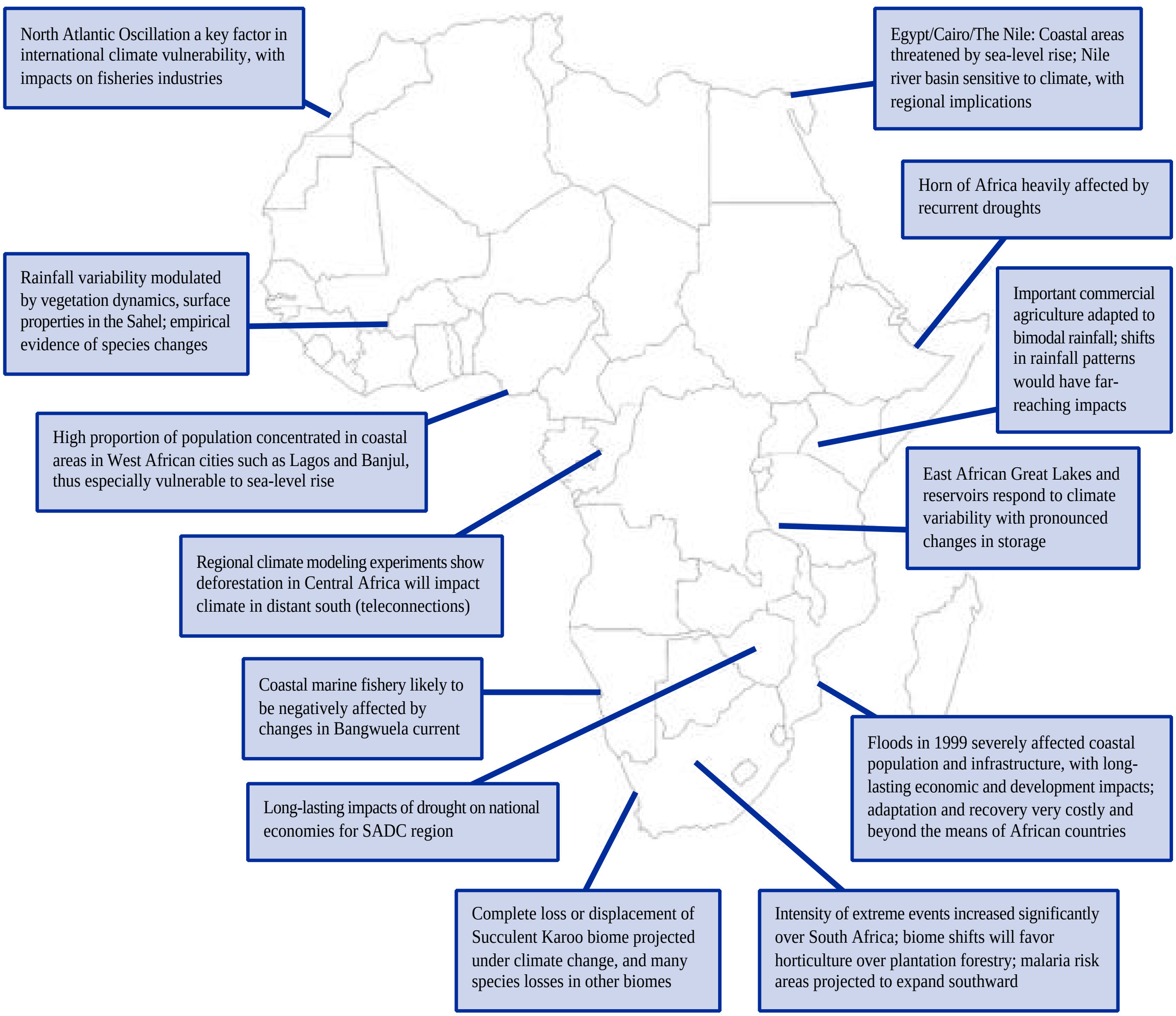


Figure TS-6: Selected key impacts for Africa.

5.1.2. Food Security

There is wide consensus that climate change will worsen food security, mainly through increased extremes and temporal/spatial shifts. The continent already experiences a major deficit in food production in many areas, and potential declines in soil moisture will be an added burden. Food-insecure countries are at a greater risk of adverse impacts of climate change. Inland and marine fisheries provide a significant contribution to protein intake in many African countries. As a result of water stress and land degradation, inland fisheries will be rendered more vulnerable to episodic drought and habitat destruction. Ocean warming is likely to impact coastal marine fisheries. [10.2.2]

5.1.3. Natural Resource Management and Biodiversity

Irreversible losses of biodiversity could be accelerated with climate change. Climate change is expected to lead to drastic shifts of biodiversity-rich biomes such as the Succulent Karoo in South Africa and many losses in species in other biomes. Changes in the frequency, intensity, and extent of vegetation fires and habitat modification from land-use change may negate natural adaptive processes and lead to extinctions. Changes in ecosystems will affect water supply, fuelwood, and other services. [10.2.3.2]

5.1.4. Human Health

Changes in temperature and rainfall will have many negative impacts on human health. Temperature increases will extend disease vector habitats. Where sanitary infrastructure is inadequate, droughts and flooding will result in increased frequency of water-borne diseases. Increased rainfall could lead to more frequent outbreaks of Rift Valley fever. Poor sanitation in urban locations and increased temperatures of coastal waters could aggravate cholera epidemics. [10.2.4.1.1, 10.2.4.4]

5.1.5. Settlements and Infrastructure

Although the basic infrastructure for development—transport, housing, and services—is inadequate in many instances, it nevertheless represents substantial investment by governments. An increase in the frequency of damaging floods, heat waves, dust storms, hurricanes, and other extreme events could degrade the integrity of such critical infrastructures at rates the economies may not be able to tolerate, leading to a serious deterioration of social, health, and economic services delivery systems. This condition will greatly compromise general human welfare. [10.2.5.3]

Sea-level rise, coastal erosion, saltwater intrusion, and flooding will have significant impacts for African communities and economies. Most of Africa's largest cities are along coasts and are highly vulnerable to extreme events, sea-level rise, and coastal erosion because of inadequate physical planning and escalating urban drift. Rapid unplanned expansion is likely to predispose large populations to infectious diseases from climate-related factors such as flooding. [10.2.5.2]

5.1.6. Desertification

Alteration of spatial and temporal patterns in temperature, rainfall, solar radiation, and winds from a changing climate will exacerbate desertification. Desertification is a critical threat to sustainable resource management in arid, semi-arid, and dry subhumid regions of Africa, undermining food and water security. [10.2.6]

5.1.7. Adaptive Capacity

Given the diversity of constraints facing many nations, the overall capacity for Africa to adapt to climate change currently is very low. National action plans that incorporate long-term changes and pursue "no regrets" strategies could increase the adaptive capacity of the region. Seasonal forecasting—for example, linking SSTs to outbreaks of major diseases—is a promising adaptive strategy that will help save lives. Current technologies and approaches, especially in agriculture and water, are unlikely to be adequate to meet projected demands, and increased climate variability will be an additional stress. It is unlikely that African countries on their own will have sufficient resources to respond effectively.

Climate change also offers some opportunities. The processes of adapting to global climate change, including technology transfer and carbon sequestration, offer new development pathways that could take advantage of Africa's resources and human potential. Regional cooperation in science, resource management, and development already are increasing, and access to international markets will diversify economies and increase food security.

This assessment of vulnerability to climate change is marked by uncertainty. The diversity of African climates, high rainfall variability, and a very sparse observational network make predictions of future climate change difficult at the subregional and local level. Underlying exposure and vulnerability to climatic changes are well established. Sensitivity to climatic variations is established but incomplete. However, uncertainty over future conditions means that there is low confidence in projected costs of climate change. This assessment can create the framework for individual states to begin to construct methodologies for estimating such costs, based on their individual circumstances.

5.2. Asia

Climate change will impose significant stress on resources throughout the Asian region. Asia has more than 60% of the world's population; natural resources already are under stress,

Table TS-6*: Sensitivity of selected Asian regions to climate change.*

Change in Climatic Elements and Sea-Level Rise	**Vulnerable Region**	**Primary Change**	**Impacts** Primary	Secondary
0.5–2°C (10- to 45-cm sea-level rise)	Bangladesh Sundarbans	– Inundation of about 15% (~750 km²) – Increase in salinity	– Loss of plant species – Loss of wildlife	– Economic loss – Exacerbated insecurity and loss of employment
4°C (+10% rainfall)	Siberian permafrosts	– Reduction in continuous permafrost – Shift in southern limit of Siberian permafrost by ~100–200 km northward	– Change in rock strength – Change in bearing capacity – Change in compressibility of frozen rocks – Thermal erosion	– Effects on construction industries – Effects on mining industry – Effects on agricultural development
>3°C (>+20% rainfall)	Water resources in Kazakhstan	– Change in runoff	– Increase in winter floods – Decrease in summer flows	– Risk to life and property – Summer water stress
~2°C (-5 to 10% rainfall; 45-cm sea-level rise)	Bangladesh lowlands	– About 23–29% increase in extent of inundation	– Change in flood depth category – Change in monsoon rice cropping pattern	– Risk to life and property – Increased health problems – Reduction in rice yield

and the resilience of most sectors in Asia to climate change is poor. Many countries are socioeconomically dependent on natural resources such as water, forests, grassland and rangeland, and fisheries. The magnitude of changes in climate variables would differ significantly across Asian subregions and countries. The climate change sensitivity of a few vulnerable sectors in Asia and the impacts of these limits are presented in Table TS-6. The region's vulnerability to climate change is captured in Table TS-7 for selected categories of regions/issues.

5.2.1. Agriculture and Food Security

Food insecurity appears to be the primary concern for Asia. Crop production and aquaculture would be threatened by thermal and water stresses, sea-level rise, increased flooding, and strong winds associated with intense tropical cyclones (high confidence). In general, it is expected that areas in mid- and high latitudes will experience increases in crop yield; yields in lower latitudes generally will decrease. A longer duration of the summer season should lead to a northward shift of the agroecosystem boundary in boreal Asia and favor an overall increase in agriculture productivity (medium confidence). Climatic variability and change also will affect scheduling of the cropping season, as well as the duration of the growing period of the crop. In China, yields of several major crops are expected to decline as a result of climate change. Acute water shortages combined with thermal stress should adversely affect wheat and, more severely, rice productivity in India even under the positive effects of elevated CO_2 in the future. Crop diseases such as wheat scab, rice blast, and sheath and culm blight of rice also could become more widespread in temperate and tropical regions of Asia if the climate becomes warmer and wetter. Adaptation measures to reduce the negative effects of climatic variability may include changing the cropping calendar to take advantage of the wet period and to avoid the extreme weather events (e.g., typhoons and strong winds) during the growing season. [11.2.2.1]

Asia dominates world aquaculture, producing 80% of all farmed fish, shrimp, and shellfish. Many wild stocks are under stress as a result of overexploitation, trawling on sea-bottom habitats, coastal development, and pollution from land-based activities. Moreover, marine productivity is greatly affected by plankton shift, such as seasonal shifting of sardine in the Sea of Japan, in response to temperature changes induced during ENSO. Storm surges and cyclonic conditions also routinely lash the coastline, adding sediment loads to coastal waters. Effective conservation and sustainable management of marine and inland fisheries are needed at the regional level so that living aquatic resources can continue to meet regional and national nutritional needs. [11.2.4.4]

5.2.2. Ecosystems and Biodiversity

Climate change would exacerbate current threats to biodiversity resulting from land-use/cover change and population pressure in Asia (medium confidence). Risks to Asia's rich array of living species are climbing. As many as 1,250 of 15,000 higher plant species are threatened in India. Similar trends are evident in China, Malaysia, Myanmar, and Thailand. Many species and a

***Table TS-7**: Vulnerability of key sectors to impacts of climate change for select subregions in Asia. Key to confidence-level rankings is provided in Section 1.4 of Technical Summary.*

Regions	Food and Fiber	Biodiversity	Water Resources	Coastal Ecosystems	Human Health	Settlements
Boreal Asia	Slightly resilient ****	Highly vulnerable ***	Slightly resilient ***	Slightly resilient **	Moderately vulnerable **	Slightly or not vulnerable ***
Arid and Semi-Arid Asia						
– Central Asia	Highly vulnerable ****	Moderately vulnerable **	Highly vulnerable ****	Moderately vulnerable **	Moderately vulnerable ***	Moderately vulnerable ***
– Tibetan Plateau	Slightly or not vulnerable **	Highly vulnerable ***	Moderately vulnerable **	Not applicable	No information	No information
Temperate Asia	Highly vulnerable ****	Moderately vulnerable ***	Highly vulnerable ****	Highly vulnerable ****	Highly vulnerable ***	Highly vulnerable ****
Tropical Asia						
– South Asia	Highly vulnerable ****	Highly vulnerable ***	Highly vulnerable ****	Highly vulnerable ****	Moderately vulnerable ***	Highly vulnerable ***
– Southeast Asia	Highly vulnerable ****	Highly vulnerable ***	Highly vulnerable ****	Highly vulnerable ****	Moderately vulnerable ***	Highly vulnerable ***

large population of many other species in Asia are likely to be exterminated as a result of the synergistic effects of climate change and habitat fragmentation. In desert ecosystems, increased frequency of droughts may result in a decline in local forage around oases, causing mass mortality among local fauna and threatening their existence. With a 1-m rise in sea level, the Sundarbans (the largest mangrove ecosystems) of Bangladesh will completely disappear. [11.2.1, 11.2.1.6]

Permafrost degradation resulting from global warming would increase the vulnerability of many climate-dependent sectors affecting the economy in boreal Asia (medium confidence). Pronounced warming in high latitudes of the northern hemisphere could lead to thinning or disappearance of permafrost in locations where it now exists. Large-scale shrinkage of the permafrost region in boreal Asia is likely. Poleward movement of the southern boundary of the sporadic zone also is likely in Mongolia and northeast China. The boundary between continuous and discontinuous (intermittent or seasonal) permafrost areas on the Tibetan Plateau is likely to shift toward the center of the plateau along the eastern and western margins. [11.2.1.5]

The frequency of forest fires is expected to increase in boreal Asia (medium confidence). Warmer surface air temperatures, particularly during summer, may create favorable conditions for thunderstorms and associated lightening, which could trigger forest fires in boreal forests more often. Forest fire is expected to occur more frequently in northern parts of boreal Asia as a result of global warming. [11.2.1.3]

5.2.3. Water Resources

Freshwater availability is expected to be highly vulnerable to anticipated climate change (high confidence). Surface runoff increases during winter and summer periods would be pronounced in boreal Asia (medium confidence). Countries in which water use is more than 20% of total potential water resources available are expected to experience severe water stress during drought periods. Surface runoff is expected to decrease drastically in arid and semi-arid Asia under projected climate change scenarios. Climate change is likely to change streamflow volume, as well as the temporal distribution of streamflows throughout the year. With a 2°C increase in air temperature accompanied by a 5–10% decline in precipitation during summer, surface runoff in Kazakhstan would be substantially reduced, causing serious implications for agriculture and livestocks. Water would be a scarce commodity in many south and southeast Asian countries, particularly where reservoir facilities to store water for irrigation are minimal. Growing populations and concentration of populations in urban areas will exert increasing pressures on water availability and water quality. [11.2.3.1]

5.2.4. Extreme Weather Events

Developing countries of temperate and tropical Asia already are quite vulnerable to extreme climate events such as typhoons/cyclones, droughts, and floods. Climate change and variability would exacerbate these vulnerabilities (high confidence). Extreme weather events are known to cause adverse effects in widely separated areas of Asia. There is some evidence of increases in the intensity or frequency of some of these extreme events on regional scales throughout the 20th century. [11.1.2.2, 11.1.2.3, 11.4.1]

Increased precipitation intensity, particularly during the summer monsoon, could increase flood-prone areas in temperate and tropical Asia. There is potential for drier conditions in arid and semi-arid Asia during summer, which could lead to more severe droughts (medium confidence). Many countries in temperate and tropical Asia have experienced severe droughts and floods frequently in the 20th century. Flash floods are likely to become more frequent in many regions of temperate and tropical Asia in the future. A decrease in return period for extreme precipitation events and the possibility of more frequent floods in parts of India, Nepal, and Bangladesh is projected. [11.1.3.3, 11.2.2.2, 11.1.2.3, 11.4.1]

Conversion of forestland to cropland and pasture already is a prime force driving forest loss in tropical and temperate Asian countries. With more frequent floods and droughts, these actions will have far-reaching implications for the environment (e.g., soil erosion, loss of soil fertility, loss of genetic variability in crops, and depletion of water resources). [11.1.4.1]

Tropical cyclones and storm surges continue to take a heavy toll on life and property in India and Bangladesh. An increase in the intensity of cyclones combined with sea-level rise would result in more loss of life and property in low-lying coastal areas in cyclone-prone countries of Asia (medium confidence). The expected increase in the frequency and intensity of climatic extremes will have significant potential effects on crop growth and agricultural production, as well as major economic and environmental implications (e.g., tourism, transportation). [11.2.4.5, 11.2.6.3, 11.3]

Awide range of precautionary measures at regional and national levels, including awareness and acceptance of risk factors among regional communities, is warranted to avert or reduce the impacts of disasters associated with more extreme weather events on economic and social structures of countries in temperate and tropical Asia. [11.3.2]

5.2.5. Deltas and Coastal Zones

The large deltas and low-lying coastal areas of Asia would be inundated by sea-level rise (high confidence). Climate-related stresses in coastal areas include loss and salinization of agricultural land as a result of change in sea level and changing frequency and intensity of tropical cyclones. Estimates of potential land loss resulting from sea-level rise and risk to population displacement provided in Table TS-8 demonstrate the scale of the issue for major low-lying regions of coastal Asia. Currently, coastal erosion of muddy coastlines in Asia is not a result of sea-level rise; it is triggered largely by annual river-borne suspended sediments transported into the ocean by human activities and delta evolution. These actions could exacerbate the impacts of climate change in coastal regions of Asia. [11.2.4.2]

5.2.6. Human Health

Warmer and wetter conditions would increase the potential for higher incidence of heat-related and infectious diseases in tropical and temperate Asia (medium confidence). The rise in surface air temperature and changes in precipitation in Asia will have adverse effects on human health. Although warming would result in a reduction in wintertime deaths in temperate countries, there could be greater frequency and duration of heat stress, especially in megalopolises during summer. Global warming also will increase the incidence of respiratory and cardiovascular diseases in parts of arid and semi-arid Asia and temperate and tropical Asia. Changes in environmental temperature and precipitation could expand vector-borne diseases into temperate and arid Asia. The spread of vector-borne diseases into more northern latitudes may pose a serious

***Table TS-8**: Potential land loss and population exposed in Asian countries for selected magnitudes of sea-level rise, assuming no adaptation.*

Country	Sea-Level Rise (cm)	Potential Land Loss (km²)	Potential Land Loss (%)	Population Exposed (million)	Population Exposed (%)
Bangladesh	45	15,668	10.9	5.5	5.0
	100	29,846	20.7	14.8	13.5
India	100	5,763	0.4	7.1	0.8
Indonesia	60	34,000	1.9	2.0	1.1
Japan	50	1,412	0.4	2.9	2.3
Malaysia	100	7,000	2.1	>0.05	>0.3
Pakistan	20	1,700	0.2	n.a.	n.a.
Vietnam	100	40,000	12.1	17.1	23.1

threat to human health. Warmer SSTs along Asian coastlines would support higher phytoplankton blooms. These blooms are habitats for infectious bacterial diseases. Waterborne diseases—including cholera and the suite of diarrheal diseases caused by organisms such as giardia, salmonella, and cryptosporidium—could become more common in many countries of south Asia in warmer climate. [11.2.5.1, 11.2.5.2, 11.2.5.4]

5.2.7. Adaptive Capacity

Adaptation to climate change in Asian countries depends on the affordability of adaptive measures, access to technology, and biophysical constraints such as land and water resource availability, soil characteristics, genetic diversity for crop breeding (e.g., crucial development of heat-resistant rice cultivars), and topography. Most developing countries of Asia are faced with increasing population, spread of urbanization, lack of adequate water resources, and environmental pollution, which hinder socioeconomic activities. These countries will have to individually and collectively evaluate the tradeoffs between climate change actions and nearer term needs (such as hunger, air and water pollution, energy demand). Coping strategies would have to be developed for three crucial sectors: land resources, water resources, and food productivity. Adaptation measures that are designed to anticipate the potential effects of climate change can help offset many of the negative effects. [11.3.1]

5.3. Australia and New Zealand

The Australia/New Zealand region spans the tropics to mid-latitudes and has varied climates and ecosystems, including deserts, rainforests, coral reefs, and alpine areas. The climate is strongly influenced by the surrounding oceans. Australia has significant vulnerability to the drying trend projected over much of the country for the next 50–100 years (Figure TS-3) because substantial agricultural areas currently are adversely affected by periodic droughts, and there already are large areas of arid and semi-arid land. New Zealand—a smaller, more mountainous country with a generally more temperate, maritime climate—may be more resilient to climate changes than Australia, although considerable vulnerability remains (medium confidence). Table TS-9 shows key vulnerabilities and adaptability to climate change impacts for Australia and New Zealand. [12.9.5]

Comprehensive cross-sectoral estimates of net climate change impact costs for various GHG emission scenarios and different societal scenarios are not yet available. Confidence remains very low in the IPCC *Special Report on Regional Impacts of Climate Change* estimate for Australia and New Zealand of -1.2 to -3.8% of GDP for an equivalent doubling of CO_2 concentrations. This estimate did not account for many of the effects and adaptations currently identified. [12.9]

Extreme events are a major source of current climate impacts, and changes in extreme events are expected to dominate the impacts of climate change. Return periods for heavy rains, floods, and sea-level surges of a given magnitude at particular locations would be modified by possible increases in intensity of tropical cyclones and heavy rain events and changes in the location-specific frequency of tropical cyclones. Scenarios of climate change that are based on recent coupled atmosphere-ocean (A-O) models suggest that large areas of mainland Australia will experience significant decreases in rainfall during the 21st century. The ENSO phenomenon leads to floods and prolonged droughts, especially in inland Australia and parts of New Zealand. The region would be sensitive to a changes towards a more El Niño-like mean state. [12.1.5]

Before stabilization of GHG concentrations, the north-south temperature gradient in mid-southern latitudes is expected to increase (medium to high confidence), strengthening the westerlies and the associated west-to-east gradient of rainfall across Tasmania and New Zealand. Following stabilization of GHG concentrations, these trends would be reversed (medium confidence). [12.1.5.1]

Climate change will add to existing stresses on achievement of sustainable land use and conservation of terrestrial and aquatic biodiversity. These stresses include invasion by exotic animal and plant species, degradation and fragmentation of natural ecosystems through agricultural and urban development, dryland salinization (Australia), removal of forest cover (Australia and New Zealand), and competition for scarce water resources. Within both countries, economically and socially disadvantaged groups of people, especially indigenous peoples, are particularly vulnerable to stresses on health and living conditions induced by climate change. Major exacerbating problems include rapid population and infrastructure growth in vulnerable coastal areas, inappropriate use of water resources, and complex institutional arrangements. [12.3.2, 12.3.3, 12.4.1, 12.4.2, 12.6.4, 12.8.5]

5.3.1. Water Resources

Water resources already are stressed in some areas and therefore are highly vulnerable, especially with respect to salinization (parts of Australia) and competition for water supply between agriculture, power generation, urban areas, and environmental flows (high confidence). Increased evaporation and possible decreases in rainfall in many areas would adversely affect water supply, agriculture, and the survival and reproduction of key species in parts of Australia and New Zealand (medium confidence). [12.3.1, 12.3.2, 12.4.6, 12.5.2, 12.5.3, 12.5.6]

5.3.2. Ecosystems

A warming of 1°C would threaten the survival of species that currently are growing near the upper limit of their temperature range, notably in marginal alpine regions and in the southwest of Western Australia. Species that are unable to migrate or relocate because of land clearing, soil differences, or topography could become endangered or extinct. Other Australian ecosystems

***Table TS-9**: Main areas of vulnerability and adaptability to climate change impacts in Australia and New Zealand. Degree of confidence that tabulated impacts will occur is indicated by stars in second column (see Section 1.4 of Technical Summary for key to confidence-level rankings). Confidence levels, and assessments of vulnerability and adaptability, are based on information reviewed in Chapter 12, and assume continuation of present population and investment growth patterns.*

Sector	Impact	Vulnerability	Adaptation	Adaptability	Section
Hydrology and water supply	– Irrigation and metropolitan supply constraints, and increased salinization—****	High in some areas	– Planning, water allocation, and pricing	Medium	12.3.1, 12.3.2
	– Saltwater intrusion into some island and coastal aquifers—****	High in limited areas	– Alternative water supplies, retreat	Low	12.3.3
Terrestrial ecosystems	– Increased salinization of dryland farms and some streams (Australia)—***	High	– Changes in land-use practices	Low	12.3.3
	– Biodiversity loss notably in fragmented regions, Australian alpine areas, and southwest of WA—****	Medium to high in some areas	– Landscape management; little possible in alpine areas	Medium to low	12.4.2, 12.4.4, 12.4.8
	– Increased risk of fires—***	Medium	– Land management, fire protection	Medium	12.1.5.3, 12.5.4, 12.5.10
	– Weed invasion—***	Medium	– Landscape management	Medium	12.4.3
Aquatic ecosystems	– Salinization of some coastal freshwater wetlands—***	High	– Physical intervention	Low	12.4.7
	– River and inland wetland ecosystem changes—***	Medium	– Change water allocations	Low	12.4.5, 12.4.6
	– Eutrophication—***	Medium in inland Aus. waters	– Change water allocations, reduce nutrient inflows	Medium to low	12.3.4
Coastal ecosystems	– Coral bleaching, especially Great Barrier Reef—****	High	– Seed coral?	Low	12.4.7
	—More toxic algal blooms?—*	Unknown	—	—	12.4.7
Agriculture, grazing, and forestry	– Reduced productivity, increased stress on rural communities if droughts increase, increased forest fire risk—***	Location-dependent, worsens with time	– Management and policy changes, fire prevention, seasonal forecasts	Medium	12.5.2, 12.5.3, 12.5.4
	– Changes in global markets due to climate changes elsewhere—***, but sign uncertain	High, but sign uncertain	– Marketing, planning, niche and fuel crops, carbon trading	Medium	12.5.9
	– Increased spread of pests and diseases—****	Medium	– Exclusion, spraying	Medium	12.5.7
	– Increased CO_2 initially increases productivity but offset by climate changes later—**	Changes with time	– Change farm practices, change industry		12.5.3, 12.5.4
Horticulture	– Mixed impacts (+ and -), depends on species and location—****	Low overall	– Relocate	High	12.5.3

Table TS-9 (continued)

Sector	Impact	Vulnerability	Adaptation	Adaptability	Section
Fish	– Recruitment changes (some species)—**	Unknown net effect	– Monitoring, management	—	12.5.5
Settlements and industry	– Increased impacts of flood, storm, storm surge, sea-level rise—***	High in some places	– Zoning, disaster planning	Moderate	12.6.1, 12.6.4
Human health	– Expansion and spread of vector-borne diseases—****	High	– Quarantine, eradication, or control	Moderate to high	12.7.1, 12.7.4
	– Increased photochemical air pollution—****	Moderate (some cities)	– Emission controls	High	12.7.1

that are particularly vulnerable include coral reefs and arid and semi-arid habitats. Freshwater wetlands in coastal zones in Australia and New Zealand are vulnerable, and some New Zealand ecosystems are vulnerable to accelerated spread of weeds. [12.4.2, 12.4.3, 12.4.4, 12.4.5, 12.4.7]

5.3.3. *Food Production*

Agricultural activities are particularly vulnerable to regional reductions in rainfall in southwest and inland Australia (medium confidence). Drought frequency and consequent stresses on agriculture are likely to increase in parts of Australia and New Zealand as a result of higher temperatures and El Niño changes (medium confidence). Enhanced plant growth and water-use efficiency (WUE) resulting from CO_2 increases may provide initial benefits that offset any negative impacts from climate change (medium confidence), although the balance is expected to become negative with warmings in excess of 2-4°C and associated rainfall changes (medium confidence). This is illustrated in Figure TS-7 for wheat production in Australia, for a range of climate change scenarios. Reliance on exports of agricultural and forest products makes the region very sensitive to changes in production and commodity prices that are induced by changes in climate elsewhere. [12.5.2, 12.5.3, 12.5.6, 12.5.9, 12.8.7]

Australian and New Zealand fisheries are influenced by the extent and location of nutrient upwellings governed by prevailing winds and boundary currents. In addition, ENSO influences recruitment of some fish species and the incidence of toxic algal blooms. [12.5.5]

5.3.4. *Settlements, Industry, and Human Health*

Marked trends toward greater population and investment in exposed regions are increasing vulnerability to tropical cyclones and storm surges. Thus, projected increases in tropical cyclone intensity and possible changes in their location-specific frequency, along with sea-level rise, would have major impacts—notably, increased storm-surge heights for a given return period (medium to high confidence). Increased frequency of high-intensity rainfall would increase flood damages to settlements and infrastructure (medium confidence). [12.1.5.1, 12.1.5.3, 12.6.1, 12.6.4]

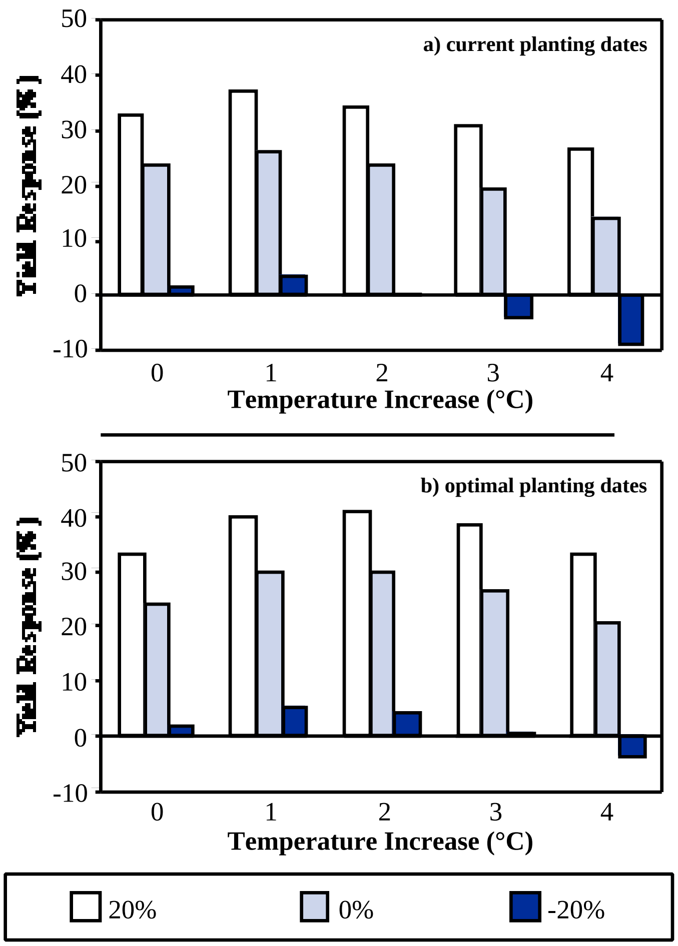


Figure TS-7: Percentage change in average annual total Australian wheat yield for CO_2 (levels of 700 ppm) and a range of changes in temperature and rainfall: a) current planting dates, and b) optimal planting dates. Yield response is shown for rainfall changes of +20% (white), 0 (light blue), and -20% (dark blue), for warmings of 0-4°C.

There is high confidence that projected climate changes will enhance the spread of some disease vectors, thereby increasing the potential for disease outbreaks such as mosquito-borne Ross River virus and Murray Valley encephalitis, despite existing biosecurity and health services. [12.7.1]

5.3.5. Key Adaptation Options

Key adaptation options include improved WUE and effective trading mechanisms for water; more appropriate land-use policies; provision of climate information and seasonal forecasts to land users to help them manage for climate variability and change; improved crop cultivars; revised engineering standards and zoning for infrastructure development; and improved biosecurity and health services. However, many natural ecosystems in Australia and New Zealand have only a limited capacity to adapt, and many managed systems will face limits on adaptation imposed by cost, acceptability, and other factors. [12.3.2, 12.3.3, 12.5.6, 12.7.4, 12.8.4, 12.8.5]

5.4. Europe

Present-day weather conditions affect natural, social, and economic systems in Europe in ways that reveal sensitivities and vulnerabilities to climate change in these systems. Climate change may aggravate such effects (very high confidence). Vulnerability to climate change in Europe differs substantially between subregions. Southern Europe and the European Arctic are more vulnerable than other parts of Europe. More-marginal and less-wealthy areas will be less able to adapt, which leads to important equity implications (very high confidence). Findings in the TAR relating to key vulnerabilities in Europe are broadly consistent with those expressed in the IPCC *Special Report on Regional Impacts of Climate Change* and the SAR, but are more specific about subregional effects and include new information concerning adaptive capacity. [13.1.1, 13.1.4, 13.4]

5.4.1. Water Resources

Water resources and their management in Europe are under pressure now, and these pressures are likely to be exacerbated by climate change (high confidence). Flood hazard is likely to increase across much of Europe—except where snowmelt peak has been reduced—and the risk of water shortage is projected to increase, particularly in southern Europe (medium to high confidence). Climate change is likely to widen water resource differences between northern and southern Europe (high confidence). Half of Europe's alpine glaciers could disappear by the end of the 21st century. [13.2.1]

5.4.2. Ecosystems

Natural ecosystems will change as a result of increasing temperature and atmospheric concentration of CO_2. Permafrost will decline; trees and shrubs will encroach into current northern tundra; and broad-leaved trees may encroach into current coniferous forest areas. Net primary productivity in ecosystems is likely to increase (also as a result of nitrogen deposition), but increases in decomposition resulting from increasing temperature may negate any additional carbon storage. Diversity in nature reserves is under threat from rapid change. Loss of important habitats (wetlands, tundra, and isolated habitats) would threaten some species (including rare/endemic species and migratory birds). Faunal shifts as a result of ecosystem changes are expected in marine, aquatic, and terrestrial ecosystems (high confidence; established but incomplete evidence). [13.2.1.4, 13.2.2.1, 13.2.2.3-5]

Soil properties will deteriorate under warmer and drier climate scenarios in southern Europe. The magnitude of this effect will vary markedly between geographic locations and may be modified by changes in precipitation (medium confidence; established but incomplete evidence). [13.2.1.2]

In mountain regions, higher temperatures will lead to an upward shift of biotic zones. There will be a redistribution of species with, in some instances, a threat of extinction (high confidence). [13.2.1.4]

Timber harvest will increase in commercial forests in northern Europe (medium confidence; established but incomplete evidence), although forest pests and disease may increase. Reductions are likely in the Mediterranean, with increased drought and fire risk (high confidence; well-established evidence). [13.2.2.1]

5.4.3. Agriculture and Food Security

Agricultural yields will increase for most crops as a result of increasing atmospheric CO_2 concentration. This increase in yields would be counteracted by the risk of water shortage in southern and eastern Europe and by shortening of the duration of growth in many grain crops because of increasing temperature. Northern Europe is likely to experience overall positive effects, whereas some agricultural production systems in southern Europe may be threatened (medium confidence; established but incomplete evidence).

Changes in fisheries and aquaculture production resulting from climate change embrace faunal shifts that affect freshwater and marine fish and shellfish biodiversity. These changes will be aggravated by unsustainable exploitation levels and environmental change (high confidence).

5.4.4. Human Settlements and Financial Services

The insurance industry faces potentially costly climate change impacts through the medium of property damage, but there is great scope for adaptive measures if initiatives are taken soon (high confidence). Transport, energy, and other industries will face changing demand and market opportunities. The concentration

***Table TS-10**: Estimates of flood exposure and incidence for Europe's coasts in 1990 and the 2080s. Estimates of flood incidence are highly sensitive to assumed protection standard and should be interpreted in indicative terms only (former Soviet Union excluded).*

		Flood Incidence	
Region	***1990*** **Exposed Population (millions)**	***1990*** Average Number of People Experiencing Flooding (thousands yr^{-1})	***2080s*** Increase due to Sea-Level Rise, Assuming No Adaptation (%)
Atlantic Coast	19.0	19	50 to 9,000
Baltic Coast	1.4	1	0 to 3,000
Mediterranean Coast	4.1	3	260 to 12,0000

of industry on the coast exposes it to sea-level rise and extreme events, necessitating protection or removal (high confidence). [13.2.4]

Recreational preferences are likely to change with higher temperatures. Heat waves are likely to reduce the traditional peak summer demand at Mediterranean holiday destinations. Less-reliable snow conditions will impact adversely on winter tourism (medium confidence). [13.2.4.4]

The risk of flooding, erosion, and wetland loss in coastal areas will increase substantially, with implications for human settlement, industry, tourism, agriculture, and coastal natural habitats. Southern Europe appears to be more vulnerable to these changes, although the North Sea coast already has a high exposure to flooding (high confidence). Table TS-10 provides estimates of flood exposure and risk for Europe's coasts. [13.2.1.3]

5.4.5. Human Health

A range of risks is posed for human health through increased exposure to heat episodes (exacerbated by air pollution in urban areas), extension of some vector-borne diseases, and coastal and riverine flooding. Cold-related risks will be reduced (medium confidence; competing explanations). [13.2.5]

5.4.6. Adaptive Capacity

The adaptation potential of socioeconomic systems in Europe is relatively high because of economic conditions [high gross national product (GNP) and stable growth], a stable population (with the capacity to move within the region), and well-developed political, institutional, and technological support systems. However, the adaptation potential for natural systems generally is low (very high confidence). [13.3]

5.5. Latin America

There is ample evidence of climate variability at a wide range of time scales all over Latin America, from intraseasonal to long-term. In many subregions of Latin America, this variability in climate normally is associated with phenomena that already produce impacts with important socioeconomic and environmental consequences that could be exacerbated by global warming and its associated weather and climate changes.

Variations in precipitation have a strong effect on runoff and streamflow, which are simultaneously affected by melting of glaciers and snow. Precipitation variations and their sign depend on the geographical subregion under consideration. Temperature in Latin America also varies among subregions. Although these variations might depend on the origin and quality of the source data as well as on the record periods used for studies and analyses,some of these variations could be attributed to a climate change condition (low confidence). [14.1.2.1]

ENSO is responsible for a large part of the climate variability at interannual scales in Latin America (high confidence). The region is vulnerable to El Niño, with impacts varying across the continent. For example, El Niño is associated with dry conditions in northeast Brazil, northern Amazonia, the Peruvian-Bolivian Altiplano, and the Pacific coast of Central America. The most severe droughts in Mexico in recent decades have occurred during El Niño years, whereas southern Brazil and northwestern Peru have exhibited anomalously wet conditions. La Niña is associated with heavy precipitation and flooding in Colombia and drought in southern Brazil. If El Niño or La Niña were to increase, Latin America would be exposed to these conditions more often. [14.1.2]

Some subregions of Latin America frequently experience extreme events, and these extraordinary combinations of hydrological and climatic conditions historically have produced disasters in Latin America. Tropical cyclones and associated heavy rain, flooding, and landslides are very common in Central America and southern Mexico. In northwestern South America and northeastern Brazil, many of the extremes that occur are strongly related to El Niño. [14.1.2]

5.5.1. Water Resources

It has been well established that glaciers in Latin America have receded in the past several decades. Warming in high mountain regions could lead to disappearance of significant *snow and ice surface (medium confidence),* which could affect mountain sport and tourist activities. Because these areas contribute to river streamflow, this trend also would reduce water availability for irrigation, hydropower generation, and navigation. [14.2.4]

5.5.2. Ecosystems

It is well established that Latin America accounts for one of the Earth's largest concentrations of biodiversity, and the impacts of climate change can be expected to increase the risk of biodiversity loss (high confidence). Observed population declines in frogs and small mammals in Central America can be related to regional climate change. The remaining Amazonian forest is threatened by the combination of human disturbance, increases in fire frequency and scale, and decreased precipitation from evapotranspiration loss, global warming, and El Niño. Neotropical seasonally dry forest should be considered severely threatened in Mesoamerica.

Tree mortality increases under dry conditions that prevail near newly formed edges in Amazonian forests. Edges, which affect an increasingly large portion of the forest because of increased

Table TS-11*: Assessments of climate change impacts on annual crops in Latin America.*

Study[a]	Climate Scenario	Scope	Crop	Yield Impact (%)
Downing, 1992	+3ºC -25% precipitation	Norte Chico, Chile	Wheat Maize Potato Grapes	decrease increase increase decrease
Baethgen, 1994	GISS, GFDL, UKMO	Uruguay	Wheat Barley	-30 -40 to -30
de Siqueira *et al*., 1994	GISS, GFDL, UKMO	Brazil	Wheat Maize Soybeans	-50 to –15 -25 to –2 -10 to +40
Liverman and O'Brien, 1991	GFDL, GISS	Tlaltizapan, Mexico	Maize	-20 -24 -61
Liverman *et al*., 1994	GISS, GFDL, UKMO	Mexico	Maize	-61 to –6
Sala and Paruelo, 1994	GISS, GFDL, UKMO	Argentina	Maize	-36 to -17
Baethgen and Magrin, 1995	UKMO	Argentina Uruguay (9 sites)	Wheat	-5 to -10
Conde *et al*., 1997a	CCCM, GFDL	Mexico (7 sites)	Maize	increase-decrease
Magrin *et al*., 1997a	GISS, UKMO, GFDL, MPI	Argentina (43 sites)	Maize Wheat Sunflower Soybean	-16 to +2 -8 to +7 -8 to +13 -22 to +21
Hofstadter *et al*., 1997	Incremental	Uruguay	Barley Maize	-10[b] -8 to +5[c] -15[d] -13 to +10[c]

[a] See Chapter 14 reference list for complete source information.
[b] For 1ºC increase.
[c] Change of -20 to +20% in precipitation.
[d] For 2ºC increase.

deforestation, would be especially susceptible to the effects of reduced rainfall.In Mexico, nearly 50% of the deciduous tropical forest would be affected. Heavy rain during the 1997–1998 ENSO event generated drastic changes in dry ecosystems of northern Peru's coastal zone. Global warming would expand the area suitable for tropical forests as equilibrium vegetation types. However, the forces driving deforestation make it unlikely that tropical forests will be permitted to occupy these increased areas. Land-use change interacts with climate through positive-feedback processes that accelerate loss of humid tropical forests. [14.2.1]

5.5.3. Sea-Level Rise

Sea-level rise will affect mangrove ecosystems by eliminating their present habitats and creating new tidally inundated areas to which some mangrove species may shift. This also would affect the region's fisheries because most commercial shellfish and finfish use mangroves for nurseries and refuge. Coastal inundation that stems from sea-level rise and riverine and flatland flooding would affect water availability and agricultural land, exacerbating socioeconomic and health problems in these areas. [14.2.3]

5.5.4. Agriculture

Studies in Argentina, Brazil, Chile, Mexico, and Uruguay—based on GCMs and crop models—project decreased yields for numerous crops (e.g., maize, wheat, barley, grapes) even when the direct effects of CO_2 fertilization and implementation of moderate adaptation measures at the farm level are considered (high confidence). Predicted increases in temperature will reduce crops yields in the region by shortening the crop cycle. Over the past 40 years, the contribution of agriculture to the GDP of Latin American countries has been on the order of 10%. Agriculture remains a key sector in the regional economy because it employs 30–40% of the economically active population. It also is very important for the food security of the poorest sectors of the population. Subsistence farming could be severely threatened in some parts of Latin America, including northeastern Brazil.

It is established but incomplete that climate change would reduce silvicultural yields because lack of water often limits growth during the dry season, which is expected to become longer and more intense in many parts of Latin America. Table TS-11 summarizes studies undertaken on the region for different crops and management conditions, all under rainfed conditions; most of these results predict negative impacts, particularly for maize. [14.2.2]

5.5.5. Human Health

The scale of health impacts from climate change in Latin America would depend primarily on the size, density, location, and wealth of populations. Exposure to heat or cold waves has impacts on mortality rates in risk groups in the region (medium confidence).

Increases in temperature would affect human health in polluted cities such as Mexico City and Santiago, Chile. It is well established that ENSO causes changes in disease vector populations and in the incidence of water-borne diseases in Brazil, Peru, Bolivia, Argentina, and Venezuela. Studies in Peru and Cuba indicate that increases in temperature and precipitation would change the geographical distribution of infectious diseases such as cholera and meningitis (high confidence), although there is speculation about what the changes in patterns of diseases would be in different places. It is well established that extreme events tend to increase death and morbidity rates (injuries, infectious diseases, social problems, and damage to sanitary infrastructure), as shown in Central America with Hurricane Mitch in 1998, heavy rains in Mexico and Venezuela in 1999, and in Chile and Argentina in 2000. [14.2.5]

5.6. North America

North America will experience both positive and negative climate change impacts (high confidence). Varying impacts on ecosystems and human settlements will exacerbate subregional differences in climate-sensitive resource production and vulnerability to extreme events. Opportunities and challenges to adaptation will arise, frequently involving multiple stresses (Table TS-12). Some innovative adaptation strategies are being tested as a response to current climate-related challenges (e.g., water banks), but few cases have examined how these strategies could be implemented as regional climates continue to change. Shifting patterns in temperature, precipitation, disease vectors, and water availability will require adaptive responses—including, for example, investments in storm protection and water supply infrastructure, as well as community health services. [15.3.2, 15.4]

5.6.1. Communities and Urban Infrastructure

Potential changes in the frequency, severity, and duration of extreme events are among the most important risks associated with climate change in North America. Potential impacts of climate change on cities include fewer periods of extreme winter cold; increased frequency of extreme heat; rising sea levels and risk of storm surge; and changes in timing, frequency, and severity of flooding associated with storms and precipitation extremes. These events—particularly increased heat waves and changes in extreme events—will be accompanied by effects on health.

Communities can reduce their vulnerability to adverse impacts through investments in adaptive infrastructure, which can be expensive. Rural, poor, and indigenous communities may not be able to make such investments. Furthermore, infrastructure

***Table TS-12**: Climate change adaptation issues in North American subregions. Some unique issues for certain locations also are indicated.*

North American Subregions	Development Context	Climate Change Adaptation Options and Challenges
Most or all subregions	– Changing commodity markets – Intensive water resources development over large areas—domestic and transboundary – Lengthy entitlement/land claim/treaty agreements—domestic and transboundary – Urban expansion – Transportation expansion	– Role of water/environmental markets – Changing design and operations of water and energy systems – New technology/practices in agriculture and forestry – Protection of threatened ecosystems or adaptation to new landscapes – Increased role for summer (warm weather) tourism – Risks to water quality from extreme events – Managing community health for changing risk factors – Changing roles of public emergency assistance and private insurance
Arctic border	– Winter transport system – Indigenous lifestyles	– Design for changing permafrost and ice conditions – Role of two economies and co-management bodies
Coastal regions	– Declines in some commercial marine resources (cod, salmon) – Intensive coastal zone development	– Aquaculture, habitat protection, fleet reductions – Coastal zone planning in high demand areas
Great Lakes	– Sensitivity to lake level fluctuations	– Managing for reduction in mean levels without increased shoreline encroachment

investment decisions are based on a variety of needs beyond climate change, including population growth and aging of existing systems. [15.2.5]

5.6.2. Water Resources and Aquatic Ecosystems

Uncertain changes in precipitation lead to little agreement regarding changes in total annual runoff across North America. Modeled impacts of increased temperatures on lake evaporation lead to consistent projections of reduced lake levels and outflows for the Great Lakes-St. Lawrence system under most scenarios (medium confidence). Increased incidence of heavy precipitation events will result in greater sediment and non-point-source pollutant loadings to watercourses (medium confidence). In addition, *in regions where seasonal snowmelt is an important aspect of the annual hydrologic regime (e.g., California, Columbia River Basin), warmer temperatures are likely to result in a seasonal shift in runoff, with a larger proportion of total runoff occurring in winter, together with possible reductions in summer flows (high confidence*). This could adversely affect the availability and quality of water for instream and out-of-stream water uses during the summer (medium confidence). Figure TS-8 shows possible impacts. [15.2.1]

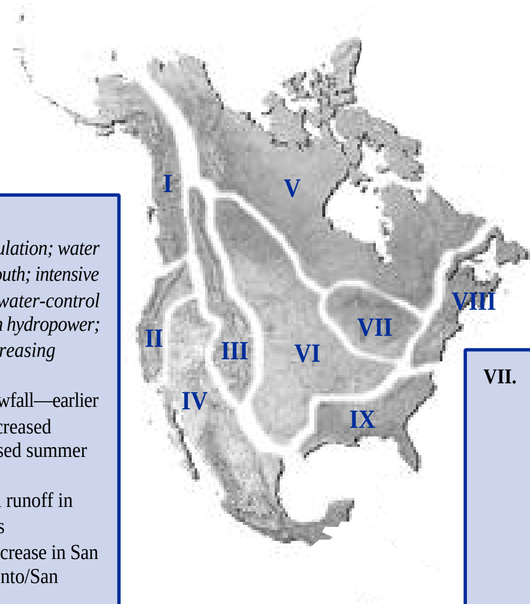
Adaptive responses to such seasonal runoff changes include altered management of artificial storage capacity, increased reliance on coordinated management of groundwater and surface water supplies, and voluntary water transfers between various water users. Such actions could reduce the impacts of reduced summer flows on water users, but it may be difficult or impossible to offset adverse impacts on many aquatic ecosystems, and it may not be possible to continue to provide current levels of reliability and quality for all water users. Some regions (e.g., the western United States) are likely to see increased market transfers of available water supplies from irrigated agriculture to urban and other relatively highly valued uses. Such reallocations raise social priority questions and entail adjustment costs that will depend on the institutions in place.

5.6.3. Marine Fisheries

Climate-related variations in marine/coastal environments are now recognized as playing an important role in determining the productivity of several North American fisheries in the Pacific, North Atlantic, Bering Sea, and Gulf of Mexico regions. There are complex links between climatic variations and changes in processes that influence the productivity and spatial distribution

I. Alaska, Yukon, and Coastal British Columbia
Lightly settled/water-abundant region; potential ecological, hydropower, and flood impacts:
- Increased spring flood risks
- Glacial retreat/disappearance in south, advance in north; impacts on flows, stream ecology
- Increased stress on salmon, other fish species
- Flooding of coastal wetlands
- Changes in estuary salinity/ecology

V. Sub-Arctic and Arctic
Sparse population (many dependent on natural systems); winter ice cover important feature of hydrologic cycle:
- Thinner ice cover, 1- to 3-month increase in ice-free season, increased extent of open water
- Increased lake-level variability, possible complete drying of some delta lakes
- Changes in aquatic ecology and species distribution as a result of warmer temperatures and longer growing season



VI. Midwest USA and Canadian Prairies
Agricultural heartland—mostly rainfed, with some areas relying heavily on irrigation:
- Annual streamflow decreasing/increasing; possible large declines in summer streamflow
- Increasing likelihood of severe droughts
- Possible increasing aridity in semi-arid zones
- Increases or decreases in irrigation demand and water availability—uncertain impacts on farm-sector income, groundwater levels, streamflows, and water quality

II. Pacific Coast States (USA)
Large and rapidly growing population; water abundance decreases north to south; intensive irrigated agriculture; massive water-control infrastructure; heavy reliance on hydropower; endangered species issues; increasing competition for water:
- More winter rainfall/less snowfall—earlier seasonal peak in runoff, increased fall/winter flooding, decreased summer water supply
- Possible increases in annual runoff in Sierra Nevada and Cascades
- Possible summer salinity increase in San Francisco Bay and Sacramento/San Joaquin Delta
- Changes in lake and stream ecology—warmwater species benefitting; damage to coldwater species (e.g., trout and salmon)

VII. Great Lakes
Heavily populated and industrialized region; variations in lake levels/flows now affect hydropower, shipping, shoreline structures:
- Possible precipitation increases coupled with reduced runoff and lake-level declines
- Reduced hydropower production; reduced channel depths for shipping
- Decreases in lake ice extent—some years w/out ice cover
- Changes in phytoplankton/zooplankton biomass, northward migration of fish species, possible extirpations of coldwater species

III. Rocky Mountains (USA and Canada)
Lightly populated in north, rapid population growth in south; irrigated agriculture, recreation, urban expansion increasingly competing for water; headwaters area for other regions:
- Rise in snow line in winter-spring, possible increases in snowfall, earlier snowmelt, more frequent rain on snow—changes in seasonal streamflow, possible reductions in summer streamflow, reduced summer soil moisture
- Stream temperature changes affecting species composition; increased isolation of coldwater stream fish

VIII. Northeast USA and Eastern Canada
Large, mostly urban population—generally adequate water supplies, large number of small dams, but limited total reservoir capacity; heavily populated floodplains:
- Decreased snow cover amount and duration
- Possible large reductions in streamflow
- Accelerated coastal erosion, saline intrusion into coastal aquifers
- Changes in magnitude, timing of ice freeze-up/break-up, with impacts on spring flooding
- Possible elimination of bog ecosystems
- Shifts in fish species distributions, migration patterns

IV. Southwest
Rapid population growth, dependence on limited groundwater and surface water supplies, water quality concerns in border region, endangered species concerns, vulnerability to flash flooding:
- Possible changes in snowpacks and runoff
- Possible declines in groundwater recharge—reduced water supplies
- Increased water temperatures—further stress on aquatic species
- Increased frequency of intense precipitation events—increased risk of flash floods

IX. Southeast, Gulf, and Mid-Atlantic USA
Increasing population—especially in coastal areas, water quality/non-point source pollution problems, stress on aquatic ecosystems:
- Heavily populated coastal floodplains at risk to flooding from extreme precipitation events, hurricanes
- Possible lower base flows, larger peak flows, longer droughts
- Possible precipitation increase—possible increases or decreases in runoff/river discharge, increased flow variability
- Major expansion of northern Gulf of Mexico hypoxic zone possible—other impacts on coastal systems related to changes in precipitation/non-point source pollutant loading
- Changes in estuary systems and wetland extent, biotic processes, species distribution

Figure TS-8: Possible water resources impacts in North America.

of marine fish populations (high confidence), as well as uncertainties linked to future commercial fishing patterns. Recent experience with Pacific salmon and Atlantic cod suggests that sustainable fisheries management will require timely and accurate scientific information on environmental conditions affecting fish stocks, as well as institutional and operational flexibility to respond quickly to such information. [15.2.3.3]

5.6.4. Agriculture

Small to moderate climate change will not imperil food and fiber production (high confidence). There will be strong regional production effects, with some areas suffering significant loss of comparative advantage to other regions (medium confidence). Overall, this results in a small net effect. The agricultural welfare of consumers and producers would increase with modest warming. However, the benefit would decline at an increasing rate—possibly becoming a net loss—with further warming. There is potential for increased drought in the U.S. Great Plains/Canadian Prairies and opportunities for a limited northward shift in production areas in Canada.

Increased production from direct physiological effects of CO_2, and farm- and agricultural market-level adjustments (e.g., behavioral, economic, and institutional) are projected to offset losses. Economic studies that include farm- and agricultural market-level adjustments indicate that the negative effects of climate change on agriculture probably have been overestimated by studies that do not account for these adjustments (medium confidence). However, the ability of farmers to adapt their input and output choices is difficult to forecast and will depend on market and institutional signals. [15.2.3.1]

5.6.5. Forests and Protected Areas

Climate change is expected to increase the areal extent and productivity of forests over the next 50–100 years (medium confidence). However, climate change is likely to cause changes in the nature and extent of several "disturbance factors" (e.g., fire, insect outbreaks) (medium confidence). Extreme or long-term climate change scenarios indicate the possibility of widespread forest decline (low confidence).

There is strong evidence that climate change can lead to the loss of specific ecosystem types—such as high alpine areas and specific coastal (e.g., salt marshes) and inland (e.g., prairie "potholes") wetland types (high confidence). There is moderate potential for adaptation to prevent these losses by planning conservation programs to identify and protect particularly threatened ecosystems. Lands that are managed for timber production are likely to be less susceptible to climate change than unmanaged forests because of the potential for adaptive management. [15.2.2]

5.6.6. Human Health

Vector-borne diseases, including malaria and dengue fever, may expand their ranges in the United States and may develop in Canada. Tick-borne Lyme disease also may see its range expanded in Canada. However, socioeconomic factors such as public health measures will play a large role in determining the existence or extent of such infections. Diseases associated with water may increase with warming of air and water temperatures, combined with heavy runoff events from agricultural and urban surfaces. Increased frequency of convective storms could lead to more cases of thunderstorm-associated asthma. [15.2.4]

5.6.7. Public and Private Insurance Systems

Inflation-corrected catastrophe losses have increased eight-fold in North America over the past 3 decades (high confidence). The exposures and surpluses of private insurers (especially property insurers) and reinsurers have been growing, and weather-related profit losses and insolvencies have been observed. Insured losses in North America (59% of the global total) are increasing with affluence and as populations continue to move into vulnerable areas. Insurer vulnerability to these changes varies considerably by region.

Recent extreme events have led to several responses by insurers, including increased attention to building codes and disaster preparedness. Insurers' practices traditionally have been based primarily on historic climatic experience; only recently have they begun to use models to predict future climate-related losses, so the potential for surprise is real. Governments play a key role as insurers or providers of disaster relief, especially in cases in which the private sector deems risks to be uninsurable. [15.2.7]

5.7. Polar Regions

Climate change in the polar region is expected to be among the greatest of any region on Earth. Twentieth century data for the Arctic show a warming trend of as much as 5°C over extensive land areas (very high confidence), while precipitation has increased (low confidence). There are some areas of cooling in eastern Canada. The extent of sea ice has decreased by 2.9% per decade, and it has thinned over the 1978–1996 period (high confidence). There has been a statistically significant decrease in spring snow extent over Eurasia since 1915 (high confidence). The area underlain by permafrost has been reduced and has warmed (very high confidence). The layer of seasonally thawed ground above permafrost has thickened in some areas, and new areas of extensive permafrost thawing have developed. *In the Antarctic, a marked warming trend is evident in the Antarctic Peninsula, with spectacular loss of ice shelves(high confidence).* The extent of higher terrestrial vegetation on the Antarctic Peninsula is increasing (very high confidence). Elsewhere, warming is less definitive. There has been no significant change in the Antarctic sea ice since 1973, although it apparently retreated by more than 3° of latitude between the mid-1950s and the early 1970s (medium confidence). [16.1.3.2.]

The Arctic is extremely vulnerable to climate change, and major physical, ecological, and economic impacts are expected to appear rapidly. A variety of feedback mechanisms will cause an amplified response, with consequent impacts on other systems and people. There will be different species compositions on land and sea, poleward shifts in species assemblages, and severe disruptions for communities of people who lead traditional lifestyles. *In developed areas of the Arctic and where the permafrost is ice-rich, special attention will be required to mitigate the detrimental impacts of thawing, such as severe damage to buildings and transport infrastructure (very high confidence).* There also will be beneficial consequences of climatic warming, such as reduced demand for heating energy. Substantial loss of sea ice in the Arctic Ocean will be favorable for opening of Arctic sea routes and ecotourism, which may have large implications for trade and for local communities. [16.2.5.3, 16.2.7.1, 16.2.8.1, 16.2.8.2]

In the Antarctic, projected climate change will generate impacts that will be realized slowly (high confidence). Because the impacts will occur over a long period, however, they will continue long after GHG emissions have stabilized. For example, there will be slow but steady impacts on ice sheets and circulation patterns of the global ocean, which will be irreversible for many centuries into the future and will cause changes elsewhere in the world, including a rise of sea level. Further substantial loss of ice shelves is expected around the Antarctic Peninsula. Warmer temperatures and reduced sea-ice extent are likely to produce long-term changes in the physical oceanography and ecology of the Southern Ocean, with intensified biological activity and increased growth rates of fish. [16.2.3.4, 16.2.4.2]

Polar regions contain important drivers of climate change. The Southern Ocean's uptake of carbon is projected to reduce substantially as a result of complex physical and biological processes. GHG emissions from tundra caused by changes in water content, decomposition of exposed peat, and thawing of permafrost are expected to increase. Reductions in the extent of highly reflective snow and ice will magnify warming (very high confidence). Freshening of waters from increased Arctic runoff and increased rainfall, melt of Antarctic ice shelves, and reduced sea-ice formation will slow the thermohaline circulations of the North Atlantic and Southern Oceans and reduce the ventilation of deep ocean waters. [16.3.1]

Adaptation to climate change will occur in natural polar ecosystems, mainly through migration and changing mixes of species. Some species may become threatened (e.g., walrus, seals, and polar bears), whereas others may flourish (e.g., caribou and fish). Although such changes may be disruptive to many local ecological systems and particular species, the possibility remains that predicted climate change eventually may increase the overall productivity of natural systems in polar regions. [16.3.2]

For indigenous communities who follow traditional lifestyles, opportunities for adaptation to climate change are limited (very high confidence). Changes in sea ice, seasonality of snow, habitat, and diversity of food species will affect hunting and gathering practices and could threaten longstanding traditions and ways of life. Technologically developed communities are likely to adapt quite readily to climate change by adopting altered modes of transport and by increased investment to take advantage of new commercial and trade opportunities. [16.3.2]

5.8. Small Island States

Climate change and sea-level rise pose a serious threat to the small island states, which span the ocean regions of the Pacific, Indian, and Atlantic Oceans as well as the Caribbean and Mediterranean Seas. Characteristics of small island states that increase their vulnerability include their small physical size relative to large expanses of ocean; limited natural resources; relative isolation; extreme openness of small economies that are highly sensitive to external shocks and highly prone to natural disasters and other extreme events; rapidly growing populations with high densities; poorly developed infrastructure; and limited funds, human resources, and skills. These characteristics limit the capacity of small island states to mitigate and adapt to future climate change and sea-level rise. [17.1.2]

Many small island states already are experiencing the effects of current large interannual variations in oceanic and atmospheric conditions. As a result, the most significant and more immediate consequences for small island states are likely to be related to changes in rainfall regimes, soil moisture budgets, prevailing winds (speed and direction), short-term variations in regional and local sea levels, and patterns of wave action. These changes are manifest in past and present trends of climate and climate variability, with an upward trend in average temperature by as much as 0.1°C per decade and sea-level rise of 2 mm yr^{-1} in the tropical ocean regions in which most of the small island states are located. Analysis of observational data from various regions indicates an increase in surface air temperature that has been greater than global rates of warming, particularly in the Pacific Ocean and Caribbean Sea. Much of the variability in the rainfall record of the Pacific and Caribbean islands appears to be closely related to the onset of ENSO. However, part of the variability also may be attributable to shifts in the Intertropical and South Pacific Convergence Zone, whose influence on rainfall variability patterns must be better understood. The interpretation of current sea-level trends also is constrained by limitations of observational records, particularly from geodetic-controlled tide gauges. [17.1.3]

5.8.1. Equity and Sustainable Development

Although the contribution of small island states to global emissions of GHG is insignificant, projected impacts of climate change and sea-level rise on these states are likely to be

***Table TS-13**: Importance of tourism for select small island states and territories.*

Country	Number of Tourists (000s)[a]	Tourists as % of Population[a]	Tourist Receipts[b] as % of GNP	as % of Exports
Antigua and Barbuda	232	364	63	74
Bahamas	1618	586	42	76
Barbados	472	182	39	56
Cape Verde	45	11	12	37
Comoros	26	5	11	48
Cuba	1153	11	9	n/a
Cyprus	2088	281	24	49
Dominica	65	98	16	33
Dominican Republic	2211	28	14	30
Fiji	359	45	19	29
Grenada	111	116	27	61
Haiti	149	2	4	51
Jamaica	1192	46	32	40
Maldives	366	131	95	68
Malta	1111	295	23	29
Mauritius	536	46	16	27
Papua New Guinea	66	2	2	3
St. Kitts and Nevis	88	211	31	64
St. Lucia	248	165	41	67
St. Vincent	65	55	24	46
Samoa	68	31	20	49
Seychelles	130	167	35	52
Singapore	7198	209	6	4
Solomon Islands	16	4	3	4
Trinidad and Tobago	324	29	4	8
Vanuatu	49	27	19	41

[a] Data on tourist inflows and ratio to population pertain to 1997.
[b] Data for tourist receipts pertain to 1997 for the Bahamas, Cape Verde, Jamaica, the Maldives, Malta, Mauritius, Samoa, Seychelles, Singapore, and Solomon Islands; 1996 for Antigua and Barbuda, Cuba, Dominica, Dominican Republic, Fiji, Grenada, Haiti, Papua New Guinea, St. Lucia, and St. Vincent; 1995 for Barbados, Comoros, Cyprus, Trinidad and Tobago, and Vanuatu; and 1994 for St. Kitts and Nevis.

serious. The impacts will be felt for many generations because of small island states'low adaptive capacity, high sensitivity to external shocks, and high vulnerability to natural disasters. Adaptation to these changing conditions will be extremely difficult for most small island states to accomplish in a sustainable manner. [17.2.1]

5.8.2. Coastal Zone

Much of the coastal change currently experienced in small island states is attributed to human activities on the coast. Projected sea-level rise of 5 mm yr^{-1} over the next 100 years, superimposed on further coastal development, will have negative impacts on the coasts (high confidence). This in turn will increase the vulnerability of coastal environments by reducing natural resilience and increasing the cost of adaptation. Given that severity will vary regionally, the most serious considerations for some small island states will be whether they will have adequate potential to adapt to sea-level rise within their own national boundaries. [17.2.2.1, 17.2.3]

5.8.3. Ecosystems and Biodiversity

Projected future climate change and sea-level rise will affect shifts in species composition and competition. It is estimated that one of every three known threatened plants are island endemics while 23% of bird species found on islands are threatened. [17.2.5]

Coral reefs, mangroves, and seagrass beds that often rely on stable environmental conditions will be adversely affected by rising air and sea temperature and sea levels (medium confidence). Episodic warming of the sea surface has resulted in greatly stressed coral populations that are subject to widespread coral bleaching. Mangroves, which are common on low-energy, nutrient/sediment-rich coasts and embayments in the tropics, have been altered by human activities. Changes in sea levels are likely to affect landward and alongshore migration of remnants of mangrove forests that provide protection for coasts and other resources. An increase in SST would adversely affect seagrass communities, which already are under stress from land-based pollution and runoff. Changes in these systems are likely to negatively affect fishery populations that depend on them for habitat and breeding grounds. [17.2.4]

5.8.4. Water Resources, Agriculture, and Fisheries

Water resources and agriculture are of critical concern because most small island states possess limited arable land and water resources. Communities rely on rainwater from catchments and a limited freshwater lens. In addition, arable farming, especially on low islands and atolls, is concentrated at or near the coast. Changes in the height of the water table and soil salinization as a consequence of sea-level rise would be stressful for many staple crops, such as taro.

Although fishing is largely artisinal or small-scale commercial, it is an important activity on most small islands and makes a significant contribution to the protein intake of island inhabitants. Many breeding grounds and habitats for fish and shellfish—such as mangroves, coral reefs, seagrass beds, and salt ponds—will face increasing threats from likely impacts of projected climate change. Water resources, agriculture, and fisheries already are sensitive to currently observed variability in oceanic and atmospheric conditions in many small island states, and the impacts are likely to be exacerbated by future climate and sea-level change (high confidence). [17.2.6, 17.2.8.1]

5.8.5. Human Health, Settlement, Infrastructure and Tourism

Several human systems are likely to be affected by projected changes in climate and sea levels in many small island states. Human health is a major concern given that many tropical islands are experiencing high incidences of vector- and water-borne diseases that are attributable to changes in temperature and rainfall, which may be linked to the ENSO phenomenon, droughts, and floods. Climate extremes also create a huge burden on some areas of human welfare, and these burdens are likely to increase in the future. Almost all settlements, socioeconomic infrastructure, and activities such as tourism are located at or near coastal areas in small island states. Tourism provides a major source of revenue and employment for many small island states (Table TS-13). Changes in temperature and rainfall regimes, as well as loss of beaches, could devastate the economies of many small island states (high confidence). Because these areas are very vulnerable to future climate change and sea-level rise, it is important to protect and nourish beaches and sites by implementing programs that constitute wise use resources. Integrated coastal management has been identified as one approach that would be useful for many small island states for a sustainable tourism industry. [17.2.7, 17.2.9]

5.8.6. Sociocultural and Traditional Assets

Certain traditional island assets (good and services) also will be at risk from climate change and sea-level rise. These assets include subsistence and traditional technologies (skills and knowledge) and cohesive community structures that, in the past, have helped to buttress the resilience of these islands to various forms of shock. Sea-level rise and climate changes, combined with other environmental stresses, already have destroyed unique cultural and spiritual sites, traditional heritage assets, and important coastal protected areas in many Pacific island states. [17.2.10]

6. Adaptation, Sustainable Development, and Equity

Adaptation to climate change has the potential to substantially reduce many of the adverse impacts of climate change and enhance beneficial impacts, though neither without cost nor without leaving residual damage. In natural systems, adaptation is reactive, whereas in human systems it also can be anticipatory. Figure TS-9 presents types and examples of adaptation to climate change. Experience with adaptation to climate variability and extremes shows that in the private and public sectors there are constraints to achieving the potential of adaptation. The adoption and effectiveness of private, or market-driven, adaptations in sectors and regions are limited by other forces, institutional conditions, and various sources of market failure. There is little evidence to suggest that private adaptations will be employed to offset climate change damages in natural environments. In some instances, adaptation measures may have inadvertent consequences, including environmental damage. The ecological, social, and economic costs of relying on reactive, autonomous adaptation to the cumulative effects of climate change are substantial. Many of these costs can be avoided through planned, anticipatory adaptation. Designed appropriately, many adaptation strategies could provide multiple benefits in the near and longer terms. However, there are limits on their implementation and effectiveness. Enhancement of adaptive capacity reduces the vulnerability of sectors and regions to climate change, including variability and extremes, and thereby promotes sustainable development and equity. [18.2.4, 18.3.4]

Planned anticipatory adaptation has the potential to reduce vulnerability and realize opportunities associated with climate change, regardless of autonomous adaptation. Adaptation facilitated

		Anticipatory	Reactive
Natural Systems			• Changes in length of growing season • Changes in ecosystem composition • Wetland migration
Human Systems	Private	• Purchase of insurance • Construction of houses on stilts • Redesign of oil rigs	• Changes in farm practices • Changes in insurance premiums • Purchase of air-conditioning
	Public	• Early-warning systems • New building codes, design standards • Incentives for relocation	• Compensatory payments, subsidies • Enforcement of building codes • Beach nourishment

Figure TS-9: Types of adaptation to climate change, including examples.

by public agencies is an important part of societal response to climate change. Implementation of adaptation policies, programs, and measures usually will have immediate and future benefits. Adaptations to current climate and climate-related risks (e.g., recurring droughts, storms, floods, and other extremes) generally are consistent with adaptation to changing and changed climatic conditions. Adaptation measures are likely to be implemented only if they are consistent with or integrated with decisions or programs that address nonclimatic stresses. Vulnerabilities associated with climate change are rarely experienced independently of nonclimatic conditions. Impacts of climatic stimuli are felt via economic or social stresses, and adaptations to climate (by individuals, communities, and governments) are evaluated and undertaken in light of these conditions. The costs of adaptation often are marginal to other management or development costs. To be effective, climate change adaptation must consider nonclimatic stresses and be consistent with existing policy criteria, development objectives, and management structures. [18.3.5, 18.4]

The key features of climate change for vulnerability and adaptation are related to variability and extremes, not simply changed average conditions (Figure TS-10). Societies and economies have been making adaptations to climate for centuries. Most sectors, regions, and communities are reasonably adaptable to changes in average conditions, particularly if the changes are gradual. However, losses from climatic variations and extremes are substantial and, in some sectors, increasing. These losses indicate that autonomous adaptation has not been sufficient to offset damages associated with temporal variations in climatic conditions. Communities therefore are more vulnerable and less adaptable to changes in the frequency and/or magnitude of conditions other than average, especially extremes, which are inherent in climate change. The degree to which future adaptations are successful in offsetting adverse impacts of climate change will be determined by success in adapting to climate change, variability, and extremes. [18.2.2]

6.1. Adaptive Capacity

The capacity to adapt varies considerably among regions, countries, and socioeconomic groups and will vary over time. Table TS-14 summarizes adaptation measures and capacities by sector, and Table TS-15 provides this information for each region covered by the TAR. The most vulnerable regions and communities are highly exposed to hazardous climate change effects and have limited adaptive capacity. The ability to adapt and cope with climate change impacts is a function of wealth, scientific and technical knowledge, information, skills, infrastructure, institutions, and equity. Countries with limited economic resources, low levels of technology, poor information and skills, poor infrastructure, unstable or weak institutions, and inequitable empowerment and access to resources have little capacity to adapt and are highly vulnerable. Groups and regions with adaptive capacity that is limited along any of these dimensions are more vulnerable to climate change damages, just as they are more vulnerable to other stresses. [18.5, 18.7]

6.2. Development, Sustainability, and Equity

Activities required for enhancement of adaptive capacity are essentially equivalent to those promoting sustainable development. Enhancement of adaptive capacity is a necessary condition for reducing vulnerability, particularly for the most vulnerable regions, nations, and socioeconomic groups. Many sectors and regions that are vulnerable to climate change also are under pressure from forces such as population growth and resource depletion. Climate adaptation and sustainability goals can be jointly advanced by changes in policies that lessen pressure on resources, improve management of environmental risks, and enhance adaptive capacity. Climate adaptation and equity goals can be jointly pursued through initiatives that promote the welfare of the poorest members of society—for example, by improving food security, facilitating access to safe water and health care, and providing shelter and access to other resources. Development decisions, activities, and programs play important roles in modifying the adaptive capacity of communities and regions, yet they tend not to take into account risks associated with climate variability and change. Inclusion of climatic risks

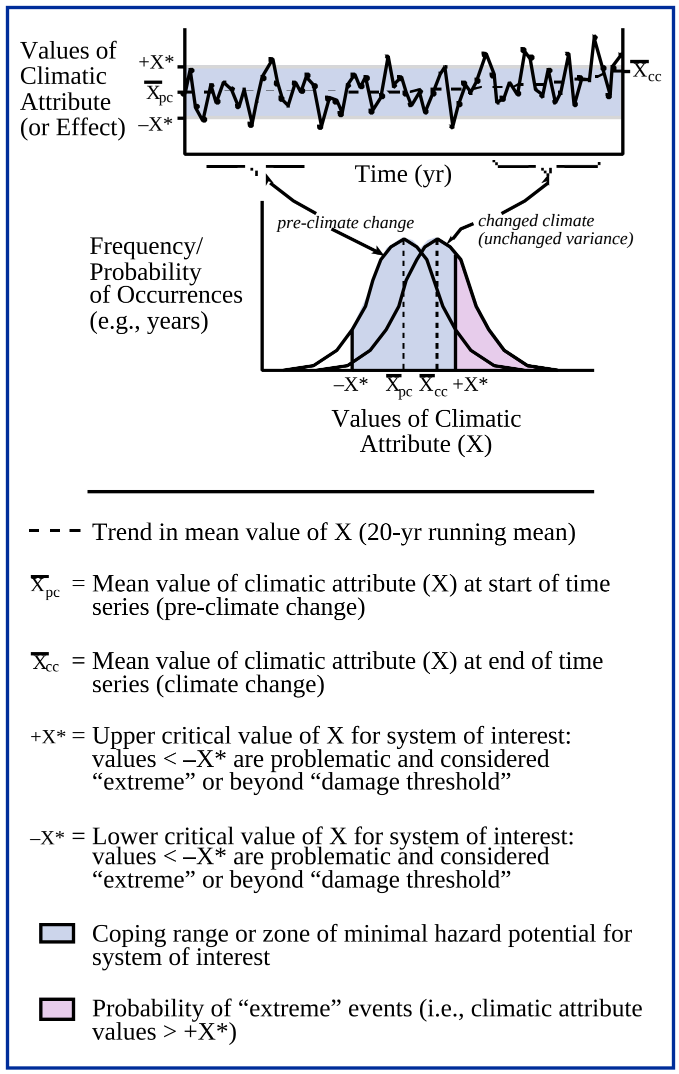


Figure TS-10: Climate change, variability, extremes, and coping range.

Table TS-14*: Adaptation and adaptive capacity in sectors (key findings from Chapters 4 through 9).*

Sector	Key Findings
Water Resources	– Water managers have experience with adapting to change. Many techniques exist to assess and implement adaptive options. However, the pervasiveness of climate change may preclude some traditional adaptive strategies, and available adaptations often are not used. – Adaptation can involve management on the supply side (e.g., altering infrastructure or institutional arrangements) and on the demand side (changing demand or risk reduction). Numerous no-regret policies exist, which will generate net social benefits regardless of climate change. – Climate change is just one of numerous pressures facing water managers. Nowhere are water management decisions taken solely to cope with climate change, although it is increasingly considered for future resource management. Some vulnerabilities are outside the conventional responsibility of water managers. – Estimates of the economic costs of climate change impacts on water resources depend strongly on assumptions made about adaptation. Economically optimum adaptation may be prevented by constraints associated with uncertainty, institutions, and equity. – Extreme events often are catalysts for change in water management, by exposing vulnerabilities and raising awareness of climate risks. Climate change modifies indicators of extremes and variability, complicating adaptation decisions. – Ability to adapt is affected by institutional capacity, wealth, management philosophy, planning time scale, organizational and legal framework, technology, and population mobility. – Water managers need research and management tools aimed at adapting to uncertainty and change, rather than improving climate scenarios.
Ecosystems and Their Services	– Adaptation to loss of some ecosystem services may be possible, especially in managed ecosystems. However, adaptation to losses in wild ecosystems and biodiversity may be difficult or impossible. – There is considerable capacity for adaptation in agriculture, including crop changes and resource substitutions, but adaptation to evolving climate change and interannual variability is uncertain. – Adaptations in agriculture are possible, but they will not happen without considerable transition costs and equilibrium (or residual) costs. – Greater adverse impacts are expected in areas where resource endowments are poorest and the ability of farmers to adapt is most limited. – In many countries where rangelands are important, lack of infrastructure and investment in resource management limit options for adaptation. – Commercial forestry is adaptable, reflecting a history of long-term management decisions under uncertainty. Adaptations are expected in land-use management (species-selection silviculture) and product management (processing-marketing). – Adaptation in developed countries will fare better, while developing countries and countries in transition, especially in the tropics and subtropics, will fare worse.
Coastal Zones	– Without adaptations, the consequences of global warming and sea-level rise would be disastrous. – Coastal adaptation entails more than just selecting one of the technical options to respond to sea-level rise (strategies can aim to protect, accommodate, or retreat). It is a complex and iterative process rather than a simple choice. – Adaptation options are more acceptable and effective when they are incorporated into coastal zone management, disaster mitigation programs, land-use planning, and sustainable development strategies. – Adaptation choices will be conditioned by existing policies and development objectives, requiring researchers and policymakers to work toward a commonly acceptable framework for adaptation. – The adaptive capacity of coastal systems to perturbations is related to coastal resilience, which has morphological, ecological, and socioeconomic components. Enhancing resilience—including the technical, institutional, economic, and cultural capability to cope with impacts—is a particularly appropriate adaptive strategy given future uncertainties and the desire to maintain development opportunities. – Coastal communities and marine-based economic sectors with low exposure or high adaptive capacity will be least affected. Communities with lower economic resources, poorer infrastructure, less-developed communications and transportation systems, and weak social support systems have less access to adaptation options and are more vulnerable.

Table TS-14 (continued)

Sector	Key Findings
Human Settlements, Energy, and Industry	– Larger and more costly impacts of climate change occur through changed probabilities of extreme weather events that overwhelm the design resiliency of human systems. – Many adaptation options are available to reduce the vulnerability of settlements. However, urban managers, especially in developing countries, have so little capacity to deal with current problems (housing, sanitation, water, and power) that dealing with climate change risks is beyond their means. – Lack of financial resources, weak institutions, and inadequate or inappropriate planning are major barriers to adaptation in human settlements. – Successful environmental adaptation cannot occur without locally based, technically competent, and politically supported leadership. – Uncertainty with respect to capacity and the will to respond hinder assessment of adaptation and vulnerability.
Insurance and Other Financial Services	– Adaptation in financial and insurance services in the short term is likely to be to changing frequencies and intensities of extreme weather events. – Increasing risk could lead to a greater volume of traditional business and development of new financial risk management products, but increased variability of loss events would heighten actuarial uncertainty. – Financial services firms have adaptability to external shocks, but there is little evidence that climate change is being incorporated into investment decisions. – The adaptive capacity of the financial sector is influenced by regulatory involvement, the ability of firms to withdraw from at-risk markets, and fiscal policy regarding catastrophe reserves. – Adaptation will involve changes in the roles of private and public insurance. Changes in the timing, intensity, frequency, and/or spatial distribution of climate-related losses will generate increased demand on already overburdened government insurance and disaster assistance programs. – Developing countries seeking to adapt in a timely manner face particular difficulties, including limited availability of capital, poor access to technology, and absence of government programs. – Insurers'adaptations include raising prices, non-renewal of policies, cessation of new policies, limiting maximum claims, and raising deductibles—actions that can seriously affect investment in developing countries. – Developed countries generally have greater adaptive capacity, including technology and economic means to bear costs.
Human Health	– Adaptation involves changes in society, institutions, technology, or behavior to reduce potential negative impacts or increase positive ones. There are numerous adaptation options, which may occur at the population, community, or personal levels. – The most important and cost-effective adaptation measure is to rebuild public health infrastructure—which, in much of the world, has declined in recent years. Many diseases and health problems that may be exacerbated by climate change can be effectively prevented with adequate financial and human public health resources, including training, surveillance and emergency response, and prevention and control programs. – Adaptation effectiveness will depend on timing. "Primary" prevention aims to reduce risks before cases occur, whereas "secondary" interventions are designed to prevent further cases. – Determinants of adaptive capacity to climate-related threats include level of material resources, effectiveness of governance and civil institutions, quality of public health infrastructure, and preexisting burden of disease. – Capacity to adapt also will depend on research to understand associations between climate, weather, extreme events, and vector-borne diseases.

in the design and implementation of development initiatives is necessary to reduce vulnerability and enhance sustainability. [18.6.1]

7. Global Issues and Synthesis

7.1. Detection of Climate Change Impacts

Observational evidence indicates that climate changes in the 20th century already have affected a diverse set of physical and biological systems. Examples of observed changes with linkages to climate include shrinkage of glaciers; thawing of permafrost; shifts in ice freeze and break-up dates on rivers and lakes; increases in rainfall and rainfall intensity in most mid- and high latitudes of the Northern Hemisphere; lengthening of growing seasons; and earlier flowering dates of trees, emergence of insects, and egg-laying in birds. Statistically significant associations between changes in regional climate and observed changes in physical and biological systems have been documented in freshwater, terrestrial, and marine environments on all continents. [19.2]

Table TS-15: *Adaptation and capacity in regions (key findings from Chapters 10 through 17).*

Sector	Key Findings
Africa	– Adaptive measures would enhance flexibility and have net benefits in water resources (irrigation and water reuse, aquifer and groundwater management, desalinization), agriculture (crop changes, technology, irrigation, husbandry), and forestry (regeneration of local species, energy-efficient cook stoves, sustainable community management). – Without adaptation, climate change will reduce the wildlife reserve network significantly by altering ecosystems and causing species'emigrations and extinctions. This represents an important ecological and economic vulnerability in Africa. – Arisk-sharing approach between countries will strengthen adaptation strategies, including disaster management, risk communication, emergency evacuation, and cooperative water resource management. – Most countries in Africa are particularly vulnerable to climate change because of limited adaptive capacity as a result of widespread poverty, recurrent droughts, inequitable land distribution, and dependence on rainfed agriculture. – Enhancement of adaptive capacity requires local empowerment in decisionmaking and incorporation of climate adaptation within broader sustainable development strategies.
Asia	– Priority areas for adaptation are land and water resources, food productivity, and disaster preparedness and planning, particularly for poorer, resource-dependent countries. – Adaptations already are required to deal with vulnerabilities associated with climate variability, in human health, coastal settlements, infrastructure, and food security. Resilience of most sectors in Asia to climate change is very poor. Expansion of irrigation will be difficult and costly in many countries. – For many developing countries in Asia, climate change is only one of a host of problems to deal with, including nearer term needs such as hunger, water supply and pollution, and energy. Resources available for adaptation to climate are limited. Adaptation responses are closely linked to development activities, which should be considered in evaluating adaptation options. – Early signs of climate change already have been observed and may become more prominent over 1 or 2 decades. If this time is not used to design and implement adaptations, it may be too late to avoid upheavals. Long-term adaptation requires anticipatory actions. – A wide range of precautionary measures are available at the regional and national level to reduce economic and social impacts of disasters. These strategies include awareness-building and expansion of the insurance industry. – Development of effective adaptation strategies requires local involvement, inclusion of community perceptions, and recognition of multiple stresses on sustainable management of resources. – Adaptive capacities vary between countries, depending on social structure, culture, economic capacity, and level of environmental disruptions. Limiting factors include poor resource and infrastructure bases, poverty and disparities in income, weak institutions, and limited technology. – The challenge in Asia lies in identifying opportunities to facilitate sustainable development with strategies that make climate-sensitive sectors resilient to climate variability. – Adaptation strategies would benefit from taking a more systems-oriented approach, emphasizing multiple interactive stresses, with less dependence on climate scenarios.
Australia and New Zealand	– Adaptations are needed to manage risks from climatic variability and extremes. Pastoral economies and communities have considerable adaptability but are vulnerable to any increase in the frequency or duration of droughts. – Adaptation options include water management, land-use practices and policies, engineering standards for infrastructure, and health services. – Adaptations will be viable only if they are compatible with the broader ecological and socioeconomic environment, have net social and economic benefits, and are taken up by stakeholders. – Adaptation responses may be constrained by conflicting short- and long-term planning horizons. – Poorer communities, including many indigenous settlements, are particularly vulnerable to climate-related hazards and stresses on health because they often are in exposed areas and have less adequate housing, health care, and other resources for adaptation.

Table TS-15 (continued)

Sector	Key Findings
Europe	– Adaptation potential in socioeconomic systems is relatively high because strong economic conditions, stable population (with capacity to migrate), and well-developed political, institutional, and technological support systems. – The response of human activities and the natural environment to current weather perturbations provides a guide to critical sensitivities under future climate change. – Adaptation in forests requires long-term planning; it is unlikely that adaptation measures will be put in place in a timely manner. – Farm-level analyses show that if adaptation is fully implemented large reductions in adverse impacts are possible. – Adaptation for natural systems generally is low. – More marginal and less wealthy areas will be less able to adapt; thus, without appropriate policies of response, climate change may lead to greater inequities.
Latin America	– Adaptation measures have potential to reduce climate-related losses in agriculture and forestry. – There are opportunities for adapting to water shortages and flooding through water resource management. – Adaptation measures in the fishery sector include changing species captured and increasing prices to reduce losses.
North America	– Strain on social and economic systems from rapid climate and sea-level changes will increase the need for explicit adaptation strategies. In some cases, adaptation may yield net benefits, especially if climate change is slow. – Stakeholders in most sectors believe that technology is available to adapt, although at some social and economic cost. – Adaptation is expected to be more successful in agriculture and forestry. However, adaptations for water, health, food, energy, and cities are likely to require substantial institutional and infrastructure changes. – In the water sector, adaptations to seasonal runoff changes include storage, conjunctive supply management, and transfer. It may not be possible to continue current high levels of reliability of water supply, especially with transfers to high-valued uses. Adaptive measures such as “water markets” may lead to concerns about accessibility and conflicts over allocation priorities. – Adaptations such as levees and dams often are successful in managing most variations in weather but can increase vulnerability to the most extreme events. – There is moderate potential for adaptation through conservation programs that protect particularly threatened ecosystems, such as high alpines and wetlands. It may be difficult or impossible to offset adverse impacts on aquatic systems.

The presence of multiple causal factors (e.g., land-use change, pollution) makes attribution of many observed impacts to regional climate change a complex challenge. Nevertheless, studies of systems subjected to significant regional climate change—and with known sensitivities to that change—find changes that are consistent with well-established relationships between climate and physical or biological processes (e.g., shifts in the energy balance of glaciers, shifts in the ranges of animals and plants when temperatures exceed physiological thresholds) in about 80% of biological cases and about 99% of physical cases. Table TS-16 shows ~450 changes in processes or species that have been associated with regional temperature changes. Figure TS-11 illustrates locations at which studies have documented regional temperature change impacts. These consistencies enhance our confidence in the associations between changes in regional climate and observed changes in physical and biological systems. Based on observed changes, there is high confidence that 20th century climate changes have had a discernible impact on many physical and biological systems. Changes in biota and physical systems observed in the 20th century indicate that these systems are sensitive to climatic changes that are small relative to changes that have been projected for the 21st century. High sensitivity of biological systems to long-term climatic change also is demonstrated by paleorecords. [19.2.2.]

Signals of regional climate change impacts are expected to be clearer in physical and biotic systems than in social and economic systems, which are simultaneously undergoing many complex non-climate-related stresses, such as population growth and urbanization. Preliminary indications suggest that some social and economic systems have been affected in part by 20th century regional climate changes (e.g., increased damages by floods and droughts in some locations, with apparent increases in insurance impacts). Coincident or alternative explanations for such observed regional impacts result in only low to medium

Table TS-15 (continued)

Sector	Key Findings
Polar Regions	– Adaptation will occur in natural polar ecosystems through migration and changing mixes of species. Species such as walrus, seals, and polar bears will be threatened; while others, such as fish, may flourish. – Potential for adaptation is limited in indigenous communities that follow traditional lifestyles. – Technologically developed communities are likely to adapt quite readily, although the high capital investment required may result in costs in maintaining lifestyles. – Adaptation depends on technological advances, institutional arrangements, availability of financing, and information exchange.
Small Island States	– The need for adaptation has become increasingly urgent, even if swift implementation of global agreements to reduce future emissions occurs. – Most adaptation will be carried out by people and communities that inhabit island countries; support from governments is essential for implementing adaptive measures. – Progress will require integration of appropriate risk-reduction strategies with other sectoral policy initiatives in areas such as sustainable development planning, disaster prevention and management, integrated coastal zone management, and health care planning. – Strategies for adaptation to sea-level rise are retreat, accommodate, and protect. Measures such as retreat to higher ground, raising of the land, and use of building set-backs appear to have little practical utility, especially when hindered by limited physical size. – Measures for reducing the severity of health threats include health education programs, health care facilities, sewerage and solid waste management, and disaster preparedness plans. – Islanders have developed some capacity to adapt by application of traditional knowledge, locally appropriate technology, and customary practice. Overall adaptive capacity is low, however, because of the physical size of nations, limited access to capital and technology, shortage of human resource skills, lack of tenure security, overcrowding, and limited access to resources for construction. – Many small islands require external financial, technical, and other assistance to adapt. Adaptive capacity may be enhanced by regional cooperation and pooling of limited resources.

confidence about determining whether climate change is affecting these systems. [19.2.2.4]

7.2. Five Reasons for Concern

Some of the current knowledge about climate change impacts, vulnerability, and adaptation is synthesized here along five reasons for concern: unique and threatened systems, global aggregate impacts, distribution of impacts, extreme weather events, and large-scale singular events. Consideration of these reasons for concern contribute to understanding of vulnerabilities and potential benefits associated with human-induced climate change that can aid deliberations by policymakers of what could constitute dangerous interference with the climate system in the context of Article 2 of the UNFCCC. No single dimension is paramount.

Figure TS-12 presents qualitative findings about climate change impacts related to the reasons for concern. At a small increase in global mean temperature,[3] some of the reasons for concern show the potential for negative impacts, whereas others show little adverse impact or risk. At higher temperature increases, all lines of evidence show a potential for adverse impacts, with impacts in each reason for concern becoming more negative at increasing temperatures. There is high confidence in this general relationship between impacts and temperature change, but confidence generally is low in estimates of temperature change thresholds at which different categories of impacts would happen. [19.8]

7.2.1. Unique and Threatened Systems

Small increases in global average temperature may cause significant and irreversible damage to some systems and species, including possible local, regional, or global loss. Some plant and animal species, natural systems, and human settlements are highly sensitive to climate and are likely to be adversely affected by climate changes associated with scenarios of <1°C mean global warming. Adverse impacts to species and systems

[3]Intervals of global mean temperature increase of 0–2, 2–3, and >3°C relative to 1990 are labeled small, moderate, and large, respectively. The relatively large range for the "small" designation results because the literature does adequately address a warming of 1–2°C. These magnitudes of change in global mean temperature should be taken as an approximate indicator of when impacts might occur; they are not intended to define absolute thresholds or to describe all relevant aspects of climate-change impacts, such as rate of change in climate and changes in precipitation, extreme climate events, or lagged (latent) effects such as rising sea levels.

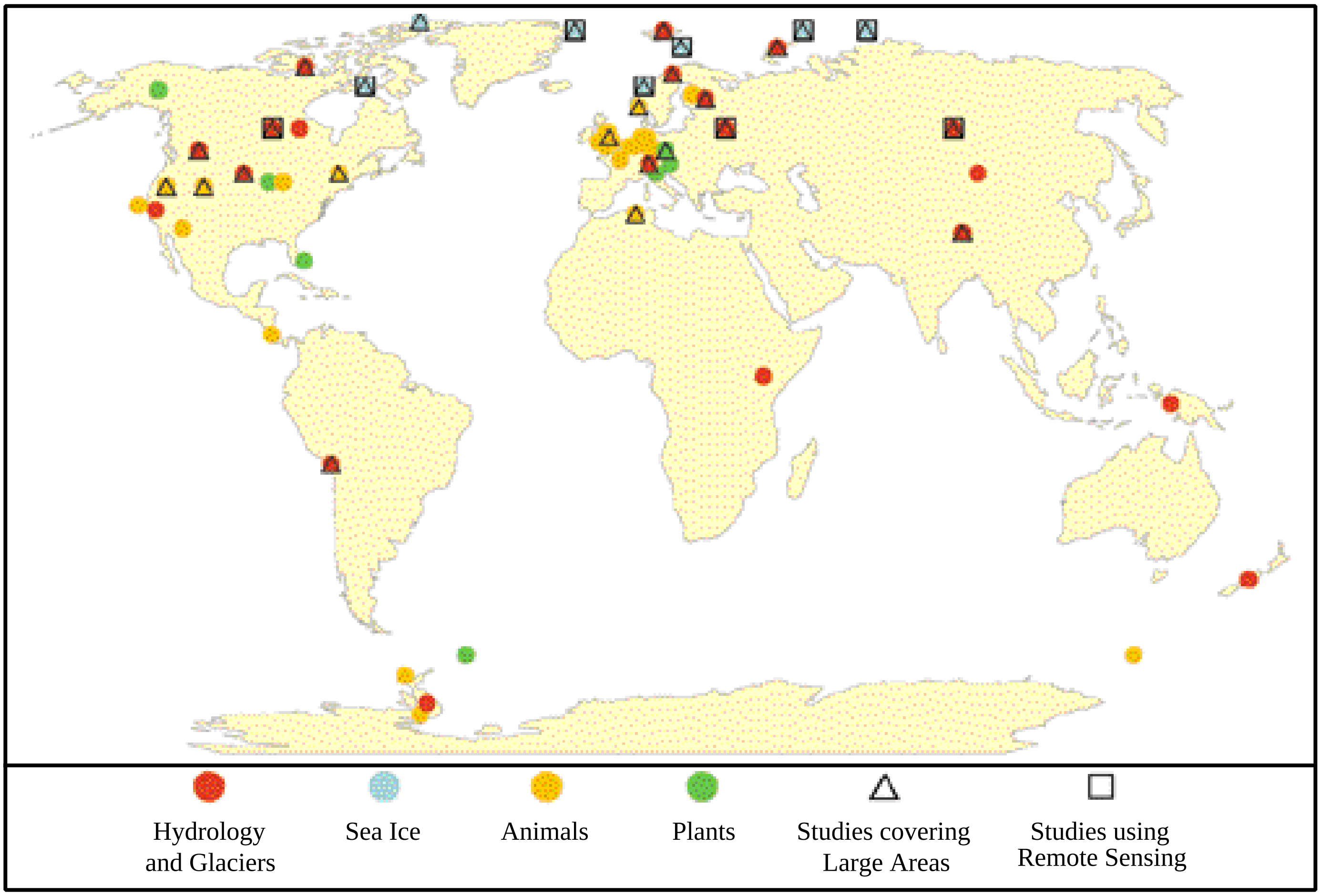


Figure TS-11: Locations at which systematic long-term studies meet stringent criteria documenting recent temperature-related regional climate change impacts on physical and biological systems. Hydrology, glacial retreat, and sea-ice data represent decadal to century trends. Terrestrial and marine ecosystem data represent trends of at least 2 decades. Remote-sensing studies cover large areas. Data are for single or multiple impacts that are consistent with known mechanisms of physical/biological system responses to observed regional temperature-related changes. For reported impacts spanning large areas, a representative location on the map was selected.

would become more numerous and more serious for climatic changes that would accompany a global mean warming of 1–2°C and are highly likely to become even more numerous and serious at higher temperatures. The greater the rate and magnitude of temperature and other climatic changes, the greater the likelihood that critical thresholds of systems would be surpassed. Many of these threatened systems are at risk from climate change because they face nonclimate pressures such as those related to human land use, land-use change, and pollution. [19.3]

Species that may be threatened with local or global extinction by changes in climate that may accompany a small mean global temperature increase include critically endangered species generally, species with small ranges and low population densities, species with restricted habitat requirements, and species for which suitable habitat is patchy in distribution, particularly if under pressure from human land-use and land-cover change. Examples of species that may be threatened by small changes include forest birds in Tanzania, the Resplendent Quetzal in Central America, the mountain gorilla in Africa, amphibians that are endemic to cloud forests of the neotropics, the spectacled bear of the Andes, the Bengal tiger and other species that are endemic to the Sundarban wetlands, and rainfall-sensitive plant species that are endemic to the Cape Floral Kingdom of South Africa. Natural systems that may be threatened include coral reefs, mangroves, and other coastal wetlands; montane ecosystems that are restricted to the upper 200–300 m of mountainous areas; prairie wetlands; remnant native grasslands; coldwater and some coolwater fish habitat; ecosystems overlying permafrost; and ice edge ecosystems that provide habitat for polar bears and penguins. Human settlements that may be placed at serious risk by changes in climate and sea level that may be associated with medium to large mean warming include some settlements of low-lying coastal areas and islands, floodplains, and hillsides—particularly those of low socioeconomic status such as squatter and other informal settlements. Other potentially threatened settlements include traditional peoples that are highly dependent on natural resources that are sensitive to climate change. [19.3]

Table TS-16: Processes and species found in studies to be associated with regional temperature change.[a]

Region	Glaciers, Snow Cover/ Melt, Lake/ Stream Ice[b]		Vegetation		Invertebrates		Amphibians and Reptiles		Birds		Mammals	
Africa	1	0	—	—	—	—	—	—	—	—	—	—
Antarctica	3	2	2	0	—	—	—	—	2	0	—	—
Asia	14	0	—	—	—	—	—	—	—	—	—	—
Australia	1	0	—	—	—	—	—	—	—	—	—	—
Europe	29	4	13	1	46	1	7	0	258	92	7	0
North America	36	4	32	11	—	—	—	—	17	4	3	0
Latin America	3	0	—	—	—	—	22	0	15	0	—	—
Total	87	10	47	12	46	1	29	0	292	96	10	0

[a] The columns represent the number of species and processes in each region that were found in each particular study to be associated with regional temperature change. For inclusion in the table, each study needed to show that the species or process was changing over time and that the regional temperature was changing over time; most studies also found a significant association between how the temperature and species or processes were changing The first number indicates the number of species or processes changing in the manner predicted with global warming. The second number is the number of species or processes changing in a manner opposite to that predicted with a warming planet. Empty cells indicate that no studies were found for this region and category.
[b] Sea ice not included.

7.2.2. Aggregate Impacts

With a small temperature increase, aggregate market-sector impacts could amount to plus or minus a few percent of world GDP (medium confidence); aggregate nonmarket impacts could be negative (low confidence). The small net impacts are mainly the result of the fact that developed economies, many of which could have positive impacts, contribute the majority of global production. Applying more weight to impacts in poorer countries to reflect equity concerns, however, can result in net aggregate impacts that are negative even at medium warming. It also is possible that a majority of people will be negatively affected by climate change scenarios in this range, even if the net aggregate monetary impact is positive. With medium to higher temperature increases, benefits tend to decrease and damages increase, so the net change in global economic welfare becomes negative—and increasingly negative with greater warming (medium confidence). Some sectors, such as coastal and water resources, could have negative impacts in developed and developing countries. Other sectors, such as agriculture and human health, could have net positive impacts in some countries and net negative impacts in other countries. [19.5]

Results are sensitive to assumptions about changes in regional climate, levels of development, adaptive capacity, rates of change, valuation of impacts, and methods used for aggregating losses and gains, including the choice of discount rate. In addition, these studies do not consider potentially important factors such as changes in extreme events, advantageous and complementary responses to the threat of non-climate-driven extreme events, rapid change in regional climate (e.g., resulting from changes in ocean circulation), compounding effects of multiple stresses, or conflicting or complementary reaction to those stresses. Because these factors have yet to be accounted for in estimates of aggregate impacts and estimates do not include all possible categories of impacts, particularly nonmarket impacts, estimates of aggregate economic welfare impacts of climate change are considered to be incomplete. Given the uncertainties about aggregate estimates, the possibility of negative effects at a small increase in temperature cannot be excluded. [19.5]

7.2.3. Distribution of Impacts

Developing countries tend to be more vulnerable to climate change than developed countries (high confidence). Developing countries are expected to suffer more adverse impacts than developed countries (medium confidence). A small temperature increase would have net negative impacts on market sectors in many developing countries (medium confidence) and net positive impacts on market sectors in many developed countries (medium confidence). The different results are attributable partly to differences in exposures and sensitivities (e.g., present temperatures are below optimal in mid- and high latitudes for many crops but at or above optimal in low latitudes) and partly to lesser adaptive

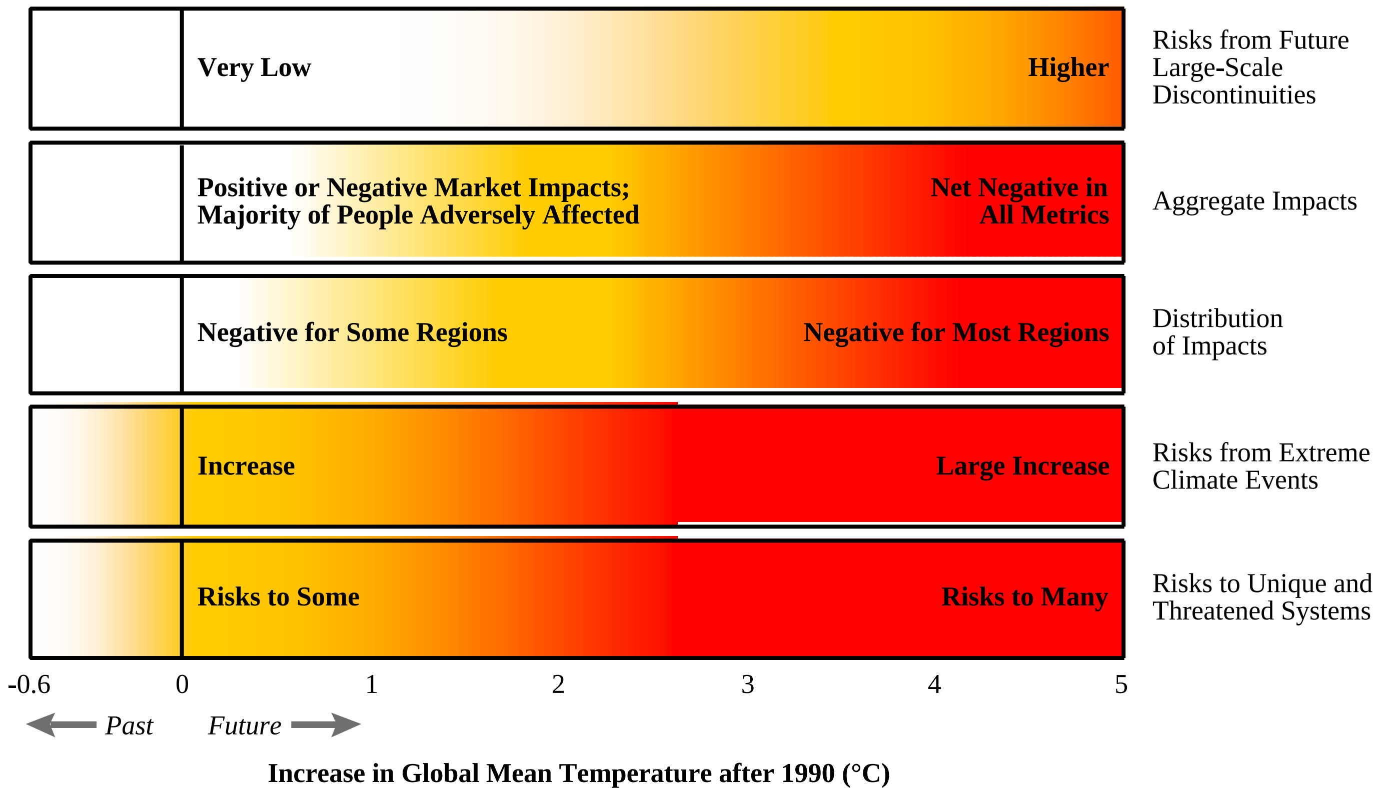


Figure TS-12: Impacts of or risks from climate change, by reason for concern. Each row corresponds to a reason for concern, and shades correspond to severity of impact or risk. White means no or virtually neutral impact or risk, yellow means somewhat negative impacts or low risks, and red means more negative impacts or higher risks. Global-averaged temperatures in the 20th century increased by 0.6°C and led to some impacts. Impacts are plotted against increases in global mean temperature after 1990. This figure addresses only how impacts or risks change as thresholds of increase in global mean temperature are crossed, not how impacts or risks change at different rates of change in climate. These temperatures should be taken as approximate indications of impacts, not as absolute thresholds.

capacity in developing countries relative to developed countries. At a medium temperature increase, net positive impacts would start to turn negative and negative impacts would be exacerbated (high confidence). The results of these studies do not fully take into account nonmarket impacts of climate change such as impacts on natural systems, which may be sensitive to small amounts of warming. Particularly vulnerable regions include deltaic regions, low-lying small island states, and many arid regions where droughts and water availability are problematic even without climate change. Within regions or countries, impacts are expected to fall most heavily, in relative terms, on impoverished persons. The poorest members of society can be inferred to be most vulnerable to climate change because of their lack of resources with which to cope and adapt to impacts, but few studies have explicitly examined the distribution of impacts on the poor relative to other segments of society. [19.4]

Impacts on unmanaged systems are likely to increase in severity with time, but impacts on managed systems could increase or decrease through the 21st century. The distribution of impacts over the 21st century is influenced by several factors. As GHG concentrations increase, the magnitude of exposure to change in climate stimuli also would increase. Nonclimate pressures on natural and social systems, which increase the vulnerability of systems, also may grow through time as a result of population growth and increased demands for land, water, public infrastructure, and other resources. Increased population, incomes, and wealth also mean that more people and human-made resources potentially would be exposed to climate change, which would tend to increase market-sector damages in absolute dollar terms; this has been the case historically. Counteracting these tendencies are factors such as increased wealth and technology and improved institutions, which can raise adaptive capacity and reduce vulnerability to climate change. [8, 19.4]

Whether impacts and vulnerability increase or decrease with time is likely to depend in part on the rates of climate change and development and may differ for managed and unmanaged systems. The more rapid the rate of climate change, the greater would be future exposure to potentially adverse changes and the greater the potential for exceeding system thresholds. The more rapid the rate of development, the more resources would be exposed to climate change in the future—but so too would the adaptive capacity of future societies. The benefits of increased adaptive capacity are likely to be greater for intensively managed systems than for systems that presently are unmanaged or lightly managed. For this reason, and because of the possibility that nonclimate pressures on natural systems may increase in the future, the vulnerability of natural systems is expected to increase with time (medium confidence). [19.4.2, 19.4.3]

Future development paths, sustainable or otherwise, will shape future vulnerability to climate change, and climate change impacts may affect prospects for sustainable development in different parts of the world. Climate change is one of many stresses that confront human and natural systems. The severity of many of these stresses will be determined in part by the development paths followed by human societies; paths that generate lesser stresses are expected to lessen the vulnerability of human and natural systems to climate change. Development also can influence future vulnerability by enhancing adaptive capacity through accumulation of wealth, technology, information, skills, and appropriate infrastructure; development of effective institutions; and advancement of equity. Climate change impacts could affect prospects for sustainable development by changing the capacity to produce food and fiber, the supply and quality of water, and human health and by diverting financial and human resources to adaptation. [18]

7.2.4. Extreme Weather Events

Many climatic impacts are related to extreme weather events, and the same will hold for the impacts of climate change. The large damage potential of extreme events arises from their severity, suddenness, and unpredictability, which makes them difficult to adapt to. Development patterns can increase vulnerability to extreme events. For example, large development along coastal regions increases exposure to storm surges and tropical cyclones, increasing vulnerability.

The frequency and magnitude of many extreme climate events increase even with a small temperature increase and will become greater at higher temperatures (high confidence). Extreme events include, for example, floods, soil moisture deficits, tropical cyclones, storms, high temperatures, and fires. The impacts of extreme events often are large locally and could strongly affect specific sectors and regions. Increases in extreme events can cause critical design or natural thresholds to be exceeded, beyond which the magnitude of impacts increases rapidly (high confidence). Multiple nonextreme consecutive events also can be problematic because they can lessen adaptive capacity by depleting reserves of insurance and reinsurance companies. [8, 19.6.3.1]

An increase in the frequency and magnitude of extreme events would have adverse effects throughout sectors and regions. Agriculture and water resources may be particularly vulnerable to changes in hydrological and temperature extremes. Coastal infrastructure and ecosystems may be adversely affected by changes in the occurrence of tropical cyclones and storm surges. Heat-related mortality is likely to increase with higher temperatures; cold-related mortality is likely to decrease. Floods may lead to the spread of water-related and vector-borne diseases, particularly in developing countries. Many of the monetary damages from extreme events will have repercussions on a broad scale of financial institutions, from insurers and reinsurers to investors, banks, and disaster relief funds. Changes in the statistics of extreme events have implications for the design criteria of engineering applications (e.g., levee banks, bridges, building design, and zoning), which are based on estimates of return periods, and for assessment of the economic performance and viability of particular enterprises that are affected by weather. [19.6.3.1]

7.2.5. Large-Scale Singular Events

Human-induced climate change has the potential to trigger large-scale changes in Earth systems that could have severe consequences at regional or global scales. The probabilities of triggering such events are poorly understood but should not be ignored, given the severity of their consequences. Events of this type that might be triggered include complete or partial shutdown of the North Atlantic and Antarctic Deep Water formation, disintegration of the West Antarctic and Greenland Ice Sheets, and major perturbations of biosphere-regulated carbon dynamics. Determining the timing and probability of occurrence of large-scale discontinuities is difficult because these events are triggered by complex interactions between components of the climate system. The actual discontinuous impact could lag the trigger by decades to centuries. These triggers are sensitive to the magnitude and rate of climate change. Large temperature increases have the potential to lead to large-scale discontinuities in the climate system (medium confidence).

These discontinuities could cause severe impacts on the regional and even global scale, but indepth impact analyses are still lacking. Several climate model simulations show complete shutdown of the North Atlantic thermohaline circulation with high warming. Although complete shutdown may take several centuries to occur, regional shutdown of convection and significant weakening of the thermohaline circulation may take place within the next century. If this were to occur, it could lead to a rapid regional climate change in the North Atlantic region, with major societal and ecosystem impacts. Collapse of the West Antarctic Ice Sheet would lead to a global sea-level rise of several meters, which may be very difficult to adapt to. Although the disintegration might take many hundreds of years, this process could be triggered irreversibly in the next century. The relative magnitude of feedback processes involved in cycling of carbon through the oceans and the terrestrial biosphere is shown to be distorted by increasing temperatures. Saturation and decline of the net sink effect of the terrestrial biosphere—which is projected to occur over the next century—in step with similar processes, could lead to dominance of positive feedbacks over negative ones and strong amplification of the warming trend. [19.6.3.2]

8. Information Needs

Although progress has been made, considerable gaps in knowledge remain regarding exposure, sensitivity, adaptability, and vulnerability of physical, ecological, and social systems to climate change. Advances in these areas are priorities for advancing understanding of potential consequences of climate change for human society and the natural world, as well as to support analyses of possible responses.

Exposure. Advances in methods for projecting exposures to climate stimuli and other nonclimate stresses at finer spatial scales are needed to improve understanding of potential consequences of climate change, including regional differences, and stimuli to which systems may need to adapt. Work in this area should draw on results from research on system sensitivity, adaptability, and vulnerability to identify the types of climate stimuli and nonclimate stresses that affect systems most. This research is particularly needed in developing countries, many of which lack historical data, adequate monitoring systems, and research and development capabilities. Developing local capacity in environmental assessment and management will increase investment effectiveness. Methods of investigating possible changes in the frequency and intensity of extreme climate events, climate variability, and large-scale, abrupt changes in the Earth system such as slowing or shutdown of thermohaline circulation of oceans are priorities. Work also is needed to advance understanding of how social and economic factors influence the exposures of different populations.

Sensitivity. Sensitivity to climate stimuli is still poorly quantified for many natural and human systems. Responses of systems to climate change are expected to include strong nonlinearities, discontinuous or abrupt responses, time-varying responses, and complex interactions with other systems. However, quantification of the curvature, thresholds, and interactions of system responses is poorly developed for many systems. Work is needed to develop and improve process-based, dynamic models of natural, social, and economic systems; to estimate model parameters of system responses to climate variables; and to validate model simulation results. This work should include use of observational evidence, paleo-observations where applicable, and long-term monitoring of systems and forces acting on them. Continued efforts to detect impacts of observed climate change is a priority for further investigation that can provide empirical information for understanding of system sensitivity to climate change

Adaptability. Progress has been made in the investigation of adaptive measures and adaptive capacity. However, work is needed to better understand the applicability of adaptation experiences with climate variability to climate change, to use this information to develop empirically based estimates of the effectiveness and costs of adaptation, and to develop predictive models of adaptive behavior that take into account decision making under uncertainty. Work also is needed to better understand the determinants of adaptive capacity and to use this information to advance understanding of differences in adaptive capacity across regions, nations, and socioeconomic groups, as well as how capacity may change through time. Advances in these areas are expected to be useful for identifying successful strategies for enhancing adaptation capacity in ways that can be complementary to climate change mitigation, sustainable development, and equity goals.

Vulnerability. Assessments of vulnerability to climate change are largely qualitative and address the sources and character of vulnerability. Further work is needed to integrate information about exposures, sensitivity, and adaptability to provide more detailed and quantitative information about the potential impacts of climate change and the relative degree of vulnerability of different regions, nations, and socioeconomic groups. Advances will require development and refinement of multiple measures or indices of vulnerability such as the number or percentage of persons, species, systems or land area negatively or positively affected; changes in productivity of systems; the monetary value of economic welfare change in absolute and relative terms; and measures of distributional inequities.

Uncertainty. Large gaps remain in refining and applying methods for treating uncertainties, particularly with respect to providing scientific information for decisionmaking. Improvements are required in ways of expressing the likelihood, confidence, and range of uncertainty for estimates of outcomes, as well as how such estimates fit into broader ranges of uncertainty. Methods for providing “traceable accounts” of how any aggregated estimate is made from disaggregated information must be refined. More effort is needed to translate judgments into probability distributions in integrated assessment models.