Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report

Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability

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Technical Summary

Confidential Second Order Draft for comment by Governments and Experts

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Important Note: This draft is not in its final form. Its content will undergo revision in response to comment. Therefore its contents should not be circulated[1] or published.

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[1] That is, circulation beyond that appropriate for a managed review.

TABLE OF CONTENTS

A. Scope, approach and method of the WGII assessment

A.1 The IPCC Fourth Assessment and this Technical Summary[2]

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

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

The Working Group II Fourth Assessment, in common with all IPCC reports, has been produced by an open and peer-reviewed process. It builds upon past assessments and IPCC Special Reports, and incorporates the results of the past five years of climate change impacts, adaptation and vulnerability research. Each chapter presents a balanced assessment of the post-TAR literature, including non-English language and 'grey' literature[3].

This Assessment aims to describe the major aspects of current knowledge of climate change impacts, adaptation and vulnerability in 2006. Specifically it addresses seven questions:

- What new research methods have led to improvements in knowledge since the 3rd Assessment? (addressed in Section A of the Technical Summary)
- What is the current knowledge about impacts of climate change which are observable now? (addressed in Section B of the Technical Summary)
- What is the current knowledge about future effects of climate change on different sectors and regions? (addressed in Section C of the Technical Summary)
- What is the current knowledge about adaptation to climate change? And what is the relationship of adaptation to mitigation? (addressed in Section D of the Technical Summary)
- What is the current knowledge about key vulnerabilities? (addressed in Section E of the Technical Summary)
- What are the implications of climate change for future sustainability? (addressed in Section F of the Technical Summary)
- What gaps exist in current knowledge and how best can these be filled? (addressed in Section G of the Technical Summary).

Each of the twenty chapters of the WGII AR4 had a minimum of two Co-ordinating Lead Authors, six Lead Authors and two Review Editors. The writing team and review editors were appointed by IPCC Bureau on the recommendation of the WGII Co-Chairs and Vice-Chairs. These were selected from the pool of nominated experts, in consultation with the international community of scientists active in the field, and taking into consideration expertise and experience. In total, the WGII AR4 involved 47 Co-ordinating Lead Authors, 127 Lead Authors, and 47 Review Editors, drawn from 74 countries. In addition there were 214 Contributing Authors and 837 Expert Reviewers.

This Technical Summary is intended to capture the most important scientific aspects of the full Assessment. Reducing the information from 800 pages to 40 requires much condensing; consequently every statement in the Summary appears with its source in the Assessment enabling the reader to pursue more detail if he or she wishes. Sourcing information is provided in square brackets in the text[4]. Uncertainty information is provided in parentheses (see Box TS-1 for definitions of uncertainty).

[2] Further information on the IPCC and the decision to produce a Fourth Assessment is given in Appendix 1.
[3] Where 'grey' literature is defined as literature which is not available through traditional commercial publication channels, such as working papers, government reports and theses, and which therefore may be difficult to access.
[4] The example source [3.3.2] refers to Chapter 3, Section 3.2. In the sourcing, F = Figure, T = Table, B = Box and ES = Executive Summary.

Box TS-1 Communication of Uncertainty in the Working Group II AR4

A set of terms to describe uncertainties in current knowledge is common to all parts of the IPCC Fourth Assessment.

Description of confidence

Authors have assigned a confidence level to the major statements in the Technical Summary on the basis of their assessment of current knowledge, as follows:

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

Description of likelihood

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

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

Box TS-2 Definitions of key terms: Climate Change, Climate Change Impacts, Adaptation, Adaptive Capacity and Vulnerability

Climate change is a statistically significant variation in either the mean state of the climate or in its variability over an extended period (typically decades or longer). This definition includes climate changes due to natural causes, and so differs from that of the United Nations Framework Convention on Climate Change where climate change is "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".

Climate change impacts are the consequences of climate change on natural and human systems.

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

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.

A.2 Underpinning scenarios for the Working Group II Fourth Assessment

A.2.1 Characterising the future in this assessment

Climate impact, adaptation and vulnerability (CCIAV) (see Box TS-2 for definitions) assessments are based around information on how climatic, socio-economic and other environmental conditions are expected to develop in the future. This information usually requires the development of scenarios, storylines or other representations of the future, preferably disaggregated to the regional or local scale [2.2.2.1].

At the time of the TAR, most CCIAV studies made use of climate scenarios (many based on the IS92 emissions scenarios), but very few studies applied contemporaneous scenarios of socio-economic, land use or other environmental changes. Those that did used a range of heterogeneous sources to develop them [2.3].

The IPCC Special Report on Emissions Scenarios (SRES), published in 2000, provided scenarios of future greenhouse gas emissions accompanied by storylines of social, economic and technological development that can be used in CCIAV studies (Fig. TS-1). Although there can be methodological problems in applying these scenarios (for example, in downscaling projections of population and GDP from global to regional scales), they nevertheless provide a coherent global quantification of socio-economic development, greenhouse gas emissions and climate [2.2.2.8; 2.3.1.5]. As such, they represent the most comprehensive scenarios presently available to CCIAV researchers. In the future, fully-integrated scenarios of future emissions, climates, societies and technologies are likely to more completely meet the needs of researchers in the areas addressed by Working Group II [2.4]. Many of the CCIAV studies assessed by the WGII AR4 are based on SRES scenarios.

Economic emphasis

Global Integration	**A1 storyline:** World: market-oriented Economy: fastest per capita growth Population: 2050 peak, then decline Governance: strong regional inter-actions; income convergence Technology: three scenario groups: • **A1FI**: fossil intensive • **A1T**:non-fossil energy sources • **A1B**: balanced across all sources	**A2 storyline** World: differentiated Economy: regionally oriented; low-est per capita growth Population: continuously increasing Governance: Self-reliance with preservation of local identities Technology: slowest and most fragmented development	**Regional emphasis**
	B1 storyline World: convergent Economy: service and information based; lower growth than A1 Population: same as A1 Governance: global solutions to economic, social and environmental sustainability Technology: clean and resource-efficient	**B2 storyline** World: local solutions Economy: intermediate growth Population: continuously increasing at lower rate than A2 Governance: local and regional solutions to environmental protec-tion and social equity Technology: More rapid than A2; less rapid, more diverse than A1/B1	

Environmental emphasis

Fig. TS-1: Summary characteristics of the four SRES storylines [2.3.1.1]

A.2.1.1 Characterising future climate

Sensitivity studies: A substantial number of model-based CCIAV studies assessed in this report employ sensitivity analysis, that is, they examine the perturbation of a response variable due to prescribed, usually arbitrary, perturbations (for example, a 2^{o}C increase in temperature and a 10% reduction in precipitation). Using a range of perturbations allows construction of impact response surfaces, which are increasingly being used in combination with probabilistic representations of future climate to assess risk of impact [2.2.2.3; 2.2.3.1].

Analogues: Historical extreme weather events, such as floods, heatwaves, and droughts, are increasingly being analysed with respect to their impacts and adaptive responses. Since these may become more frequent and/or severe in the future, such studies can be useful for planning adaptation responses [2.2.2.4].

Climate model data. The majority of quantitative CCIAV studies assessed in the AR4 use climate models to generate the underlying scenarios of climate change. Some scenarios are based on pre-SRES emissions scenarios, such as IS92a, or even on equilibrium climate model experiments. However, the greatest proportion are derived from SRES emissions scenarios, principally the A2 scenario. A few scenario-driven studies explore singular events with widespread consequences, such as an abrupt cessation of the North Atlantic meridional overturning circulation [2.2.2.6; 2.2.2.12]

The CCIAV studies assessed in the WGII AR4 are generally based on climate model simulations assessed by WGI in the TAR. Since the TAR, new simulations have been performed with coupled atmosphere-ocean general circulation models (AOGCMs) assuming SRES emissions. These are assessed in the WGI AR4, but most were not available for the CCIAV studies assessed by the WGII AR4. Fig. TS-2 compares the temperature and precipitation projections from the recent model runs (assessed by WGI AR4) with those from the model runs used for scenario construction in the CCIAV studies assessed by the WGII AR4 (and assessed by WGI TAR). WGI AR4 authors conclude that the basic pattern of projected warming is little changed from previous assessments, with the inter-model range of warming at 2100 for the A2 scenario somewhat smaller than the range in the TAR, despite the larger number of models. [2.3.1.2]

A.2.1.2 Non-climate scenarios of the future

CCIAV studies increasingly include scenarios of changing socio-economic, land use and other environmental conditions, which can substantially alter assessments of the effects of future climate change. Thus, while TAR impact studies typically gave a single estimate of impacts, based around a single climate model simulation of the future, AR4 studies which include SRES assumptions may now have several estimates, taking into account different storylines. The role of non-climate drivers such as technological change and regional land use policy is shown in some studies to be more important in determining outcomes than climate change. This expansion of scenario scope and application has brought into focus the wide range of potential future impacts and their associated uncertainties. [2.2.2.8; 2.3.1.6]

A.2.1.3 Mitigation/stabilisation scenarios

The SRES storylines assume that no specific climate policies will be implemented to reduce GHG emissions (i.e. mitigation). CCIAV studies which assume mitigation are important because they provide crucial information for weighing trade-offs between the potential costs of mitigation and the impacts of climate change. [2.3]

Stabilisation scenarios are a type of mitigation scenario describing futures in which emissions reductions are undertaken so that greenhouse gas concentrations or global average temperature changes do not exceed a prescribed limit. There have been very few studies of the impacts of climate change assuming stabilisation [2.3.2.1]. One reason for this is that relatively few AOGCM stabilisation runs have been completed so far, although the situation is rapidly changing. Some of the SRES scenarios closely resemble mitigation scenarios and could be used as surrogates. The radiative forcing associated with stabilisation at 750 ppm is very similar to that associated with the A1B scenario, at 650 ppm with the B2 scenario and at 550 ppm with the B1 scenario. No SRES surrogates exist for stabilisation below 550 ppm. More problematic is the identification of regional socio-economic, land use and other scenarios that are commensurate with a future of mitigated emissions. [2.3.2.2]

A.2.1.4 Singular events with widespread consequences

Very few studies have been conducted on the impacts of singular events with widespread consequences (principally climates under an abrupt cessation of the North Atlantic meridional overturning circulation, and rapid global sea-level rise due to Antarctic and/or Greenland ice sheet melting) [2.2.2.12]. Due to incomplete understanding of the underlying mechanisms, in particular timing of the events, only exploratory studies have been carried out. For example, in terms of exploring the worst case scenario of abrupt sea level rise, impact assessments have been conducted for the coastal zone for a 5 m rise, and for a 2.2 m rise by 2100 [2.2.2.12]. This is the first time these scenarios have been included in any WGII assessment, and the expectation is that many more such studies will become available for assessment in future.

A.2.1.5 Probabilistic characterisations

Probabilistic characterisations of future climate and non-climate conditions are increasingly becoming available. A number of studies focused on the climate system have generated probabilistic estimates of climate change, conditional on selected emissions scenarios, but deriving probabilistic representations of global emissions has been more controversial [2.2.2.14]. Probabilistic futures have been applied in a few CCIAV studies to estimate the probability of exceeding predefined thresholds of impact and the associated timing of this exceedance. [2.2.3.1]

A.3 Developments in methods available to researchers on climate change impacts, adaptation and vulnerabilities

Since the Third Assessment Report, the demand for policy-relevant information concerning CCIAV has seen the number of different methods in use expand significantly [2.1]. Although the standard climate scenario-driven approach dominates the assessments described in this report, a number of other approaches have been developed and their use is increasing. [2.2.3]. They include assessments of current and future adaptations to climate, social vulnerability, adaptive capacity and how climate change can be incorporated with sustainable development. The sophistication and range of scenarios is also increasing, driven in part by policy demand, and also due to better access to data and to model improvements. [2.2.2]

Risk management. There is an emerging recognition that risk management is an appropriate unifying framework for decision-making on climate change related threats and opportunities [2.ES]. Advantages of risk management methods include the flexibility to incorporate a range of mental models, formalised methods to manage uncertainty, stakeholder involvement, methods for evaluating policy options without being policy prescriptive and integration of different disciplinary approaches. [2.2.1]

A wider range of methods is being applied. A range of approaches is being utilized under both risk assessment and in their own right. They include adaptation assessment and vulnerability assessment along with mainstreaming climate adaptation into more conventional development processes. [2.2.3]

Integration of current and future adaptation. An understanding of the ability of a group or system to cope with current climate risks is an important part of undertaking CCIAV assessments for the future. [2.2.3.5]

Stakeholder participation is vital to the assessment process, and the majority of vulnerability and adaptation assessments now being undertaken are now engaging stakeholders. [2.2.3.3]

(a) Temperature change (°C per century) **(b) Precipitation change (percent per century)**

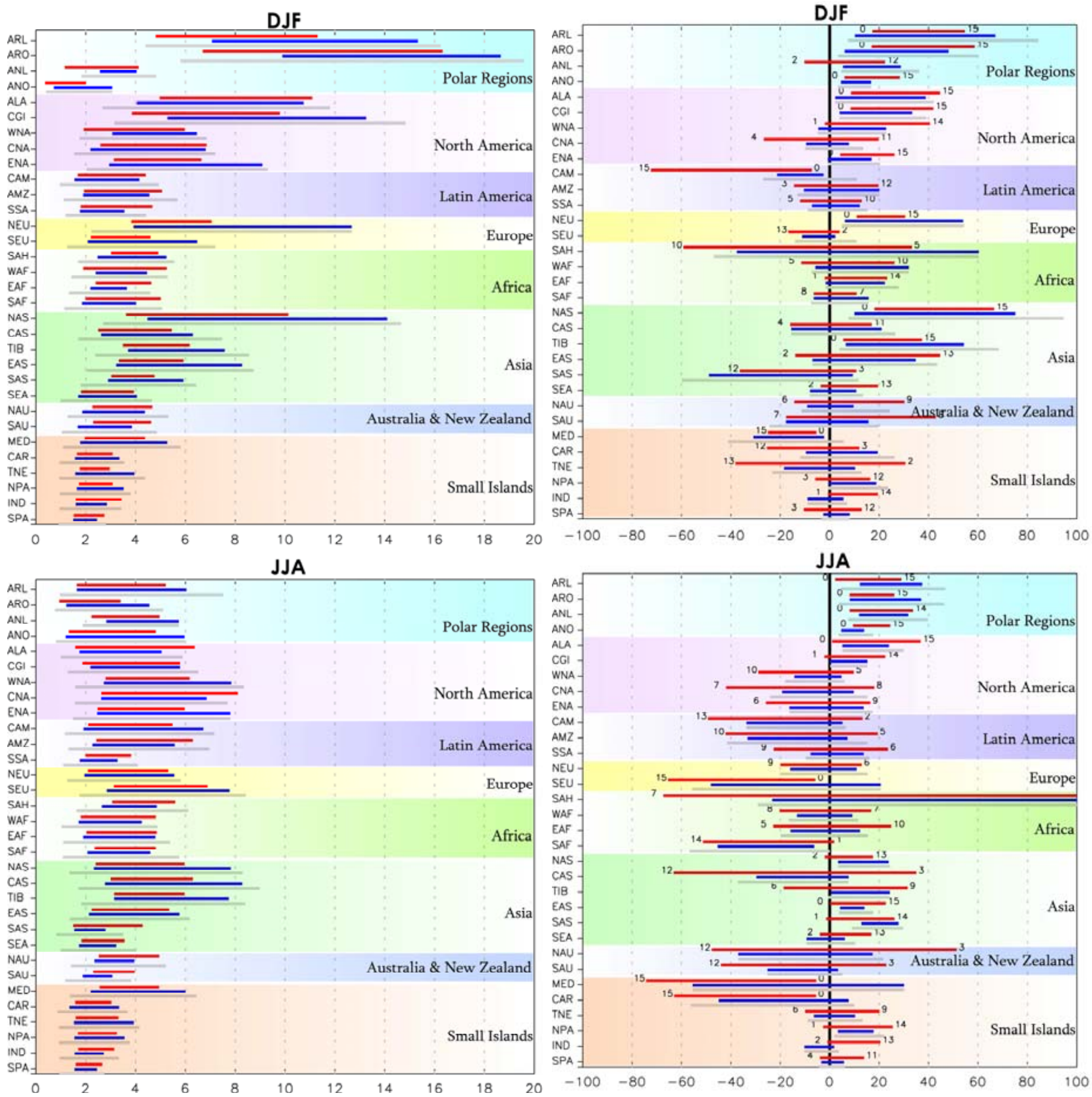


Fig. TS-2: AOGCM projections of winter and summer seasonal temperature and precipitation changes up to the end of the 21st century for 32 world regions, expressed as rate of change per century. [F2.7]
Red bar: range from 15 recent AOGCM simulations for the SRES A2 emissions scenario.
Blue bar: range from 7 pre-TAR AOGCMs for the A2 emissions scenario.
Grey bar: range from 7 pre-TAR AOGCMs for the B1, B2, A2 and A1FI SRES emissions scenarios.
DJF: December, January, February. JJA: June, July, August.
For full explanation of regions see Chapter 2 Fig. 2.7.

B. Impacts observable now

Many of the climate-driven observed changes in physical and biological systems can now be jointly attributed[5] to temperature increase caused by greenhouse gas emissions (high confidence).

The IPCC WGII TAR found evidence that recent regional climate changes, particularly temperature increases, have already affected physical and biological systems [1.1.1]. AR4 has analysed studies since the TAR showing changes in physical, biological and human systems mainly from 1970 to 2005 in relation to climate drivers and has found stronger quantitative evidence [1.3, 1.4]. The major climate factors are global and regional surface temperature increases. [1.2]

Evaluation of evidence on observed changes related to climate is made difficult because the observed responses of systems and sectors are influenced by many other factors. Non-climatic drivers can influence systems and sectors directly and/or indirectly through their effects on climate variables such as reflected solar radiation and evaporation [1.2.1.2]. Socio-economic processes, including land-use change (e.g., agriculture to urban area), land-cover modification (e.g., ecosystem degradation), technological change, and pollution are of major importance [1.2.1.2]. Increasing understanding of the interactions among physical, biological and socio-economic systems means that we have more confidence in interpreting the responses and in causally linking them to climate change. [1.2.1]

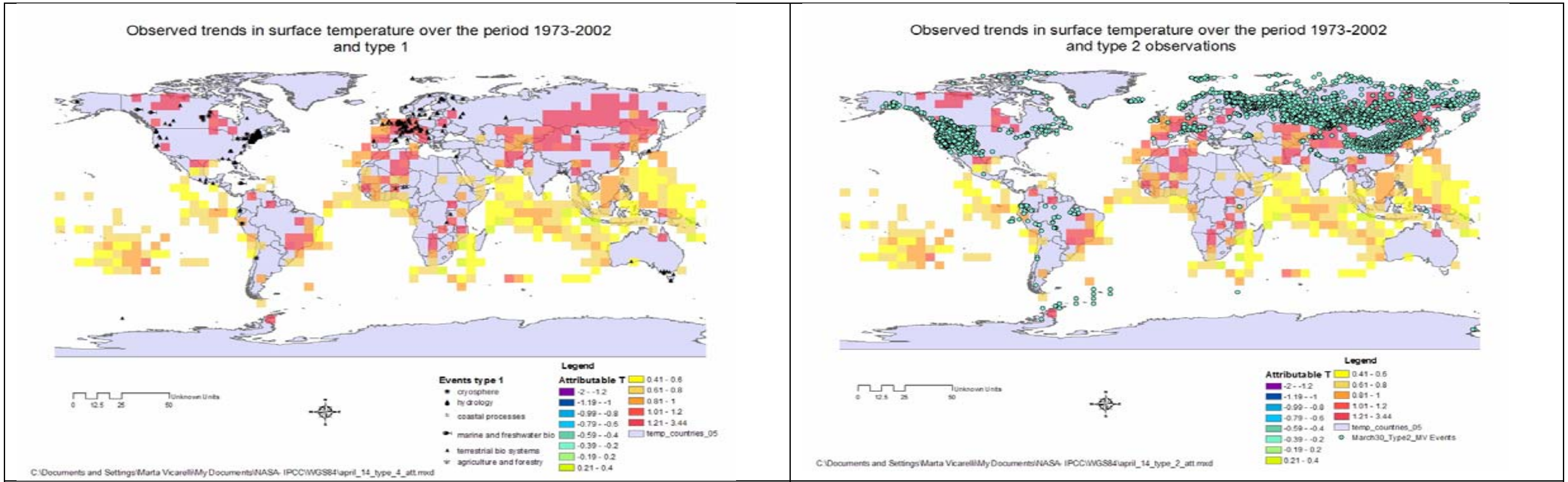
Nevertheless, the balance of evidence points to a clear response of physical and biological systems to greenhouse gas and aerosol forcing. [1.4] Observed responses in multiple systems and sectors have been jointly attributed to anthropogenic climate change through attribution of the responses to regional warming and attribution of the regional warming to anthropogenic climate change (Fig. TS-3) [1.4.2]. A statistical comparison shows that the agreement between the regions of significant and attributable regional warming across the globe and the locations of significant observed changes in systems consistent with warming is very unlikely to be due to natural variability in temperatures or natural variability in the systems (Table TS-1).

Table TS-1: Presence/absence of regional temperature changes and presence/absence of observed responses.

	Observed responses in sectors and systems:		
	Type 1	**Type 2**	**Type 3**
Consistent with warming	83	312	426
Not consistent with warming	13	29	-
	106	341	426

The figures above indicate total amount of cells. Total amount of cells (world coverage): 2560 [T1.12]

[5] Joint attribution: a two-stage process whereby system response is linked to climate change forcing through, first, attribution of the system response to regional warming and, second, attribution of regional warming to anthropogenic global climate change.



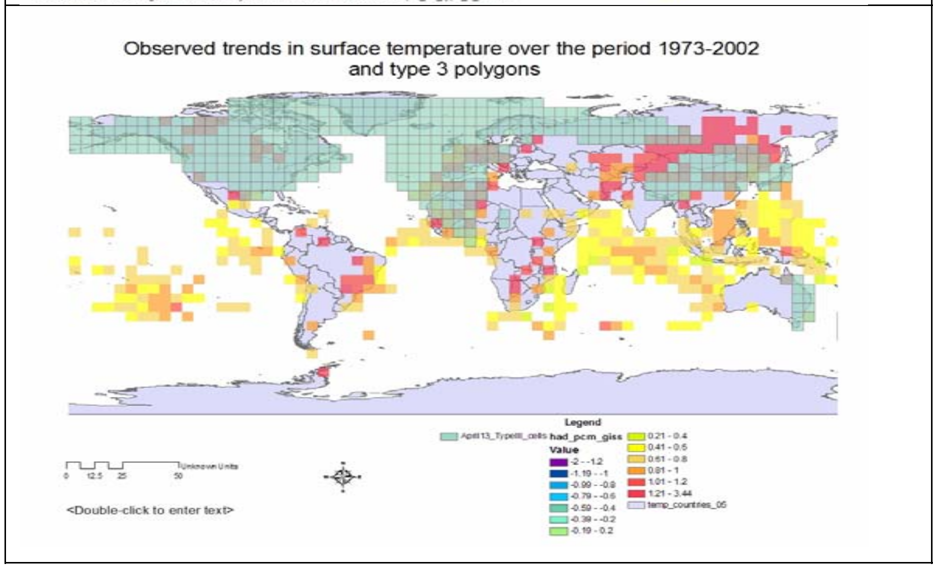


Fig. TS-3: Observed trends in sectors and systems, shown with regional temperature warming attributable to anthropogenic forcing.
Map A shows Type 1 observations, i.e., individual observations analysed individually
Map B shows Type 2 observations, i.e., individual observations analyzed collectively
Map C shows Type 3 studies, i.e., studies corresponding to very large areas not associated with individual sites. [F1.8]

1

B.1 Physical Systems

For physical systems, i) there is more and stronger evidence since the TAR that climate change is affecting natural and managed systems in the cryosphere, and ii) there is now evidence of effects on hydrology and water resources, oceans, and coastal processes and zones, a finding that is new since the TAR (high confidence).

The main cryosphere evidence is found in increasing glacial floods, ice and rock avalanches in mountain regions, runoff in snow and glacial basins, changes in Arctic mammals and Antarctic Peninsula fauna, effects on permafrost-based infrastructure and indigenous livelihoods in the Arctic, and ski centres affected by decreasing snow cover in lower-elevation alpine areas [1.3.1]. These changes parallel the abundant evidence that the cryosphere, including Arctic sea ice, freshwater ice, ice shelves, Greenland ice sheet, alpine and Antarctic Peninsula glaciers and ice caps, snow cover, and permafrost, is undergoing melting in response to global warming**.** [1.3.1]

Recent evidence in hydrology and water resources shows that since the TAR, there is more evidence that the hydrological cycle is intensifying in regard to runoff/streamflow, droughts and floods, thermal structure of lakes, and water quality [1.3.2]. There is an increasing trend in runoff in large basins in the Eurasian Arctic which agrees with recent regional rainfall trends and permafrost melting. Areas most affected by increasing long-term droughts, decreasing runoff and decreases in some lake levels related in some cases to human activities, are located in drier regions [1.3.2]. However, in wetter areas there is no consistent pattern of trends [1.3.2.2]. Lakes and rivers around the world are warming, with effects on thermal structure and lake chemistry. [1.3.2.1]

Ocean acidification is occurring although the impacts, for example on corals and the marine biosphere are as yet uncertain [1.3.4]. Evidence indicates that the average pH of surface sea water has fallen by 0.1 units in the last 200 years. This represents a 30% increase in the concentration of hydrogen ions in the surface oceans. [1.3.4]

Coastal processes and zones indicate evidence that sea-level rise, enhanced wave heights, and increased intensity of storms are affecting some coastal regions distant from human modification, e.g., polar areas and barrier beaches, mainly through coastal erosion [1.3.3]. Although local sea-level rise is contributing to losses of coastal wetlands and mangroves, and increased damages from coastal flooding in many areas, human modifications of coasts, such as increased construction in vulnerable zones, play an important role as well [1.3.3.2]. In many coastal regions, local sea level rise exceeds the global trend of ~1.7mm/yr, due to both climate change (thermal expansion of seawater and meltwater additions) and local land subsidence. These areas are more vulnerable to coastal flooding, shoreline erosion, and losses of wetlands. [1.3.3]

B.2 Biological Systems

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

In marine and freshwater biological systems, many observed responses in phenology and distribution have been associated with rising water temperatures, as well as changes in salinity and oxygen levels [1.3.4]. Climate change and variability, in combination with human impacts, have already caused substantial damage to coral reefs [1.3.4.1]. The documented poleward movement of plankton and fish by 10^{o} over a period of 4 decades in the North Atlantic is larger than any documented terrestrial study [1.3.4.2]. Warming lakes and rivers are affecting abundance and productivity, community composition, phenology, distribution and migration. [1.3.4.4]

In terrestrial biological systems the overwhelming majority of studies exhibiting significant warming impacts on terrestrial species reveal consistent responses to regional climate trends, including poleward and elevational range expansions of flora and fauna [1.3.5]. Responses of terrestrial species to warming across the northern hemisphere are well documented by phenological changes, especially the earlier onset of spring events and a lengthening of the growing season [1.3.5.2]. Changes in abundance for certain species over the last few decades have been attributed to climate change, including a few key butterfly examples of disappearance. [1.3.5.4]

B.3 Human Systems

Although responses to recent climate changes in human systems are difficult to detect due to multiple non-climate driving forces and the presence of adaptation, effects are now detectable in a few agricultural and health systems (medium confidence).

Regarding agriculture and forestry, in temperate regions in large parts of North America and Europe, there is an advance in phenology, with limited evidence documenting management responses to the shortening of crop-cycle duration [1.ES]. Lengthening of the growing season contributes to an observed increase in forest productivity [1.3.6]. For arid regions such as the Sahel, reductions in precipitation and temperature increases on decadal scales have contributed to lower crop yields [1.3.6.1]. The effects of gradual warming to date are of limited consequence for crop production in comparison with other non-climatic factors, except for viticulture, with documented improvement of grape quality in Europe and the U.S. However, both the agriculture and forestry sectors have shown vulnerability to recent extremes in heat, droughts, and floods [1.3.6].

There is emerging evidence of climate change having some detectable effects on human health. There have been changes in the distribution of some vectors of human diseases, such as ticks in Sweden; and of changes in the seasonal production of pollens that cause allergenic diseases in Europe [1.3.7]. High temperature extremes, which are an important exposure for human health, were associated with excess mortality during the 2003 heatwave in Europe, although health effects related to increasing heatwaves elsewhere have not been demonstrated [1.3.7].

Global losses reveal rapidly rising costs due to extreme weather-related events since the 1970s. While the dominant signal remains that of the significant increases in the values of exposure at risk, once losses are normalised for exposure, there still remains an underlying rising trend (medium confidence).

For specific regions and perils, including extreme floods on some of the largest rivers, there is evidence for an increase in occurrence [1.3.8]. For tropical cyclones, in particular in the Atlantic Ocean and Northwest Pacific, over the past 30 years, significant increases have occurred in the proportion of storms at the highest intensity (Categories 4 and 5) as well as in the cumulative ‘power dissipation’ of storms (a combination of intensity and duration) that correlates with increases in sea surface temperatures in the main cyclone development regions. [1.3.8]

C. Current knowledge about the main likely future effects

C.1 Impacts on, adaptations and vulnerabilities of sectors

A summary of impacts expected for each sector is given in Box TS-3

WATER RESOURCES

Climate-driven changes in volume and timing of river flow have already been observed and have effects on water management (high confidence).
In many pristine rivers in parts of North America, increases in strong winter climate-related runoff have been detected. In some other regions, snowmelt has led to water supply reductions. In Australia, a strong decrease in precipitation during the last decades has led to large investments in water management [3.2].

The most certain impacts of climate change on freshwater and its management are due to increases in temperature and sea level rise (high confidence).
More than one sixth of the global population lives in snow-dominated river basins and will be affected by seasonal shifts in streamflow caused by decreased snow water storage. Sea level rise will extend areas of salinization of groundwater. Thus, freshwater availability in the coastal zone will decrease [3.3.1, 3.4.1, 3.4.3].

Increases in precipitation variability in future are expected to increase the risk of floods and hydrological droughts (high confidence).
Since TAR, there has been new understanding of changes in extreme climate events affecting water and the occurrence of floods and droughts. Changes in precipitation extremes are projected in many areas of the globe. For example, extremes of daily precipitation in northern Europe are very likely to increase, as is drought in southern areas of Australia. Increases in the number of days with intense precipitation have been projected in most parts of Europe [3.4.4].

Quantitative projections of changes in flows and water levels at the basin scale, especially beyond 2020, remain uncertain (high confidence).
Since TAR, uncertainties have been evaluated and improved. However, regional precipitation projections differ widely between climate models. This has implications for adaptation procedures, which need to be developed based on imperfect projections of changes, for example, in river discharge. The uncertainties of the impact of climate change on water resources have been shown to be mainly due to uncertainties in precipitation inputs and less due to the uncertainties in greenhouse gas emissions or to climate sensitivities or in the hydrological models themselves. [3.3.1, 3.4.1]

Warming and extreme events are expected to worsen different types of water pollution, with impacts on human health and the environment (high confidence).
Nitrates, dissolved organic carbons, viruses, thermal pollution and enteric bacteria, among others, are affected by warming and extremes events. It can be expected that the impact of climate change on other pollutants will become evident in the future. [3.4.5]

Climate change is one of multiple pressures on water resources (high confidence).
In many areas, and particularly in water-shortage areas, anthropogenic pressures such as population and economic growth, land use and urbanization, rather than climate change, can be the most decisive factors behind adverse changes in freshwater resources. However, climate change is expected to exacerbate the effects of these multiple stresses on water resource conditions. [3.1]

Water management should incorporate the impacts of climate change on water resources (high confidence).
In water management, the past can no longer be the only basis for planning the future, since the stationarity assumption is no longer valid. Water managers in some countries or regions have adopted a risk management approach in order to account for the uncertainties (e.g., the Caribbean, Canada) [3.5].

Globally, water demand will grow due to climate change, and groundwater recharge in some already water stressed regions will decrease very strongly due to climate change [3.4.3]. Estimates of future changes in runoff are shown in Fig. TS-4, together with future climate impacts on freshwater resources which pose a risk to sustainable development [3.7].

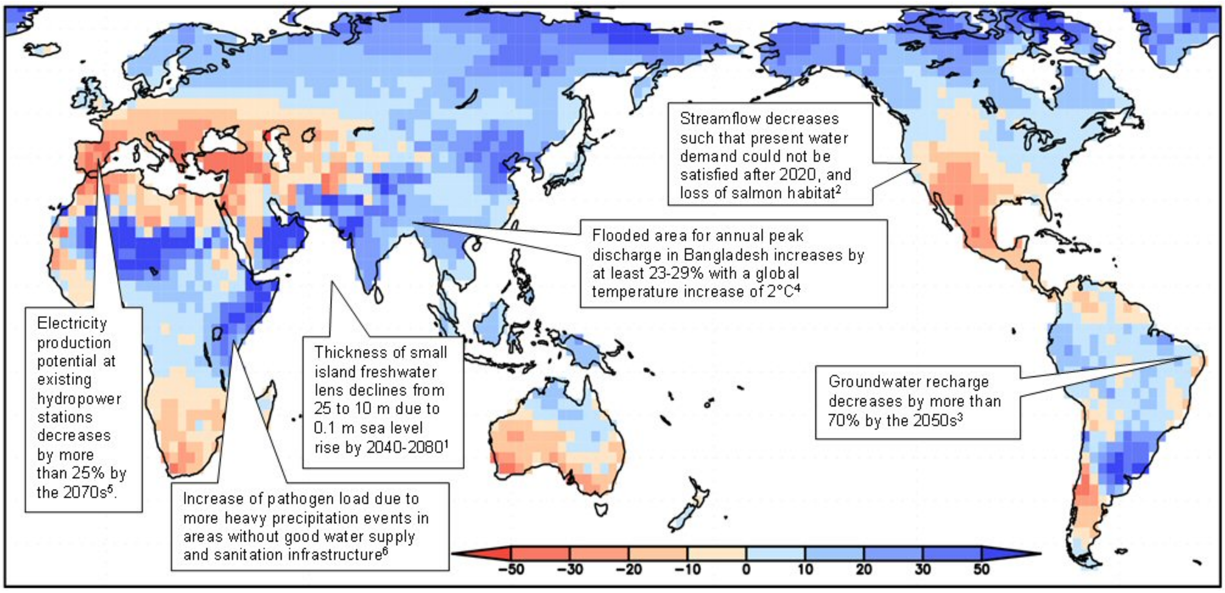


Fig. TS-4: Global map of future runoff changes and future climate impacts on freshwater resources which pose a risk to sustainable development. Runoff changes are between present (1981-2000) and 2100, in units of mm/day, where blue indicates increased runoff and red decreased runoff. [F3.7]

ECOSYSTEMS

The responses of ecosystems and their component species to climate change are complex and include rapid, lagged and threshold effects, many of which interact with other anthropogenic drivers (high confidence).

New evidence and findings demonstrate that ecosystems will be affected by climate and global change in a range of ways through

- direct impacts on the physical (temperature, precipitation) and chemical (CO2 fertilization, ocean acidification) environment,
- impacts on their component species such as geographic range shifts, changing interactions between species and changing species composition,
- changes in functions such as diversity maintenance, productivity, carbon sequestration, water cycling, and
- shifts in natural disturbance regimes such as fire, grazing, pests, extreme climatic events.

[4.1.2, 4.1.3, 4.2]. While some of these effects may be considered beneficial with low levels of change, (e.g., increased global terrestrial productivity with temperatures below 2ºC mean global change), many will be detrimental, e.g. increased risk of irreversible extinction [4.4.11]. Fig. TS-5 gives examples of impacts on ecosystems [T4.2, F4.5].

Expected trends in anthropogenic drivers of biodiversity, such as land use change, will tend to exacerbate climate change impacts, with few exceptions [4.4.10, 4.4.11]. In several cases impacts from human drivers will surpass those from climate change in the short to medium term (~2030). [4.2.3, 4.4.10, 4.4.11]

The mechanisms behind ecosystem and species responses to climate change have become better understood since the TAR, though significant uncertainties remain in projections of system thresholds of key relevance and irreversible developments such as growing risks of species' extinctions (high confidence).

This improved understanding suggests mostly species-specific responses [4.2.1, 4.4]. In some cases, novel ecosystems may be expected to form [4.4]. Uncertainties confront human use of services and goods coming from such ecosystems, and their properties [4.4.11]. Studies based on palaeo data suggest that, in addition, major shifts in ecosystem structure will occur in some regions [4.2.1, 4.4.10]. It is to be expected that strong ecosystem responses will in many instances become evident only once the resilience of the impacted ecosystems has already been exceeded. [4.4.5, 4.4.6, 4.4.10, 4.4.11]

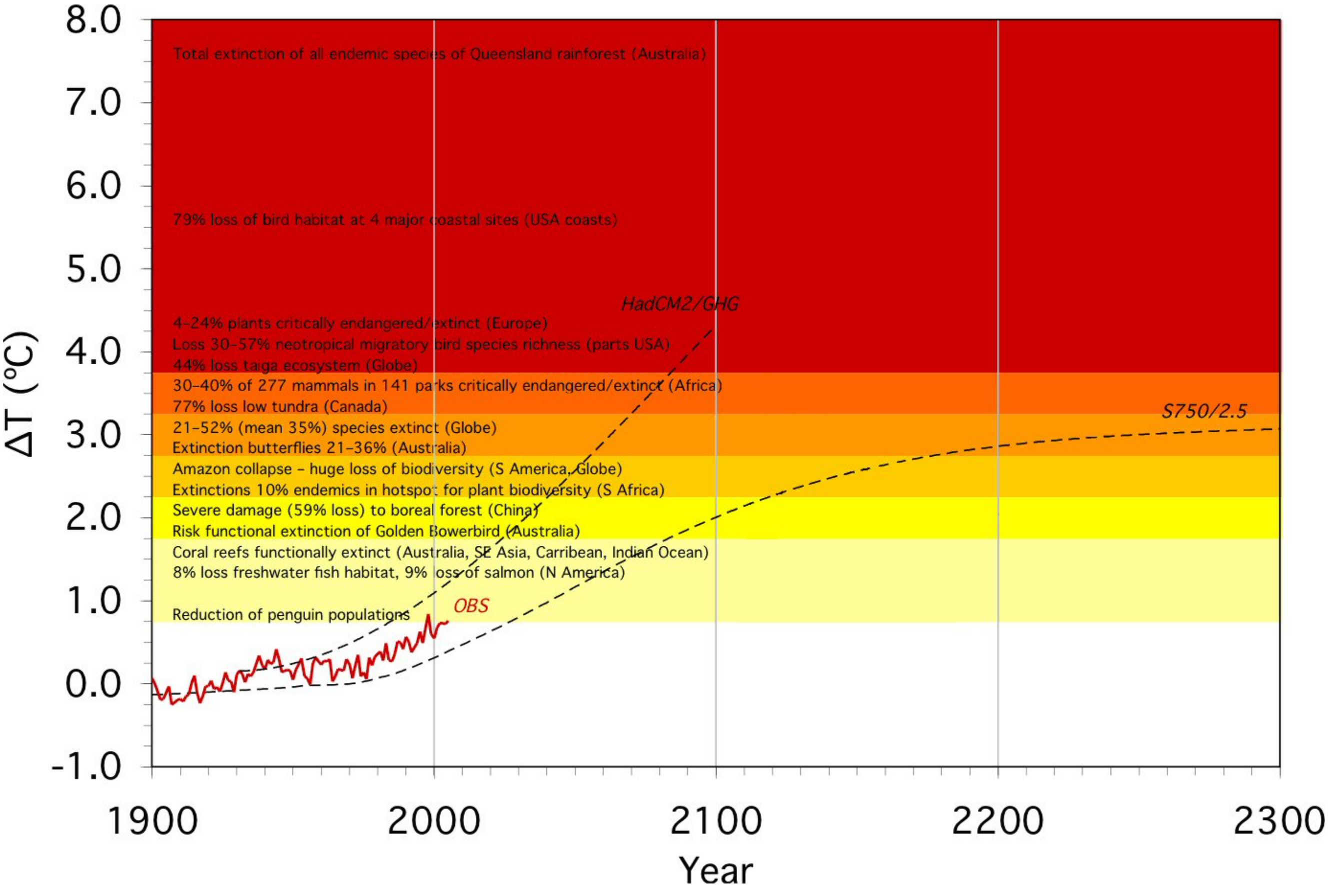


Fig. TS-5: Selected key impacts of climate change on ecosystems. [F4.5]

Projected impacts on biodiversity are significant and of key relevance, since global losses in biodiversity are irreversible, see Fig. TS-5 (high confidence).
Biodiversity is a prerequisite for the functioning of any ecosystem. If diversity losses exceed certain thresholds of resilience, ecosystem services will falter or stop, goods and services will diminish and human welfare will be significantly impacted. [4.4, in particular 4.4.11]

Species ranges are likely to shrink by 2050. About one fifth to one third of the species may be committed to extinction by that time with those risks increasing for the second half of this century [4.4.11] and beyond [Fig. TS-5]. Particularly vulnerable are mountains [4.4.7], polar regions [4.4.6], the Southern Ocean, and coral reefs [4.4.9]. In many cases, the ability of species to persist in the wild requires migration rates that exceed their natural adaptive capacity [4.4.5]. However, time-lag effects [4.4.5, 4.4.6, 4.4.10] and other uncertainties still confound projections of increasing risk of species extinctions. [4.4]

Though autonomous adaptation by mobile wild species in response to temperature increases in the past three decades has been observed, past extinctions and model based projections into the future suggest limits to adaptation and consequently vulnerability of many endemic species such as corals [B4.5], amphibians in tropical montane cloud forests [4.4.5], Antarctic birds or Arctic marine mammals [B4.4; 4.4]

Considerable progress has been achieved in understanding the role of ecosystems in the global biogeochemical cycles such as the global carbon cycle (high confidence).

The relative roles of CO_2 fertilization, nutrient loads, water balance, and age structure effects on carbon sequestration by ecosystems are now better understood: CO_2 fertilization is expected to be more constrained than was previously thought and other effects are likely to be at least as relevant [4.4.1]. Impacts on water use efficiency, albedo and surface roughness arising from CO_2 fertilization effects on vegetation are considerably less well understood. [4.4.1]

It is expected that, during the next two decades, biospheric sinks will continue to offset the projected anthropogenic emissions in a similar magnitude as at present (~ one quarter), but are expected to peak by or before the second half of this century, decline afterwards, and turn into a net carbon source towards the end of this century. [4.4.1, F4.2]

Strong interactions between species, and other unknowns such as future human drivers, remain a significant uncertainty for projecting impacts on species under climate change (high confidence). Climate change may foster or reduce the occurrence of particular pests, diseases, or pathogens [e.g. 4.4.5], which represents a major source of uncertainties and risks [4.4]. The increased susceptibility of ecosystems to alien invasive species under most climate change scenarios is a major uncertainty for both biodiversity and ecosystem functioning. [4.2.3, 4.4]

FOOD, FIBRE AND FOREST PRODUCTS (FFF)

While moderate warming benefits crop and pasture yields in temperate regions, even slight warming decreases yields in seasonally dry and tropical regions (medium confidence). The preponderance of evidence from models suggests that moderate local increases in temperature (to 3ºC) can have small beneficial impacts on major rain-fed crops (maize, wheat, rice) and pastures in temperate regions but even slight warming in seasonally dry and tropical regions reduces yield. Further warming has increasingly negative impacts in all regions (see Fig. TS-6) [5.4.2]. Furthermore, modelling studies that include extremes in addition to changes in mean climate show lower crop yields than for changes in means alone, strengthening similar TAR conclusions [5.4.1]. A change in frequency of extreme events is likely to disproportionately impact small-holder farmers and artisan fishers. [5.4.7]

New experimental research on CO_2 fertilisation suggests smaller effects on crop and forest systems than earlier experimental results suggested. Crop models include CO_2 estimates close to the upper range of new research (high confidence) while forest models may overestimate CO_2 effects (medium confidence). Recent results from Free Air Carbon Enrichment (FACE) studies of carbon dioxide fertilisation confirm conclusions from the TAR that crop yields at 550 ppm CO_2 concentration increase by an average of 15%. Crop model estimates of CO_2 fertilisation are in the range of FACE results [5.4.1.1]. Results from the FACE studies of CO_2 enrichment to 550 ppm on trees suggest a smaller overall effect than is assumed by some of the forest sector models. [5.4.1.1]

Globally, forestry production is estimated to change only modestly with climate change in the short and medium term (high confidence). Overall, changes in global forest products output at 2020 and 2050 range from a modest increase to a slight decrease, depending on the assumed impact of CO_2 fertilisation and the effect of processes not well represented in the models (e.g., pest effects). Regional and local changes will be large. [5.4.5.2]

Local extinctions of particular fish species are expected at edges of ranges (high confidence). Regional changes in the distribution and productivity of particular fish species will continue and local extinctions will occur at the edges of ranges, particularly in freshwater and diadromous species (e.g. salmon, sturgeon). In some cases, ranges and productivity will increase. Emerging evidence suggests concern that the Meridional Overturning Circulation is slowing down, with serious potential consequences for fisheries. [5.4.6]

Food and forestry trade is projected to increase in response to climate change, with increased food import-dependence of most developing countries (medium to low confidence).

While the purchasing power for food is reinforced in the period to 2050 by declining real prices, it would be adversely affected by higher real prices for food from 2050 to 2080 [5.6.1, 5.6.2]. Food security in many of the regions expected to suffer more severe yield declines is already challenged. Agricultural and forestry trade flows are foreseen to rise significantly. Exports of temperate zone food products to tropical countries will rise, [5.6.2] while the reverse may take place in forestry. [5.4.5]

Simulations suggest rising relative benefits of adaptation with low to moderate warming (medium confidence), although adaptation may stress water and environmental resources as warming increases (low confidence).
There are multiple adaptation options that imply different costs, ranging from changing practices in place to changing locations of FFF activities [5.5.1]. The potential effectiveness of the adaptations varies from only marginally reducing negative impacts to in some cases changing a negative impact into a positive impact. On average in cereal cropping systems adaptations such as changing varieties and planting times enable avoidance of a 10-15% reduction in yield. The benefit from adapting tends to increase with the degree of climate change up to a point (Fig. TS-6). Pressure to cultivate marginal land or to adopt unsustainable cultivation practices as yields drop may increase land degradation and endanger biodiversity of both wild and domestic species. Climate changes increase irrigation demand in the majority of world regions due to a combination of decreased rainfall and increased evaporation arising from increased temperatures which, combined with expected reduced water availability, adds another challenge to future water and food security. [5.7]

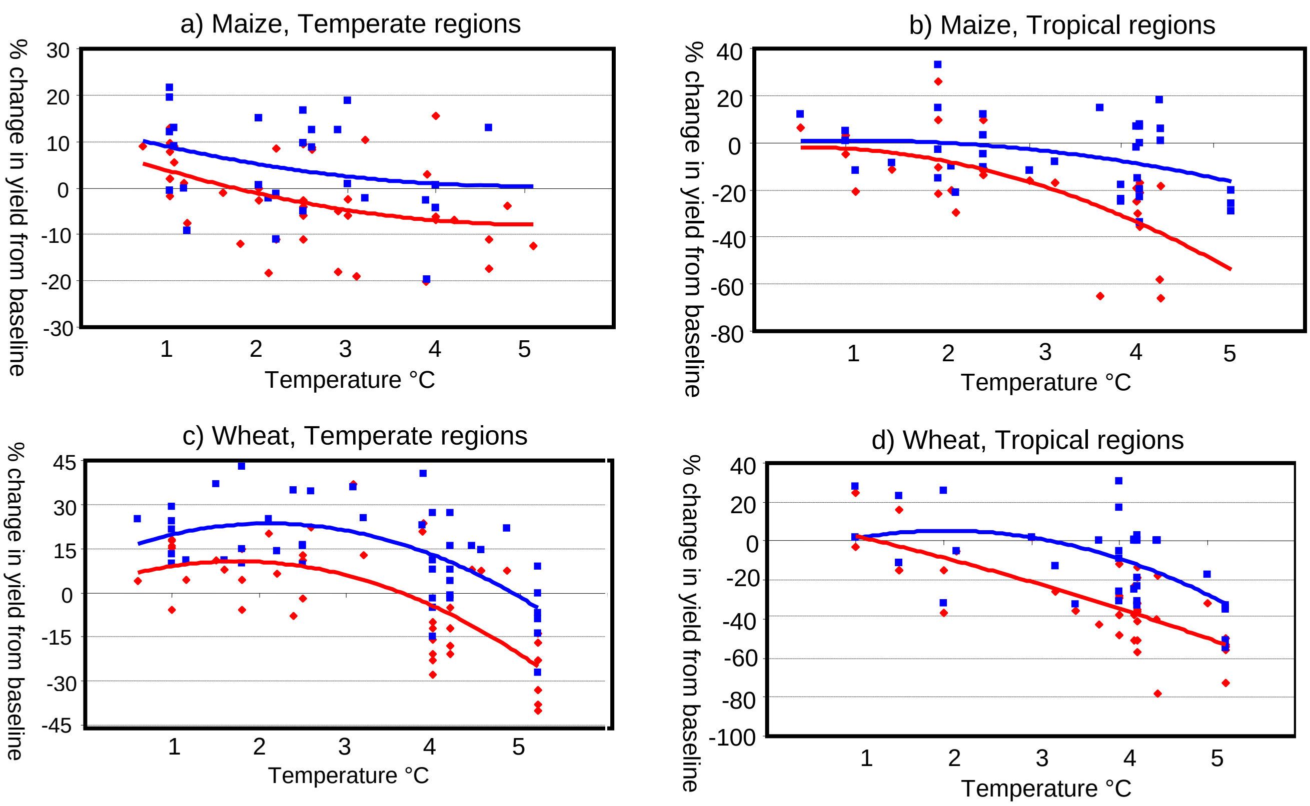


Fig. TS-6: Yield sensitivity to climate change for wheat and maize, for temperate and tropical regions. Red: without adaptation. Blue: with adaptation. [F5.2]

COASTS

Coastal and low-lying areas are highly vulnerable to climate-induced hazards (very high confidence).
Coastal areas contain globally significant numbers of people and produce important ecosystem services. As identified in the TAR, coastal areas are already under multiple stresses from both natural and human pressures, and it is almost certain that these stresses will intensify through the 21st Century due to significant population growth and urbanisation among other changes. Recent events have shown that these

areas are highly vulnerable to climate-related hazards, even in wealthy countries (e.g. Hurricane Katrina). Thus climate change is a major challenge in coastal areas. [6.2]

Climate change for coastal systems and low-lying areas is more than sea-level rise (very high confidence).
Coastal areas are threatened by a combination of additional climate change effects, including rising temperature (which are already observed to cause increased coral bleaching at low latitudes, and increasing permafrost and sea ice melt at high latitudes), an increase in the intensity of extreme events due to tropical cyclones, rising atmospheric CO2 concentration, acidification of seawater, and changes in wave climate, storm surge characteristics and precipitation. Our understanding of the impacts of these changes has improved since the TAR, especially concerning rising temperature and extreme events. The other change factors require more investigation, most especially acidification of seawater whose coastal impacts remain poorly understood. [6.2, 6.4]

The impacts of sea-level rise on coasts, contributing to coastal erosion, coastal inundation and ecosystem losses, are overwhelmingly negative (very high confidence).
There is a range of direct and indirect socio-economic impacts. These impacts are among the most costly and most certain consequences of climate change. Human stresses, such as the destruction of coral reefs and mangroves, removal of coastal dunes, modified sediment budgets and increased subsidence, generally exacerbate climate impacts. [6.4.1, 6.5.3]

The most vulnerable coastal areas are populated megadeltas (Fig. TS-7), coastal urban areas, and small islands (high confidence).
Under climate change and sea-level rise, people, economic assets and ecosystem services in these areas are threatened with a range of impacts and potential disasters. Low income coastal communities and countries appear most susceptible to these risks, and even allowing for protection where benefits exceed costs, some models still suggest millions of people could be displaced from coastal areas during the 21st Century under plausible sea-level rise scenarios. [6.4.2]

For coastal communities in developing countries there is concern about the combined impacts of flooding, saltwater intrusion on freshwater resources, health problems and food insecurity (high confidence).
Flooding is a multiple hazard as it affects water supply, spreads diseases and reduces food sources. Saltwater intrusion threatens sources of freshwater and food. Rising temperatures and increased flooding would have impacts on water-borne pathogens, although the multiple and interacting effects need better definition. Food security concerns relate to the effects of rising temperatures on aquaculture and coastal fisheries (causing increasing disease and algal blooms), and sea-level rise impacts on the rice-growing deltas of Asia. [6.4.2]

For coastal tourism, climate change produces both winners and losers (very high confidence).
Rising temperature would reduce the traditional tourism flows from temperate countries to tropical countries based on sun, sea and sand resources. Tropical coastal tourism could also be negatively impacted by increased erosion from rising sea level and increased storms and surges, coral bleaching, and restrictions on freshwater availability. Tropical developing countries with a high dependency on coastal tourism, particularly small islands, would be severely impacted by climate change and changes in perceived climate risks, transport costs and travel decisions. However, tourism along temperate coastlines may be at a competitive advantage due to a longer season. [6.4.2]

Present responses to climate-related coastal hazards are often inadequate relative to the high and growing levels of risk (very high confidence).
Adaptation can greatly reduce both present and future risks under climate change. In many cases this is cost effective, but there are limits to adaptation. It remains unclear to what extent protection is desirable as costs will progressively rise, there are often impacts on ecosystem services, and the provision of protection encourages further development in increasingly hazardous areas. [6.6]

Integration of adaptation to climate change with disaster management can enhance the sustainability of coastal communities (very high confidence).
Adaptation and disaster management integrate the response to climate variability and climate change in a mutually reinforcing manner, by increasing the socio-ecological resilience of coastal communities [6.6].

Sea-level rise has the greatest inertia of climate change factors, and it is likely to continue for centuries with a significant ongoing demand for adaptation (high confidence).
This has implications for coastal planning, especially siting of long-life coastal infrastructure (e.g., transport links, nuclear power stations) and requires selection of flexible adaptation measures that can be upgraded as required. [6.3.2, 6.6.5, 6.7]

Fig. TS-7: Relative vulnerability of coastal delta populations as indicated by the population potentially displaced by current sea level trends to 2050, including local effects. Extreme $\geq$ 1 million people; high = around 500,000 people; medium > 5000 people potentially displaced. [B.6.4.1]

INDUSTRY, SETTLEMENT AND SOCIETY

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

Inherent uncertainties in predicting the path of technological and institutional change and trends in socioeconomic development over a period of many decades limit the potential to predict future prospects for industry, settlements, and society involving *considerable* climate change from prospects involving *relatively little* climate change. In many cases, therefore, research to date has tended to focus on vulnerabilities to impacts rather than on projections of impacts of change. [7.4]

Key vulnerabilities of industry, settlement, and society are most often related to (a) climate phenomena that exceed thresholds for adaptation, related to the rate and magnitude of climate change, particularly extreme weather events and/or abrupt climate change, and (b) limited access to resources (financial, human, institutional) to cope, rooted in issues of development context (see Table TS-2). [7.4.1, 7.4.3, 7.6, 7.7]

Findings about the context for assessing vulnerabilities are:

- **Climate change vulnerabilities of industry, settlement, and society are mainly to extreme weather events rather than to gradual climate change (high confidence)**. The significance of gradual climate change, e.g., increases in the mean temperature, lies mainly in changes in the intensity and frequency of extreme events. [7.2; 7.4]

- **Aside from major extreme events, climate change is often a secondary factor in considering stresses on sustainability (very high confidence).** Its significance (positive or negative) lies in its interactions with other sources of change and stress, and its impacts should be considered in such a multi-cause context. [7.1.3; 7.2; 7.4]
- **Vulnerabilities to climate change depend considerably on relatively specific geographic and sectoral contexts (very high confidence).** They are not reliably estimated by large-scale (aggregate) modelling and estimation. [7. 2; 7.4]
- **Climate change impacts spread from directly impacted areas and sectors to other areas and sectors through extensive and complex linkages (very high confidence).** In many cases, total impacts are poorly estimated by considering only direct impacts. [7.4]

Table TS-2: Selected examples of current and projected climate change impacts on human settlements, energy and industry, and their interaction with other processes [T7.4]

Climate Driven Phenomena	Evidence for Current Impact/ Vulnerability	Other Processes/ Stresses	Projected Future Impact/ Vulnerability	Zones, Groups Affected
a) Changes in extremes				
Major storms, in coastal areas combined with SLR	Population dead, injured, displaced; damages to settlements, economic activities, transportation systems; impacts on tourism; demands for insurance coverage [7.4.2.2; 7.4.3; B7.5; 7.5]	Population density, land uses in vulnerable areas; institutional capacities	Increased vulnerability in storm-prone coastal areas; possible effects on settlements, health, tourism, economic and transportation systems	Coastal areas, settlements, and activities; regions and populations with limited capacities and resources; fixed infrastructures; insurance sector
Riverine floods	Similar to coastal storms, especially vulnerabilities of settlements and transportation systems (see regional chapters)	Similar to coastal storms	Similar to coastal storms	Similar to coastal storms
Heat or cold waves	Effects on human health, social stability, energy requirements [7.2; B7.2; 7.4.2.2]	Limited capacities in some areas for internal temperature control; demographic and social contexts; institutional capacities	Increased vulnerabilities in some regions and populations; health effects; energy requirements	Mid-latitude areas; elderly, very young, and/or very poor populations
Drought	Reduced water availability in dry areas [7.4.2.3]; environmental migration [7.4.2.5]	Land uses; resources and capacities for alternative water supply	Water resource challenges in affected areas; shifts in locations of population and economic activities	Affected regions; poor regions and populations; settlements and societies in dry areas
b) Changes in means				
Temperature	Effects on energy demands and costs; on urban air quality; on tourism; on retail consumption; and on societies/livelihoods: e.g., traditional societies in the Arctic [7.4.2.1, 7.4.2.2, 7.4.2.4, 7.4.2.5]	Demographic and economic changes, land use changes, sustainable development paths, technological change, institutional capacities	Greater vulnerabilities away from coasts; diverse vulnerabilities in particular locations and sectors, both to temperature increase and to its association with storms and other extreme events	Very diverse, but greater vulnerabilities in places and populations with more limited capacities and resources for adaptation
Precipitation	Effects on water infrastructures, tourism, energy supplies; also see flooding above [7.4.2.1, 7.4.2.2, 7.4.2.3]; special concerns include reduced snow cover as an issue for tourism and seasonal water supply	Processes related to water demand and management	Depending on the region, vulnerabilities in some areas to effects of precipitation increases (e.g., flooding, but could be positive) and in some areas to decreases (see drought above)	Poor regions and populations
Saline intrusion	Effects on water infrastructures [7.4.2.3]	Trends in groundwater withdrawal	Increased vulnerabilities in coastal areas	Low-lying coastal areas, especially those with limited capacities and resources
Sea level rise	Effects on coastal land uses: greater exposure to flooding, water logging; effects on water infrastructures [7.4.2.3; 7.4.2.4[	Trends in coastal settlement and land uses	Long-term increases in vulnerabilities of low-lying coastal areas	Same as above
c) Abrupt climate change	Analyses of potentials	Demographic, economic, and technological changes; institutional developments	Possible significant effects on most places and populations in the world, at least for a limited time	Most zones and groups

HEALTH

Since the TAR, evidence on the current sensitivity of population health to weather and climate factors has grown. More is known about the early effects of climate change on: population vulnerability at national and local level; climate change within the context of other social and environmental determinants of disease risk; climate-specific adaptation measures (high confidence).
New evidence comes from:

- empirical studies, for example on the health impacts of individual extreme events such as heat waves, floods, storms, droughts, extreme cold;
- spatial studies, where climate is an explanatory variable which determines the distribution of disease and disease vectors;
- temporal studies, that have assessed the health effects of inter-annual climate variability, of short term (daily, weekly) changes in temperature or rainfall, and of longer term (decadal) changes in the context of detecting the early effects of climate change;
- experimental laboratory and field studies of vector, pathogen, or plant (allergenic) biology; and,
- studies that examine the effects of adaptation strategies on the sensitivity of population health to climate variability [8.1.3; 8.2; 8.6; 8.1.3].

Climate change is already affecting health (low to medium confidence).
A standardized approach to estimating the global burden of disease which can be attributed to climate change in cases of malnutrition, malaria, mortality from inland floods and diarrhoeal diseases indicates that climate change contributed to mortality and morbidity in 2000. These impacts arise through changes in the distribution of disease vectors, changes in environmental exposures and changes in health determinants [8.2; 8.4.1.1].

Projected increases in temperatures and changes in rainfall patterns are likely to have a range of health impacts (see Fig. TS-8) (high confidence).

- Increases in heat waves are likely to lead to increases in heat-related illnesses and deaths.
- Increases in ground-level ozone concentrations could increase respiratory and cardiovascular morbidity and mortality.
- Increases in mean temperature could facilitate the spread of malaria and dengue fever along the current edges of their geographic distributions in some regions, as well as increasing the length of the transmission season for malaria.
- Increases in temperature and changes in rainfall distribution patterns are likely to be associated with increases in diarrhoeal diseases.
- Droughts and floods can affect the nutritional status of large numbers of people.
- Regions that are already vulnerable to food insecurity may observe increases in malnutrition.

[8.2.1.1; 8.2.5.1; 8.4.2; 8.7]

Projected climate changes will probably have some health benefits (medium/high confidence).
These benefits include reduced cold-related mortality and restricted distribution of infectious diseases where temperatures or rainfall exceed threshold values for vectors or parasites. The degree of positive and negative health effects will vary from one location to another, and will alter over time if temperatures continue to rise [8.2.1.2; 8.2.9].

Some populations are likely to struggle with the additional stress provided by climate change (high confidence).
These are:

- people living in areas particularly affected by the consequences of climate change, (e.g., coastal and low-lying areas, the Arctic region, water-stressed regions);
- populations depending on natural resources; and,
- communities lacking basic public infrastructure, including sanitation. [8.4.3; 8.4.4]

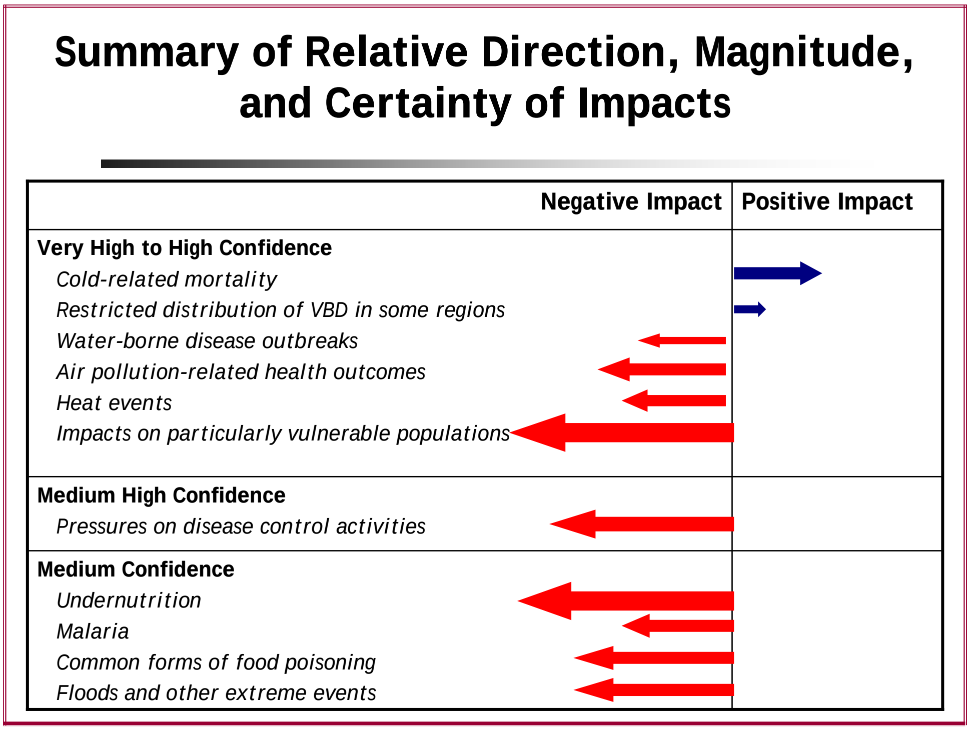


Fig. TS-8: A summary of the health impacts arising from climate change. [F8.3]

Box TS-3: What are the Main Likely Future Impacts and Adaptations for Sectors?

WATER

- Annual mean soil moisture is expected to decrease in many semi–arid regions of the world. Over very extensive regions of the Eurasian and North American continents, in middle to high latitudes, soil moisture is expected to decrease in summer but increase substantially in winter. [3.4.2]
- In many aquifers, spring recharge is expected to retreat towards winter and summer recharge is expected to decline dramatically, by up to 50%. [3.2]
- In the western USA, large streamflow changes are projected, so that not all the present-day water demands could be met even with adapted management. River basins in developing countries are even more vulnerable, as future population and water demand is expected to grow rapidly, and coping capacity is low. [3.5, 3.6] Average annual runoff is expected to increase in high latitudes and the wet tropics; decrease in mid-latitudes and some parts of the dry tropics, as shown in Fig. TS-4. [3.4.1]
- In semi-arid river basins, percentage changes in runoff are projected to be high, for example up to ±50%. Irrespective of the direction of change, management adaptation would be essential to avoid strong negative impacts. [3.5; 3.6]
- Projected increases in summer drying over mid-latitude continental interiors and hence drought risk would lead to adverse impacts on crop yields; building foundations; water resource quantity and quality; and risk of forest fire. [3.5]
- The uncertainty associated with projections in precipitation can be large. However, in areas dependent on the snow pack for water resources, such as the western U.S., large changes in the seasonal distribution of streamflow can be expected with high certainty and adaptations to water management will be required. [3.4.1]
- Climate change is very likely to have a strong impact on saltwater intrusion in coastal areas, and on salinization of groundwater. Where relative sea-level rise occurs, it will adversely affect groundwater aquifers and freshwater coastal ecosystems. [3.4.1; 3.4.3; 3.5]
- The hydrological cycle is likely to intensify. There is already evidence of increases in the number of very wet and very dry areas. [3.4.4]
- In many aquifers, spring recharge is expected to retreat towards winter, and summer recharge is expected to decline dramatically. [3.4.2]
- The thickness of small island freshwater lens in the Indian Ocean declines from 25 to 10 m with a 10 cm rise in sea level by 2040-2080 [F3.7]

ECOSYSTEMS

- Terrestrial ecosystems provide a net global carbon sink until ~2030 (0.5-1.0°C warming), but a likely net source by ~2100 under SRES A2 and B1 scenarios [4.4.1, F4.2]. Sequestration by expanding taiga [4.4.5] may be offset by albedo change and CH_4 losses from tundra [4.4.6]; that of tropical forests depends on their persistence under socio-economic pressures [4.4.5; 4.4.10]. Nutrient (mainly nitrogen) constraints on CO2 fertilization are a key uncertainty in terrestrial carbon sink projections [4.4.1; 4.4.10; 4.8].
- Amazon forests, China's taiga and 77% of Canadian tundra are at risk of degradation, and Australian Kakadu wetlands of inundation with >3°C warming [T4.2, 4.4.1, F4.2, 4.4.10, F4.4], with ~25% global biodiversity loss possible [4.4.11].
- Global distribution of wildfire increases with increasing temperature, dry spell duration and fuel availability [4.4.2; 4.4.3; 4.4.4; 4.4.5]
- Forest expansion is projected in North America with <2°C warming [4.4.10; F4.4; T4.3], while other vulnerable (e.g., tropical) ecosystems are likely to experience severe impacts, including some biodiversity loss [4.4.10; 4.4.11; T4.2].
- Inland and coastal wetlands will be strongly affected by climate change. Any increased variability in precipitation regime will affect the timing, duration and depth of water, with impacts for plants and animals at all stages of their life cycle. [4.4.8]
- For a 1°C temperature rise above pre-industrial levels, salmon and trout are expected to disappear from a large part of their current range in the USA. [4.4.8]
- A decline in oceanic primary productivity is expected at low latitudes, with increases at high latitudes. The low-productivity permanently stratified subtropical gyre biome is expected to expand by 4% in the Northern Hemisphere and 9.4% in the Southern Hemisphere. [4.4.9]
- The productive sea ice biome is predicted to contract by 42% in the Northern Hemisphere, and 17% in the Southern Hemisphere, in response to climate change under IS92a [4.4.9]. The distribution of Arctic species adapted to living on the ice margin will diminish as their habitat retreats, with implications for predators such as seals and polar bears. [4.4.6]
- Massive loss of corals due to bleaching is expected over the next 50 years [B4.5; 4.4.9]. Annual coral bleaching is expected between 2030 and 2050 for the Great Barrier Reef, due to climate change and other pressures [B4.5; 4.4.9].
- Tuna populations can be expected to spread towards presently temperate regions in response to climate change, based on predicted warming of surface water and increasing primary production at mid and high latitudes. This has been observed during El Niño events. [4.4.9]
- Surface ocean pH is expected to continue decreasing as long as atmospheric concentrations of CO2 increase. Recent findings indicate concern for marine ecosystems with key organisms requiring calcium carbonate to make shells or other hard structures (e.g. corals). [4.4.9; B4.5]

FOOD, FIBRE AND FOREST PRODUCTS (FFF)

- In temperate regions, moderate increases in temperature (1 to 3ºC), with associated CO2 increase and rainfall changes, can have small beneficial impacts on crops. In tropical regions, even moderate temperature increases are likely to have negative yield impacts for major cereals. Short-term adaptations may enable avoidance of a 10-15% reduction in yield. [F5.2]
- Trade flows are foreseen to rise significantly with climate change; export of temperate zone food products to tropical countries is likely to increase whereas there is likely to be greater export of forest products from tropical and sub-tropical regions to temperate regions. [5.6.2, 5.4.5]
- Globally, there should be major gains of potential agricultural land by the 2080s, particularly in North America (20-50%) and the Russian Federation (40-70%). However, substantial losses (up to 9%) are predicted for sub-Saharan Africa, due to increased frequency of drought [5.5.3].
- In Asia, although most land that is suitable for cultivation is already in use, geographical shifts in suitability and productivity are likely. Taking into account direct CO2 effects, yields of wheat, maize and rice are predicted to increase in SE and East Asia, but to decline in Central and South Asia. It is expected that the triple-planting boundary in China will shift around 500 km northward, from the Yangtze River valley to the Yellow River basin [5.5.3].
- In seasonally dry regions, warming and increased frequency of heat waves and droughts would reduce pasture and livestock productivity. In humid and temperate grasslands, an incremental warming up to +3°C without rainfall pattern changes would increase pasture productivity and reduce the need for housing and for feed concentrates in some areas [5.4.3]. Pasture diversity is likely to change with, for example, woody shrub invasion in drier rangelands [5.4.2.2].
- Globally, forest area and productivity is expected to increase with climate change [5.4.4.1], with the benefits felt first by producers in lower latitudes [5.4.4.2]. However, increased fire damage could have negative impacts, especially paper and pulp operations. Predictions of insect outbreaks under climate change are highly uncertain [5.4.4.1].
- The positive and negative impacts of climate change on aquaculture outlined in the TAR remain valid [5.4.5.1].
- Changes in primary production and transfer through the food chain will have a key impact on capture fisheries. Regional impacts, including poleward shifts and local extinctions, are expected but the aggregate impact at the global level is unknown [5.4.5.1].
- In all the FFF sectors, the role of pests has become clearer since the TAR. The current boundaries of pests and diseases are likely to shift poleward. The changing magnitude of damage for the FFF sectors is unknown, but is likely to be regionalized [5.4.2.6; 5.4.4.1; 5.4.5.1].
- Temperature-dependent animal diseases such as Malignant Catarrhal Fever are likely to spread poleward and upward. Cattle tick diseases currently cause losses of 6000 tonnes/year in Australia, and this is estimated to rise to 7800 tonnes/year by 2030 and 21600 tonnes/year by 2100 [5.4.2.6].

COASTAL SYSTEMS AND LOW-LYING AREAS

- Present-day key vulnerabilities in coastal zones related to climate change and sea level rise (SLR) are [T6.4]:
    - Human communities in low-lying areas, especially where there are constraints on adaptation.
    - Where the cost-benefit ratio for adaptation is high (e.g., low-lying islands and deltas).
    - Densely-populated megadeltas, atolls and coastal wetlands.
    - Coastal areas subject to multiple natural and human-induced stresses, e.g., subsiding or sediment-starved. These include the Mississippi delta, Netherlands, Gulf of Thailand, much of the Mediterranean, Male (capital of the Maldives) and Venice.
    - Coastal areas already experiencing adverse effects of temperature rise, including ice-bound coasts and coral reefs.
    - Coastal areas exposed to significant extreme water levels (e.g., Bay of Bengal, the US Gulf and East Coast and the Caribbean, Rio de la Plata).
- All coastal ecosystems are particularly vulnerable including saltmarshes, mangroves, sea grasses and corals. [6.4.1]
- The greatest increase in vulnerability is expected to lie on the coastal strips of South and SE Asia, and urbanized coastal locations around the African continent, where the combination of coastal topography, numbers of people, poverty and lack of adaptive capacity combine to enhance exposure to risk. [6.4.2.4]
- Areas most vulnerable to sea level rise are likely to be (i) beaches, where SLR is expected to exacerbate erosion and coast retreat, and (ii) deltas, estuaries, and lagoons, with inundation, salinization and erosion. [6.4.3]
- By the 2080s, with 40 cm of SLR, 5-18% of the world's coastal wetlands might be lost, possibly reaching 42% by the 2140s without emissions mitigation. It is estimated that encroaching seas will inundate 21% of coastal wetlands of the US mid-Atlantic coast by 2100. [6.4.1.3]
- Coastal flooding is likely to become a greater risk than at present, without significant adaptation. [6.1.2]. By the 2080s, and assuming adaptation, between 2 and 50 million additional people could experience coastal flooding (depending on the SRES scenario). Without adaptation, nearly 40 times more people per year could be affected by sea floods by 2100. [6.4.2.4]
- Estimated costs and impacts of the consequences of 65 cm SLR by 2100 show 30 times more people displaced in developing countries than in developed countries, 12 times the area of land inundated in developing countries than in developed countries, and flood protection costing 3 times more in developing countries than in developed countries. [6.5.3]

INDUSTRY, SETTLEMENT AND SOCIETY

- Vulnerabilities of industry, infrastructures, settlements, and society are greater in certain high-risk locations, particularly coastal and riverine areas subject to flooding and areas whose economies are closely linked with climate-sensitive resources, such as agroprocessing, water resources, and tourism. [7.4; 7.5]
- Because a substantial share of projected population growth is likely to be in areas vulnerable to impacts of climate change, such as coastal areas, potential effects of climate change on settlements and populations are likely to increase through time. [7.3; 7.4.3]
- Expressed in terms of annual regional GDP and/or capital formation, costs of extreme weather events -- which are likely to become more intense and/or more frequent with climate change, -- can range from several percent in larger, more developed and diversified impacted regions to more than 25% in smaller less developed, less diversified, and/or more natural resource dependent regions. At a local scale, however, such events can be catastrophic, with much higher levels of costs, at least in the short run. [7.5]
- In most parts of the world and most segments of populations, lifestyles are likely to change as a result of climate change. Net valuations of benefits vs. costs will vary, but they are more likely to be negative if climate change is substantial and rapid rather than if it is moderate and gradual. [7.4; 7.6]
- Poor communities and households are especially vulnerable to climate change because they tend to be located in relatively high-risk areas and to have limited access to services and other resources for coping. They are likely to be impacted at lower levels and rates of climate change than the relatively wealthy. [7.4.5; 7.4.6]
- With increased catastrophe loss costs, the private insurance sector is likely to increase prices and withdraw coverage from situations at highest risk, leaving an increased role for governments and individuals as risk bearers. [7.4.2]
- Urban water supply infrastructures are vulnerable, especially in coastal areas, to sea level rise and climate changes that reduce regional precipitation. Together or singly, these may increase saline intrusion to rivers and aquifers used for water supply. [7.4.3]
- Climate change is likely in many areas to increase pressures on governmental infrastructures and institutional capacities and to raise social equity concerns. [7.4.5; 7.6.5]

HEALTH

- Given present trends in child mortality, HIV/AIDS, malaria, extreme poverty and hunger, primary education and gender equality, it is unlikely that the health-related Millennium Development targets will be met in 2015, in particular in Africa. [8.1; 8.7]
- For low-income populations, the risk of dying as a result of climate change is expected to increase by 2030, principally due to increases in malnutrition and diarrhoeal diseases. [8.4.1.1]
- Most models project modest changes in the burden of climate-sensitive diseases over the next few decades, with larger increases beginning mid-century. [8.4.1]
- Increases in mean temperature could facilitate the spread of malaria and dengue fever along the current edges of their geographic distribution in some regions, and increase the length of the transmission season for malaria, although the magnitude of the effect is thought to be smaller than previously estimated. [8.4.1.2; 8.7]
- Projected changes in climate are expected to increase the pressures on disease control activities in many parts of the world. [8.4.1.2.]
- New studies from a wider range of countries provide evidence that increases in daily temperature are likely to increase the number of cases of some common forms of food poisoning in temperate regions, and rising sea surface temperatures are expected to increase rates of fish poisoning in tropical settings. [8.2.4]
- Climate change is likely to bring about increased concentrations of ground-level ozone, thus increasing respiratory and cardiovascular morbidity and mortality, all other considerations unchanged. [8.2.6]
- Between now and 2100 the large increase in the number of older adults world-wide will expand greatly the population at highest risk from heat. Acclimatization and adaptation may reduce the impacts of more frequent heat extremes, but will not eliminate them. [8.2.1; 8.4.1] Increases in heat waves are likely to lead to increases in heat-related deaths. [8.4.1.3; 8.7]
- Extreme rainfall events test the integrity of water management systems and increase the risk of outbreaks of water-borne disease. The impacts of flooding are particularly severe in areas of environmental degradation, and where basic public infrastructure, including sanitation and hygiene, is lacking. [8.2.2]
- There are important prerequisites for adaptation that are currently not met in many parts of the world. For instance, access to primary health care, an adequate public health infrastructure and basic education are essential elements of strategies to cope with climate change, but are not available to millions of people. [8.6; 8.7]
- There has been progress in the design and implementation of climate-health warning systems, established to reduce effects of weather extremes as well as for the seasonal predictions of infectious diseases. Limited evidence suggests that such systems can be effective. [8.6]
- Critically important for the future will be the manner in which economic growth occurs, the distribution of the benefits of growth, and trends in other factors such as education, health care and public health infrastructure. [8.ES; 8.3.2]

Box TS-4: What are the Main Likely Future Impacts and Adaptations for Regions?

AFRICA

- The impacts of climate change in Africa are likely to be greatest where they ‘co-occur’ with a range of other stresses (e.g. unequal access to resources [9.4.1]; enhanced food insecurity [9.6]; poor health management systems [9.2.2; 9.4.3]. These stresses, enhanced by climate variability and change, further enhance the vulnerabilities of many in Africa.
- Declining agricultural yields are likely due to drought and land degradation, especially in marginal areas. In a few regions climate change may lengthen the growing season increasing agricultural output [9.4.4].
- By 2080, model estimates of an increase in arid and semi-arid areas by about 5-8% or 60-90 million hectares are estimated [9.4.4].
- The proportion of the African population at risk of water stress and scarcity could increase from 47% in 2000 to 65% in 2025, (c. 370 million people) [9.4.1]. These estimates, based on population and proportion of water available, would appear to concur with those using GCM and SRES scenarios that show parts of southern Africa and North Africa to experience future water stress. Eastern Africa, however, may experience increases in rainfall and drainage density using certain model projections [9.4.1].
- In the South-western Cape, South Africa, for example, in response to climate change, water supply capacity is predicted to decline by 0.3% per annum, whilst demand may rise by 0.6% per annum in the Cape Metropolitan Region [9.4.1]
- Any changes in the primary production of large lakes will have important impacts on local food supplies. For example, Lake Tanganyika currently provides 25-40% of animal protein intake for the population of the surrounding countries and it is expected that climate change may reduce primary production and possible fish yields by an estimated 30% [9.4.5; 3.4.7; 5.4.5.1].
- Ecosystems in Africa could experience dramatic shifts and changes in species range and possible extinctions. Plant biodiversity could undergo changes, including the fynbos and succulent Karoo biomes in southern Africa [9.4.5].
- Mangroves could degrade due to sea level rise, changes in salinity and sedimentation. Any loss or degradation of mangrove ecosystems will have adverse impacts on coastal fisheries [9.4.5].
- Extreme wind and turbulence could decrease coastal fisheries by 50-60% [9.4.4].
- Recent initial assessments show that despite water deficits that may arise with climate change (e.g. in the Komati and Ngwavuma catchments in Swaziland) efficient water utilisation and adaptation through drip irrigation could save water and therefore offset some water losses [9.5.1].
- With climate change, preferred tourist destinations may shift to higher latitudes and altitudes. The tourism sectors in Zambia and Zimbabwe could, for example, benefit greatly from climate change if other problems are solved [9.4.7].

ASIA

- A 1 m rise in sea level would lead to a loss of 250,000 ha of mangrove, while approximately 100,000 ha of cultivated land and sea product culturing area would become salt marsh. [10.4.3.3]
- For a 1 m rise in sea level, 500,000 ha of Red River delta, and 15,000 – 20,000 km^2 of Mekong River delta are projected to be flooded [10.4.3.2].
- Tibetan Plateau glaciers of under 4 km in length are projected to disappear with a temperature increase of 3^oC and no change in precipitation. [10.4.4.3]
- Around 30% of Asian coral reefs are expected to be lost in the next 30 years, compared with 18% globally under IS92a, but this is due to multiple stresses and not to climate change alone. [10.4.3.2]
- The per capita availability of freshwater in India is expected to drop from around 1900 m^3 currently to 1000 m^3 by 2025 [10.4.2.3]. More intense rain and more frequent flash floods during the monsoon would result in a higher proportion of runoff and a reduction in the proportion reaching the groundwater [10.4.2.3].
- If current warming rates are maintained, Himalayan glaciers could decay at very rapid rates, shrinking from the present 500,000 km^2 to 100,000 km^2 by 2035. [10.6.2]
- Substantial decreases in crop yields have been suggested in parts of Asia, with expected yield losses as high as 30%. [10.4.1.1]
- Agricultural irrigation demand in arid and semi-arid regions of East Asia is expected to increase by 10% for an increase in temperature of 1^oC. [10.4.1.2]
- Indonesia’s forests could benefit from carbon fertilization. It is estimated that around 20 million ha of managed forests will be established in Indonesia by 2030, which would make a large contribution to global sequestration of carbon. [10.4.4.1]

AUSTRALIA AND NEW ZEALAND

- Many ecosystems are likely to be altered. [11.4.1] Among the most vulnerable are the Great Barrier Reef, south-western Australia, Kakadu wetlands, rainforests, coasts and alpine areas [11.4.2]. This implies substantial loss of biodiversity, with knock-on effects on tourism and management of the conservation estate. [11.4.5]
- Future declines in water supply are likely for many Australian and eastern New Zealand cities; for example, the SRES A1 and B1 scenarios suggest a 10-25% reduction in river flow in the Murray-Darling Basin by 2050. [11.4.1]
- Soil acidification, salinization and reduced run-off over much of Australia and for smaller eastern New Zealand catchments are very likely. [11.4.1; 11.4.3]
- Increased fire danger is likely with climate change; for example, in southeast Australia the frequency of very high and extreme fire danger days is likely to rise 4-25% by 2020 and 15-70% by 2050 [11.3.1]
- Up to about 2050, enhanced growing conditions from higher CO_2, longer growing seasons and less frost risk are likely to be beneficial for agriculture, horticulture and forestry over much of New Zealand and Tasmania. The impacts become negative for warming in excess of 2–4°C where it is associated with reduced run-off. [11.4.3]
- Wheat yield in western Australia is likely to decline by 2070, but yield in north-eastern Australia is likely to increase moderately. Median national wheat yield is likely to decline. [11.4.3]
- The net impacts on cropping depend on the availability of irrigation water; impacts of climate change on pests and crop diseases remain uncertain. [11.4.3]
- In the south and west of New Zealand, growth rates of economically-important plantation crops (mainly P. radiata) are likely to increase with carbon dioxide fertilization, warmer winters and wetter conditions. [11.4.4]
- Increased temperatures and demographic change are likely to increase peak energy demand in summer. [11.4.10, 11.4.11]
- Increased heat related deaths in Australian capital cities are expected, with an extra 3200-5200 deaths on average per year by 2050 (allowing for population growth and assuming no adaptation) [11.4.11]
- Ongoing coastal development is very likely to exacerbate risk to lives and property from sea level rise and storms. There is very likely to be loss of high-value land, faster road deterioration, degraded beaches, social and economic trauma. [11.4.5]
- An increase in the occurrence of intense rainfall events is likely. Design criteria for extreme events are very likely to be exceeded more frequently than under the present climate. Risks include threats to hydro dams, failure of floodplain levees and urban drainage systems, and glacier-lake outburst floods. [11.4.7]

EUROPE

- The probability of total winter precipitation exceeding two standard deviations above normal is expected to increase by up to a factor of five in some areas. [12.3.1]
- By the 2080s, annual runoff is projected to increase by up to 50 % in northern Europe, and decrease by up to 60% in south-eastern Europe, with summer low flows reduced by up to 80% under IS92a. [T12.2]
- The percentage of river basin area in the severe water stress category (withdrawal/availability higher than 0.4) is expected to increase from 19% today to 34-36% by the 2070s. [12.4.1]
- Under A1FI scenarios, by the 2080s, up to 2.5 million people each year are expected to be affected by coastal flooding. [12.4.2]
- In some countries it is estimated that insurance costs associated with river floods will increase by 2-4% annually. [12.4.10]
- Lowest river flows shift from winter to summer in Eastern-central Europe, and decrease by up to 50% under SRES A1 by 2080. [12.4.1]
- By the 2070s, hydropower potential for the whole of Europe is expected to decline by 6%, with strong regional variations from a 20-50% decrease in the Mediterranean region to a 15-30% increase in Northern and Eastern Europe. [12.4.8.1]
- Up to 50% of European flora could become vulnerable, endangered, critically endangered or extinct by the end of the 21st century under a range of SRES scenarios [12.4.6].
- By 2050, crops are expected to show a northward expansion in area [12.4.7.1]. Climate-related increases in crop yields are only expected in Northern Europe, while the largest reductions are expected in the Mediterranean, the Southwest Balkans and the South of European Russia. [12.4.7.1]
- Forested area is likely to increase in the north and decrease in the south. A redistribution of tree species is expected, and an elevation of the mountain tree line. [12.4.4.1]
- Most amphibian (45% to 69%) and reptile (61% to 89%) species are virtually certain to expand their range. [12.4.6]
- Small Alpine glaciers will disappear, while larger glaciers will suffer a volume reduction between 30% and 70% by 2050 under a range of emissions scenarios, with concomitant reductions in discharge in spring and summer. [12.4.3]
- Decreased comfort of the Mediterranean region in the summer, and improved comfort in the North and West, could lead to a reduction in Mediterranean summer tourism, and an increase in spring and autumn. [12.4.9]
- A shutdown of the North Atlantic thermohaline circulation, although assigned a low probability, would have widespread severe impacts in Europe, especially in western coastal areas. These would include reductions in crop production with associated price increases, increased cold-related deaths, population migration to southern Europe and a shift in the economic centre of gravity, winter transport disruption, and increased winter energy demand. [12.6.2]

LATIN AMERICA

- As a result of climate change, rice yields are expected to decline after the year 2010, whilst an increase in soybean yields is expected when direct CO_2 effects are taken into account under a range of SRES and incremental scenarios [13.4.2].
- Cattle productivity is expected to decline in response to increasing temperatures. [13.4.2]
- It is expected that, by 2025, between 30 and 90 million people will suffer from the lack of adequate water supplies and, by 2055, between 100 and 180 million, depending on the SRES scenario considered [13.4.3]
- Due to climate change, in arid and semi-arid regions of Argentina and Brazil future water shortages may be severe [13.4.3].
- In the future, as a result of climate change, it is likely that sea level rise, weather and climatic variability and extremes will have impacts on:
    - low-lying areas (e.g., in El Salvador, Guyana, Uruguay),
    - buildings and tourism, (e.g., in Uruguay);
    - coastal morphology (e.g., in Peru);
    - mangroves (e.g., in Brazil, Ecuador, Colombia, Venezuela);
    - availability of drinking water in the Pacific coast of Costa Rica and Ecuador.

  Sea level rise alone is likely to affect:
    - Mesoamerican coral reefs, and the
    - location of fish stocks in the south-east Pacific.

  [13.4.4]
- The Latin American region, concerned with the potential effects of climate variability and change, has introduced some adaptation measures including:
    - the use of climate forecasts in sectors such as fisheries (Peru) and agriculture (Peru, NE Brazil);
    - early warning systems for flood in the Rio de la Plata Basin based on the "Centro Operativo de Alerta Hidrológico."

  The region has also created new Institutions to mitigate and prevent natural hazards, such as the Regional Disaster Information Centre for Latin America and the Caribbean, the International Center for Research on El Niño Phenomenon in Ecuador; and the Permanent Commission of the South Pacific. [13.2.5]
- By 2050, 24% of 138 tree species in Central Brazil savannas could become extinct. [13.4.1]

NORTH AMERICA

- Population growth, rising property values and continued investment increase coastal vulnerability. Any increase in destructiveness of coastal storms could lead to dramatic increases in losses from severe weather and storm surge, with the losses exacerbated by sea-level rise. Current adaptation is uneven and readiness for increased exposure is poor. [14.2.3; 14.4.3]
- Sea level rise and any associated increase in tidal surge and flooding have the potential to severely affect transport and infrastructure. Facilities at risk in New York include surface road and rail lines, bridges, tunnels, marine and airport facilities, and transit stations. [14.4.3, 14.4.6]
- Heat waves are projected to increase in magnitude and duration. By 2090, Chicago may have 25% more heat waves annually. The average number of heat wave days in Los Angeles may increase from 12 to 44-95 by 2070-99. The population over age 65, which is expected to grow dramatically after 2010, is most at risk. [14.4.5]
- In 2050, daily average ozone levels could increase by 3.7 ppb across the eastern U.S., with the most polluted cities today experiencing the greatest increases. Ozone-related deaths may increase by 4.5%. [14.4.5]
- Warming will probably reduce snowpack at moderate elevations in the western cordillera by the mid 21st century. Earlier snowmelt and winter rain events will likely increase peak winter flows and flooding, while summer flows decrease. [14.4.1] Supply and demand mismatches will complicate already difficult water management. [14.2.1, B14.2]
- Vulnerability to climate change will likely be concentrated in specific groups and regions, including indigenous peoples and others dependent on narrow resource bases, and the poor and elderly in cities. [14.2.6; 14.4.6]
- Moderate climate change will likely increase yields of rainfed agriculture but with smaller increases and more spatial variation than earlier estimates. [14.4.4]
- Forest growth should modestly increase (+10 to 20%) over the 21st century, with forests expanding into higher latitudes and altitudes in response to longer growing seasons and elevated CO_2. [14.4.2]
- The greatest impacts on forests will likely be through changing disturbances from pests, diseases, and fire. Warmer summer temperatures could extend the annual window of high fire ignition risk by 10-30%, and increase the area burned by 74-118% in Canada by 2100. [14.4.4; B14.1]
- Present rates of coastal wetland loss should increase with accelerated relative sea-level rise, in part due to coastal squeeze. Salt-marsh biodiversity is expected to decrease in northeastern marshes. [14.4.3]
- Continued investments in adaptation in response to historical experience rather than projected future conditions may increase vulnerability of many sectors to climate change. [14.5]

POLAR REGIONS

- In the Arctic, predictions for annually-averaged sea ice area show average reductions between 22% and 31% by 2080-2100, depending on the emissions scenario. In Antarctica, predictions range from a complete loss to a slight increase of sea ice. [15.3.4.3]
- Northern Hemisphere permafrost is projected to reduce by 20-35% by 2050. The depth of seasonal thawing is likely to increase by 15-25% in most areas by 2050, and by 50% and more in northernmost locations under SRES scenarios. [15.3.4.]
- Initial permafrost thaw will form depressions for new wetlands, ponds and drainage networks, allowing establishment of aquatic communities in areas formerly dominated by terrestrial species. Further thawing will increasingly couple surface drainage to the groundwater, resulting in limnology changes and decreases in habitat suitability/availability. [15.4.1.3]
- Models project replacement of 11% of tundra by forest by 2100, whilst tundra is expected to replace 14-23% of polar desert by 2080. [15.4.2.2]
- Geographic patterns of habitat use of migratory aquatic birds and mammals will be affected by climate change, with implications for predators such as seals and polar bears. [15.4.3.2; 15.4.1.3]
- Reductions in lake and river ice cover are expected, especially in near-coastal regions. These will affect lake thermal structures, the quality/quantity of under-ice habitats, and the timing and severity of ice jamming and related flooding. [15.4.1.2]
- Projected hydrological changes will influence the productivity and distribution of aquatic species, particularly fish. Warming of lake waters is likely to lead to reductions in fish stock, especially such species as lake trout, which prefer colder waters. [15.4.1.3]
- In Siberia and North America, there may be an increase in agriculture and forestry as the northern limit for these activities shifts by several hundred kilometres by 2050. [15.4.2.4] This should create possibly more cost efficient local food sources. [15.4.6.2]
- Arctic warming will reduce excess winter mortality, primarily through a reduction in cardiovascular and respiratory deaths, and injuries. [15.4.6.1]
- Arctic warming will be associated with increased vulnerability to pests and diseases in wild life, such as tick-borne encephalitis, which can be transmitted to humans. [15.4.6.2]
- Increases in frequency and severity of flooding, erosion, drought, and destruction of permafrost, threaten community and public health infrastructure and water supply. [15.4.6.2]
- The climatic barriers that hitherto have protected polar species from competition will be lowered and loss of some of these species can be expected. [15.6.3]

SMALL ISLANDS

- Port facilities at Suva, Fiji, and Apia, Samoa, could experience overtopping, damage to wharves and flooding of the hinterland following a 0.5 m rise in sea level combined with waves associated with a 1/50 year cyclone. In November 1999, storm surge in St. Lucia associated with Hurricane Lenny generated damages in excess of US$6 million, and surge damage in Grenada from Hurricane Ivan in 2004 was even greater. [16.4.7]
- Any reduction in average rainfall will reduce the size of the freshwater lens. For example, a 10% reduction in mean annual rainfall (by 2050) would lead to a 20% reduction in the freshwater lens on Tarawa Atoll, Kiribati. This lens reduction will be further exacerbated by rising sea levels to around 29%. [16.4.1]
- Without adaptation, agricultural economic costs from climate change could reach between 2-3% and 17-18% of 2002 GDP by 2050, on high terrain (e.g., Fiji) and low terrain (e.g., Kiribati) islands, respectively under SRES A2 and B2. [16.4.3]
- Climate change is expected to have significant impacts on tourism destination selection. Surveys show that, in some islands, up to 80% of tourists would be unwilling to return for the same holiday price in the event of coral bleaching and reduced beach area resulting from elevated sea surface temperatures and sea level rise. [16.4.6]
- Dominica and Seychelles are almost entirely dependent on surface water from streams. Both experienced serious water shortages in the 1997/1998 El Niño. The strong 1998-2000 La Niña caused acute water shortages on many Indian and Pacific Oceans islands, leading to a partial shut-down in tourism and industry. In Fiji and Mauritius, borehole yields decreased by 40% during the dry periods, and export crops including sugar cane were severely affected. [16.4.1]
- Several small island countries (e.g., Barbados, Maldives, Seychelles, Tuvalu) have begun to invest in the implementation of adaptation strategies, including desalination, to offset current and projected water shortages. [16.4.1]
- While some small islands are morphologically more resilient to climate change and sea level rise than others, many are so vulnerable that there are recent examples of island abandonment. [16.4.2]
- With climate change, increased numbers of introductions and enhanced colonization by alien species are likely to occur on middle and high latitude islands. These changes are already evident on some islands. [16.4.4]
- In small islands, energy is primarily from non-renewable sources, mainly imported fossil fuels. To enhance their resilience, many islands have already embarked on initiatives aimed at ensuring that renewables constitute a significant percentage of the energy mix. [16.4.7]
- Use of insurance as an adaptation strategy for small islands has many constraints, including the size of the risk pool, lack of availability of financial instruments and services for risk management. [16.5.3]

C.2 Impacts on, adaptations and vulnerabilities of regions

A summary of impacts expected for each region is given in Box TS-4

AFRICA

The food security threat posed by climate change is arguably greatest for Africa, where agricultural yields and per capita food production constitute a large part of local livelihoods (high confidence).
Agriculture is a major contributor to the current economy of most African countries, averaging 21% and ranging from 10% to 70% of GDP [9.4.4]. As a fraction of GDP, possible losses in agricultural production due to climate change are in the range 2 - 7% for the Sahara and IGAD regions, and 0.4 - 1.3% for Northern and Southern Africa [9.4.4]. Such examples of loss may detract from adaptation and development inputs that could be made to enhance resilience to climate change. At the local level, many people may suffer additional losses to their livelihood when climate change occurs together with other stressors (e.g. conflict). [9.6.1]

Climate change and variability may result in species loss, extinctions and also constrain the 'climate spaces' and ranges of many plants and animals (high confidence)
Assessments of over 5000 African plant species show that areas suitable of suitable climate for 81-97% of the plant species examined may undergo decreases in size and/or shifts in location [9.4.5]. Two biomes, the fynbos and succulent Karoo in southern Africa, are shown to be vulnerable to projected climate changes, whilst the savanna may be more resilient. [9.4.5]

In unmanaged environments, multiple, interacting impacts and feedbacks are expected, triggered by changes in climate, but exacerbated by non-climatic factors (high confidence)
Impacts on Kilimanjaro, for example, show that glaciers have been retreating, with estimates of 55% of glacier loss between 1962 and 2000 (see Fig. TS-9). By 2020, indications are that the ice cap could disappear for the first time in 11 000 years. With rising temperature, impacts could include upward migration of vegetation zones. However, increased forest fires, as a result of drier and warmer conditions, might lead to a *downward* rather than *upward* migration of species and animals [9.4.5]. The loss of 'cloud forests' through fire since 1976 has resulted in 25% annual reductions of fog water (the equivalent of the annual drinking water of 1 million people living in Kilimanjaro). [9.4.5]

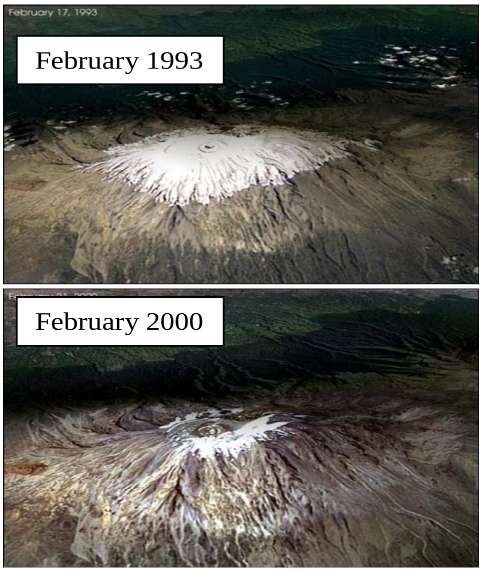


Fig. TS-9: Changes in the Mt Kilimanjaro ice cap over time. [Box 9.2].
Source:
http://earthobservatory.nasa.gov/Newsroom/NewImages/kilimanjaro-etm-93-00.jpg

Lack of access to safe water, arising from multiple factors, is a key vulnerability in many parts of Africa (very high confidence).
Water access is threatened not only by climate change [9.4.1] but also by complex river basin management (with several of Africa's major rivers being shared by several countries) and degradation of water resources by excessive abstraction of water and pollution of water sources [9.4.1].

Attributing the contribution of climate change to changes in the risk of malaria remains problematic (high confidence).
While some studies have suggested links to climate change (temperature and rainfall) in increasing malaria incidence in the Eastern Highlands, others show no marked trends in climate over a period of almost a 100 years (1911-1995) and hence suggest that the increases in malaria are not linked to climate variables but to drug resistance and decreased management (e.g., spraying of DDT). [9.4.3]

The areas of possible expansion and contraction of malaria are also debated, with some arguing that expansion is driven more by precipitation than temperature. Some projections show that, by the 2050s, continuing into the 2080s, a large area of south–central Africa and the western Sahel will no longer be suitable for *falciparum* transmission. Among all scenarios, the highlands of eastern and southern Africa appear to be areas most likely to become more suitable for transmission. [9.4.3]

Africa is characterized by low coping and adaptive capacity. This is due to the extreme poverty of many Africans, frequent natural disasters such as droughts and floods, and agriculture heavily dependent on rainfall. Cases of remarkable resilience in the face of multiple stressors have, however, been shown (high confidence).
Africa possesses a wealth of coping and adaptation strategies that are used to manage a range of stresses including climate extremes (e.g. droughts and floods). Possible increases in such stresses, may, however, erode coping and adaptive capacity, particularly if the frequency of extreme events increases. Poor governance, poor access to data and information, poverty and growing health burdens severely constrain the ability of Africa to effectively adapt to climate change [9.2.1]. Moreover, assessments have shown that certain institutional and policy measures could also contribute to coping capacity. [9.5.1; 9.6.]

Some adaptation measures to climate variability have proved successful: for example, efficient water utilization through drip irrigation and use of drought resistant and early maturing crop varieties (9.5.1). Seasonal rainfall forecasts promise to be an effective adaptive tool but their use is currently still limited by timeliness and appropriateness of the information (9.5.1; T9.3). The 'de-agrarianization' or 'de-peasantization' process observed in some African countries, whereby dependence on agriculture to rural livelihoods is decreasing from approximately 60% to 20-40%, may mean that alternative adaptive options may be required, including various social protection measures [9.5.1].

ASIA

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

Future climate change is expected to affect agriculture through declining production, and reductions in arable land area and food supply for fishery (medium confidence).
Projected surface warming and shifts in rainfall in most countries of Asia will induce substantial declines in agricultural productivity as a consequence of thermal stress and more severe droughts and

floods [10.4.1.1]. This is apart from soil degradation, coastal inundation and salt water intrusion due to sea level rise. The decline in agricultural productivity will be more pronounced in areas already suffering from increasing scarcity of arable lands [10.4.1.2]. Subsistence farmers are at risk from climate change; marginal crops such as sorghum, millet etc., could be at the greatest risk, both from a drop in productivity and from loss of crop genetic diversity [10.4.1.4]. With respect to aquaculture, in response to climate change it is expected that changes will occur in fish breeding habitats and food supply for fish, and ultimately the abundance of fish populations [10.4.1.3].

Climate change has the potential to exacerbate water resource stresses in most regions of Asia (high confidence).
The most serious potential threat arising from climate change in Asia is water scarcity. Freshwater availability in Central, South, East and Southeast Asia is expected to be highly vulnerable to climate change, which could adversely affect more than a billion people in Asia by the 2050s [10.4.2]. Runoff changes could have a significant effect on energy production and agricultural productivity [10.4.2.1].

Increases in temperature are expected to result in more rapid recession of Himalayan glaciers and the continuation of permafrost thaw across North Asia (Fig. TS-10) (medium confidence).
If current warming rates are maintained, Himalayan glaciers could decay at very rapid rates. Accelerated glacier melt would result in increased flows in some river systems for a few decades, followed by a decrease in flows as the glaciers disappear [10.6.2]. Permafrost degradation can result in ground subsidence and can affect drainage characteristics and infrastructure stability. [10.4.4.3]

Asian marine and coastal ecosystems are expected to be affected by sea level rise and temperature increases (high confidence).
Projected sea level rise could result in many additional millions of people being flooded each year [10.4.3.1]. Sea water intrusion could increase the habitat of brackish water fisheries but significantly damage the aquaculture industry [10.4.1.3]. Overall, sea level rise is expected to exacerbate already declining fish productivity in Asia [10.4.1.3]. Arctic marine fisheries should be greatly influenced by climate change, with some species, such as cod and herring, benefiting at least for modest temperature increases, and others suffering declining productivity, such as the northern shrimp [10.4.1.3].

Climate change is expected to exacerbate threats to biodiversity resulting from land use/cover change and population pressure in most parts of Asia (high confidence).
Increased risk of extinction for many flora and fauna species in Asia is likely as a result of the synergistic effects of climate change and habitat fragmentation [10.4.4.1]. Threats to the ecological stability of wetlands, mangroves, and coral reefs around Asia would also increase [10.4.3.2, 10.6.1].

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

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

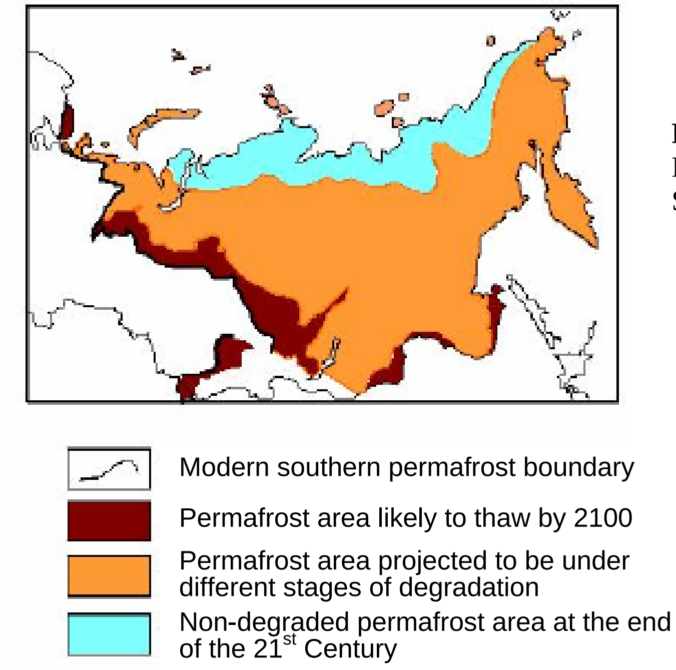


Fig. TS-10: Projected future changes in the North Asia permafrost boundary under the SRES A2 scenario for 2100 [F10.5].

AUSTRALIA AND NEW ZEALAND

Evidence for climate change has become clearer and adaptation has started in some sectors and regions (high confidence).
Since 1950 there has been 0.3-0.7°C warming in the region, with more heat waves, fewer frosts, more rain in north-west Australia and south-west New Zealand, less rain in southern and eastern Australia and north-eastern New Zealand, an increase in the intensity of Australian droughts, and sea level rise. [11.2.1]. Impacts are now evident in water supply, agriculture, natural ecosystems and New Zealand glaciers [11.2.2; 11.2.3]. Some adaptation has occurred, for example from sectors such as water, agriculture, horticulture and coasts. [11.2.5]

Climatic trends since 1950 are likely to accelerate in the future (high confidence).
The frequencies of major floods, fires, droughts, heat waves and severe tropical storm surges are likely to increase [11.3.1]. Large areas of mainland Australia and eastern New Zealand are likely to become warmer with reduced runoff, although western New Zealand is likely to become warmer with increased runoff. [11.3.1; 11.4.1]

Without further adaptation, potential impacts are likely to be substantial (high confidence).
- Some benefits are likely for particular sub-regions and sectors. Up to about 2050, enhanced average growing conditions are likely for agriculture, horticulture and forestry over much of New Zealand and Tasmania, provided adequate water is available [11.4.3]. Reduced energy demand is very likely in cities in winter [11.4.10]. Higher flows in New Zealand's largest rivers are very likely to benefit hydroelectricity generation and irrigation water supply [11.4.1; 11.4.10].
- Water security problems are very likely to be exacerbated over large areas of southern and eastern Australia and in areas distant from major rivers in eastern New Zealand. [11.4.1]
- Impacts on many natural ecosystems are very likely to exacerbate existing stresses such as invasive species, habitat loss and fragmentation and glacier shrinkage, thereby reducing ecosystem services, e.g. for tourism, fishing, water supply. [11.4.2]
- Coastal settlements are likely to be highly vulnerable. Ongoing coastal development is very likely to exacerbate risks from projected sea level rise, larger storm surges and more intense cyclones [11.4.5]. There is likely to be loss of high-value property, degraded beaches, social and economic trauma, loss of items of cultural significance, and higher insurance costs. [11.4.5]

- Risks to critical infrastructure are likely to increase. These risks include failure of flood protection and urban drainage systems, increased storm and fire damage in major cities, and more heatwaves causing higher human mortality and peak summer energy demand. [11.4.1; 11.4.7; 11.4.10; 11.4.11]
- Biosecurity threats are likely to increase. Many invasive species and disease vectors are likely to damage health, agriculture, forestry and natural ecosystems. [11.4.2; 11.4.3; 11.4.4; 11.4.11]
- Agriculture and forestry are likely to be vulnerable to reduced run-off over much of Australia and north-eastern New Zealand [11.4.3; 11.4.4]. In southern Australia, cropping is likely to become unviable at the dry margins if rainfall is reduced substantially, even though yield increases from elevated CO_2 will partly offset this effect [11.4.3]. In New Zealand, farming and forestry are very likely to expand to higher elevations and horticulture to higher latitudes. [11.4.3; 11.4.4]

Some sectors and regions are likely to be more vulnerable than others, due to differing adaptive capacity (medium confidence).
Natural systems have limited adaptive capacity [11.2.5]. Projected rates of climate change are very likely to exceed rates of evolutionary adaptation in many species [11.5]. Habitat loss and fragmentation are also very likely to limit movement in response to shifting climatic zones [11.5]. Most human systems have considerable adaptive capacity, but there are likely to be considerable cost and institutional constraints to implementation of adaptation options [11.5]. The most vulnerable systems relate to water supply, coastal communities and infrastructure, and some agriculture. [11.5]

Vulnerability cannot be eliminated entirely by adaptation (high confidence).
Risks from extreme weather, sea-level rise and drought are very likely to increase and provide major challenges for adaptation [11.5]. Vulnerability hotspots (Fig. TS-11) have been identified. [11.7] By the end of the century, vulnerability is likely to be substantially greater under high emissions scenarios than under low emission scenarios. [11.7]

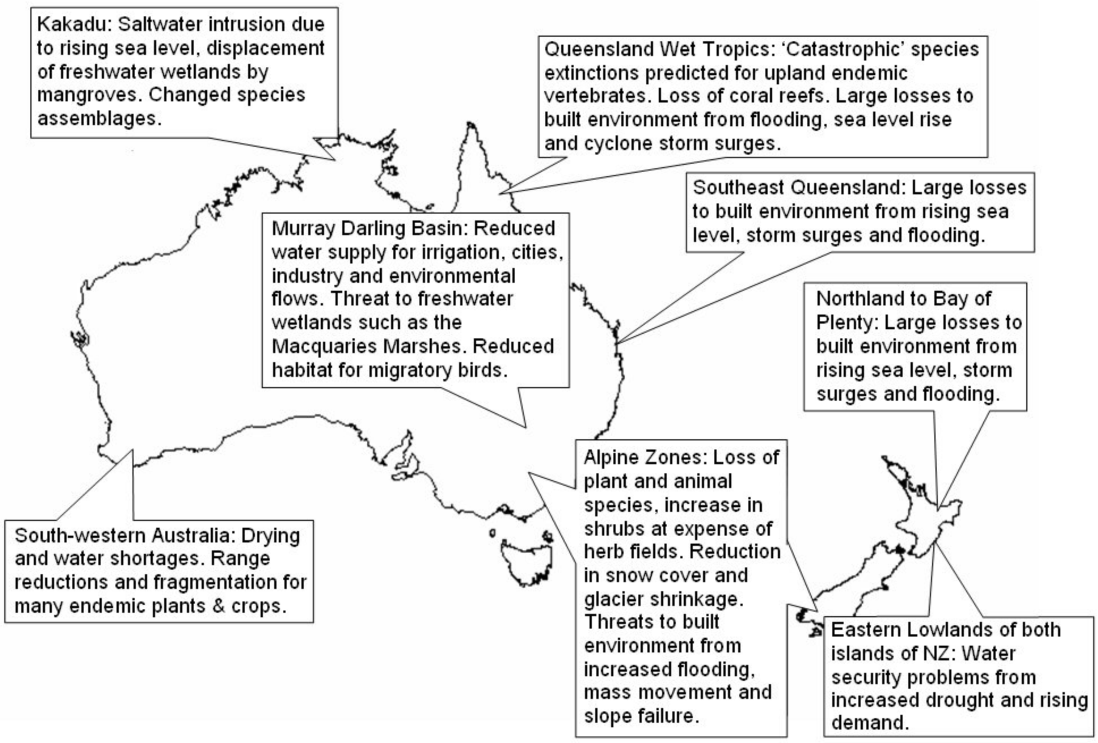


Fig. TS-11: Key hotspots in Australia and New Zealand, based the following criteria: large impacts, but low adaptive capacity; economically important, with substantial exposed infrastructure and population; subject to other multiple stresses (e.g., continued rapid population growth, ongoing development, ongoing land degradation, ongoing habitat loss, threats from rising sea level). [11.6]

EUROPE

It is expected that the climate of Europe will continue to change throughout the 21st century, with the changes unevenly distributed across regions and between seasons (very high confidence). Projected changes in temperature for the 21st century show the greatest warming across Northern Europe in winter and across Southern and Central Europe in the summer [12.3.1.1]. Future projections of precipitation indicate wintertime precipitation as likely to increase across Northern, Central and Western Europe, and decrease across the Mediterranean. Summer precipitation is expected to decrease substantially across Western, and Central Europe, as well as the Mediterranean. Reduced intensity of precipitation, earlier start of drought and longer drought periods are expected in southern Europe. [12.3.1.1]

It is likely that the area and number of people under water stress will increase, and that differences in water availability between countries will be exacerbated (very high confidence). Annual runoff and water availability is likely to increase in the North and North-west and decrease in the South and South-east [12.4.1]. Water availability in Southern and South-eastern Europe in the summer is likely to decrease, leading to a deterioration of water quality [12.4.1]. Irrigation demands are likely to increase in Southern and South-eastern Europe. Industrial and domestic demands are expected to stabilise in the West but increase in the East due to economic growth [12.4.1]. It is likely that the reliability of water reservoirs in Southern and South-eastern Europe will reduce [12.4.1].

Climate-induced natural hazards are expected to increase throughout Europe, with the type of hazard varying depending on the region (very high confidence). The risk of flooding in maritime regions is expected to increase due to rising sea levels and increases in rainfall intensity, particularly in winter. Central and Eastern Europe are expected to see an increased risk of flooding from snowmelt. The risk of flash flooding increases throughout Europe but is particularly high in the South and South-east (Table TS-3) [12.4.1]. The number and intensity of storms in the North-eastern Atlantic will likely increase, while the Mediterranean is expected to see a decline in storminess and wind intensity [12.4.2]. Mountainous regions are expected to see an increase in snow avalanches and rock falls due to changes in snow cover and temperature [12.4.2]. The risk of fire in the Mediterranean is expected to increase due to higher temperatures and reduced precipitation leading to a longer fire-season [12.4.4.1]. Overall, interannual variability is expected to increase, thus affecting the occurrence of heat waves and drought. Towards the end of the 21st century the Mediterranean and much of Western Europe will very likely experience recurring dry periods [12.3.1.2].

The persistence and nature of some major European (eco)systems is seriously endangered (very high confidence). Sea-level rise is expected to result in the inland migration of Europe’s beaches and low-lying soft sedimentary coasts [12.4.2]. Warmer temperatures may result in the loss of permafrost areas in Arctic areas [12.4.5]. Tree-line areas in the upper mountains are likely to become forested [12.4.4]. Increased fire frequency could result in the greater dominance of shrubs over trees in the Mediterranean. Forested areas are expected to be replaced by grassy glades or wetlands due to increased fire frequency at the forest-tundra ecotone [12.4.4]. Many ephemeral aquatic ecosystems may disappear, and permanent ones shrink in the Mediterranean [12.4.5]. Increasing temperature would cause changes in the growing season and productive capacity of marine water bodies [12.4.7.2].

European biodiversity will be severely threatened (high confidence). Higher temperatures may lead to increased species richness in freshwater ecosystem in Northern Europe and a decrease in the South-west [12.4.5]. Aquatic, cold-adapted species could be forced further north and upstream, some eventually disappearing from Europe [12.4.5]. Increases in sea temperature are expected to cause changes in the distribution and abundance of exploited and non-exploited fish species [12.4.7.2]. Under the assumption of no dispersal, more than half of European flora could be vulnerable, endangered, critically endangered or extinct by 2080 [12.4.6]. Endemic plants and vertebrates of the Mediterranean Basin appear to be especially vulnerable to climate change [12.4.6].

It is likely that climate change will challenge some European economic sectors and alter current balances within and among countries (high confidence).
The seasonal cycles of tourism and energy demand are expected to change under climate change. Mediterranean tourism is likely to shift from the summer to spring and autumn seasons, thereby flattening the seasonal cycle [12.4.9]. Higher temperatures would encourage travel northwards and to higher altitudes and shorten the length of the ski season due to reductions in snow cover [12.4.9]. Electricity demand can be expected to increase in summer and decrease in winter, with the peak in demand shifting, in some locations, from the winter to summer [12.4.8.1].

Climate change is very likely to magnify the differences within Europe in terms of natural resources and assets (low confidence).
The differences in natural resources between European nations are likely to be enhanced under climate change [12.4.1, 12.4.2, 12.4.7, 12.4.8]. In general, impacts are expected to be more negative in the South and South-east and less negative, even positive, across Central and Northern Europe [12.7]. Adaptive capacity is higher in the West than in the East, and, within the West, it is greatest in the Central and Northern parts than in the South [12.7].

Table TS-3: Annual expected river flood damage in the UK at present day and in 2080s (In 2004 £) under different SRES scenarios. [T12.4]

Basis	**Present day**	**A1**	**A2**	**B1**	**B2**
Annual expected damage (10^9 £)	1.3	28.4	20.7	6.7	2.2

LATIN AMERICA

Climatic variability and extreme events, primarily those related to precipitation variability, have been severely affecting the Latin America (LA) region over recent years (high confidence).
Severe droughts and flood episodes have occurred in most countries. Unexpected extreme weather events were reported, for example the Venezuelan intense precipitations of 1999 and 2005, the destructive hail storm in Bolivia of 2002, Hurricane Catarina in the South Atlantic in 2004 and the record hurricane season of 2005 in the North Atlantic. [13.2.2]

During the last hundred years, important changes have been observed in precipitation, increases in temperature and in the rate of se level rise (high confidence).
Increases in rainfall in southeast Brazil, Uruguay, the Argentine Pampas and some parts of Bolivia have had impacts on land use, crop yields and flooding. Inversely, a declining trend in precipitation has been observed in Ecuador and central Chile [13.2.4.1]. A warming close to 1^oC in Meso-America and South- America has been observed [T13.2.a]. Increases in the rate of sea level rise have been observed in south-eastern South America, where the rate reached 2-3 mm/year during the last 10-20 years. [13.ES]

The glacier retreat trend reported in the TAR is accelerating (high confidence).
This issue is critical in Bolivia, Peru, Colombia and Ecuador (see Fig. TS-12), where water availability has already been compromised either for consumption or hydropower generation. These problems with supply are expected to increase in the future becoming chronic if neglected. Recent research in the Andes shows that in the next 15 years inter-tropical glaciers could disappear, affecting water availability and hydropower generation. [13.2.4.1]

The use of natural resources has intensified land use changes and exacerbated many of the processes of land degradation (high confidence).

In Latin America, almost three quarters of the dry lands are moderately or severely affected by degradation processes and droughts [13.2.3.2]. Natural land cover in general continued to decline at very high rates. In particular, rates of deforestation of tropical forests have increased during the last five years [13.ES].

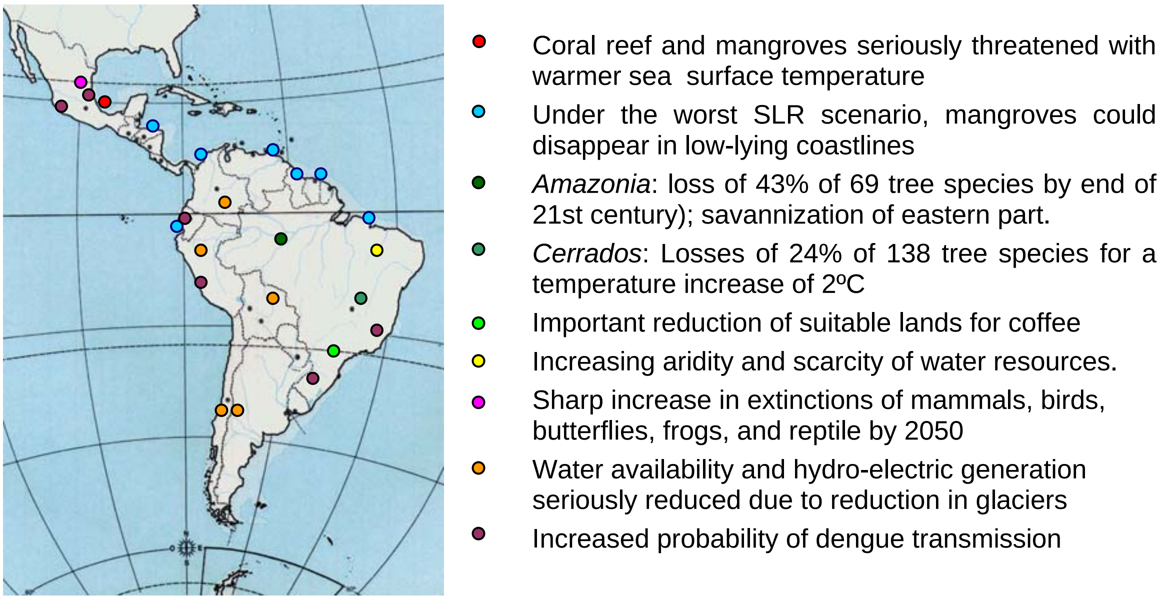


Fig. TS-12: Key hotspots for Latin America, where climate change impacts may be expected to be particularly severe. [13.2]

Improved understanding of current vulnerability to extreme events and the costs of reactive policies has led to the strengthening of institutions and creation of new ones (high confidence).
New legal frameworks, capacity building and new institutions capable of dealing with current threats from a preventive perspective represent a new strategy to confront climatic challenges. The development of early warning systems and risk analysis in several sectors such as agriculture, human health, water resources, fisheries and coastal resources, has increased their capacity for planning and management. However low economic growth and institutional weaknesses in some parts of LA decrease the resilience of the social systems to cope with climate variability and change by hindering adaptation measures. [13.2.5]

Under future climate change, there is the likelihood of significant species extinctions in many areas of tropical Latin America (high confidence).
Replacement of tropical forest by savannas is expected in eastern Amazonia (see Fig. TS-12), along with replacement of semi-arid by arid vegetation in parts of Northeast Brazil due to synergistic effects of both land use and climate changes. [13.4.1]. With important consequences for the well being of the population by the year 2050, 50% of agricultural lands will be subjected to desertification and salinization processes in many areas of Latin America [13.4.2].

The expected increase in SLR and weather and climatic variability and extremes will likely affect coastal areas (high confidence).
Sea level rise will lead to loss of low-lying areas (i.e. El Salvador, Guyana, Uruguay), will threaten the built environment and tourism, (i.e. Uruguay), will produce alterations of coastal morphology (i.e. Peru), loss of mangroves in low lying coastlines (i.e. Brazil, Ecuador, Colombia, Venezuela, see Fig. TS-12), scarcity of drinking water in the Pacific coast of Costa Rica and Ecuador, and threaten Mesoamerican coral reefs; it will also perturb the location of fish stocks in the south-east Pacific. Many of these impacts are already observed [13.4.4].

NORTH AMERICA

North America has considerable adaptive capacity, which has been deployed effectively at times, but this capacity has not always protected its population from adverse impacts of climate variability and extreme weather events (very high confidence).
Damage and loss of life from hurricane Katrina in August, 2005, starkly illustrate the limitations of existing adaptive capacity. Cultural traditions and institutions in North America tend to be decentralized, and effective adaptation depends on the consistent and often voluntary action of many. Past responses to climate experience have often been reactive, unevenly distributed, or focused on coping with rather than preventing problems. [14.5; 14.7]

Emphasis on effective adaptation is critical, because economic damage from extreme weather will likely continue increasing, with direct and indirect consequences of climate change playing a growing role (high confidence).
Over the past three decades, economic damage from hurricanes in North America has increased over four-fold (Fig. TS-13), due largely to an increase in the value of infrastructure at risk [14.2]. Costs to North America include billions of dollars in damaged property and diminished economic productivity, as well as lives disrupted and lost [14.2.6; 14.4.6]. Hardships from extreme events disproportionately affect those who are socially and economically disadvantaged, especially indigenous peoples of North America who often depend on a diverse ecological, and cultural resource base [14.2.6; 14.4.6]. This pattern is likely to persist and, when coupled with climate change, reduce the overall well-being of the most vulnerable populations. [14.2.6; 14.4.6]

Climate change will exacerbate other stresses on infrastructure and human well-being in urban centres as well as communities and habitats in coastal areas (high confidence).
Climate change impacts in urban centres will be compounded by urban heat islands, air and water pollution, aging infrastructure, maladapted urban form and building stock, water quality and supply challenges, immigration and population growth, and a growing elderly population [14.4.6; 14.4.1]. In coastal communities, sea-level rise and increased intensity and severity of storms will likely interact with development and pollution [14.4.3], exacerbating the impacts of progressive inundation, storm-surge flooding, and shoreline erosion [14.2.3; 14.4.3]. Coastal habitats are threatened now and increasingly in future decades by sea-level rise, fixed structures blocking landward migration, and changes in species composition resulting from altered freshwater, nutrient, and contaminant inputs. [14.2]

Warm temperatures and extreme weather already affect human health via heat-related mortality, pollution, storm-related fatalities and injuries, and infectious diseases and are likely to increase with climate change (medium confidence).
Depending on progress in health care, early warning capacity, and infrastructure, increased future mortality is possible from heat waves, waterborne diseases and degraded water quality [14.4.1], exposure to pollen and fungi, and vector-borne infectious diseases (low confidence) [14.2.5; 14.4.5].

Climate change will constrain North America's already intensively managed system of water distribution and flood control, interacting with other stresses (high confidence).
More intense rainfall events and diminishing snowpack and glacier storage will affect timing and availability of water and intensify competition among uses [B14.2; 14.4.1]. Warming also adds additional stress on groundwater availability, compounding effects of higher demand from economic development and population growth (medium confidence) [14.4.1]. In the Great Lakes-St. Lawrence system, lower lake levels are likely to exacerbate issues of water quality, navigation, hydropower generation, water diversions, and bi-national cooperation. [14.4.1]

Impacts of climate change will depend on investments in adaptation (medium confidence).
In agriculture, for example, elevated CO2 will tend to increase yields, even with modest warming, but with effects that vary among crops and regions and that depend on changes in technology, and water

availability. Adaptation is likely to be most challenging in regions that rely on irrigation, long-lived perennial crops, or crops with high cultural and tourism value. [14.4.4; 14.5.4]

Disturbances like wildfire and insect outbreaks are increasing and are likely to intensify in a warmer future with drier soils and longer growing seasons and to interact with changing land-use and development affecting the future of wildland ecosystems (high confidence).
Recent climate trends have increased ecosystem net primary production, and this trend is likely to continue for the next few decades [14.2.2]. However, wildfire and insect outbreaks are increasing, a trend that is likely to intensify in a warmer future [14.4.2; Box-14.1]. Over the 21st century, the tendency for species and ecosystems to shift north and to higher elevations will rearrange the map of North American ecosystems. Continuing increases in disturbances are likely to limit carbon storage, facilitate invasives, and amplify the potential for major changes in ecosystem services. [14.4.2]

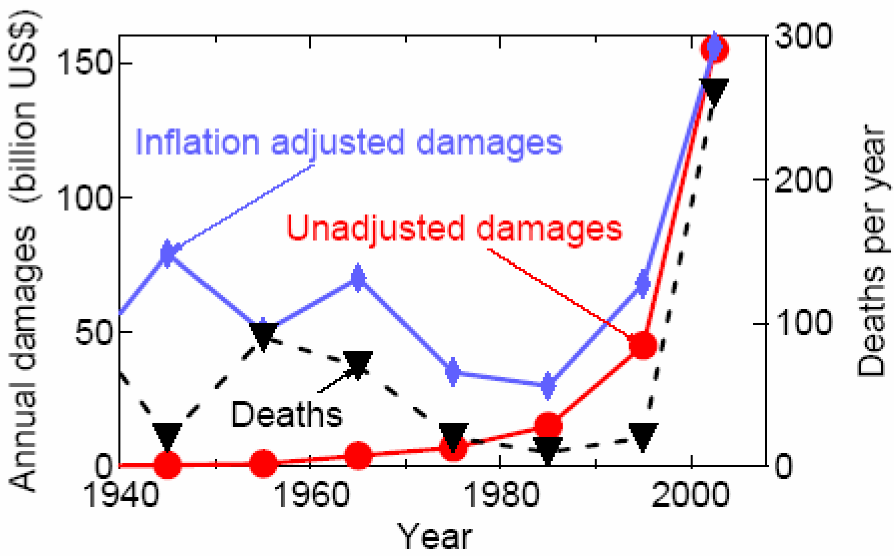


Fig. TS-13: Loss of life and damages from hurricanes making landfall in the continental United States since 1940. Source US National Hurricane Center, NOAA. [F14.1]

POLAR REGIONS

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

There is a growing evidence of the impacts that climate change has had on the ecosystems in both Polar Regions (high confidence).
There has been a measured change in composition and range of plants and animals on the Antarctic Peninsula and on the sub-Antarctic islands. There is a documented increase in the overall greenness of parts of the Arctic, an increase in biological productivity, a change in species ranges (e.g., shifts from tundra to shrublands), some changes in position of the northern limit of trees, and changes in the ranges and abundance of some animal species. In both the Arctic and Antarctic, research indicates that such changes in biodiversity and vegetation zone relocation will continue. The poleward migration of existing species and competition from invading species is already occurring, and will continue to alter species composition and abundance in terrestrial and aquatic systems. Associated vulnerabilities pertain to biodiversity and the spread of animal-transmitted diseases beyond the Arctic. [15.4.2.1; 15.4.2.2; 15.2.2.1]

The continuation of hydrologic and cryospheric changes will have significant regional impacts on freshwater, riparian and near-shore marine systems (high confidence0.
The combined discharge of Eurasian rivers draining into the Arctic Ocean shows an increase since the 1930s, largely consistent with increased precipitation although changes to cryospheric processes (snowmelt and permafrost thaw) are also modifying routing and seasonality of flow. [15.3.1; 15.4.1]

The retreat of Arctic sea ice over recent decades has led to improved marine access, changes in coastal ecology/biological production, adverse effects on many ice-dependent marine mammals and increased coastal wave action (high confidence).
Continued loss of sea ice will potentially create issues of national sovereignty. Reductions in freshwater ice will affect lake/river ecology and biological production, and will require changes in water-based transportation. For many stakeholders, economic benefits may accrue, but some activities and livelihoods may be adversely affected. [15.ES; 15.4.7.1; 15.4.3.2; 15.4.1.2; 15.4.1.4]

Around the Antarctic Peninsula, a newly documented decline in krill abundance, together with an increase in salp abundance, has been attributed to a regional reduction in the extent and duration of sea ice. If there is a further decline in sea ice, a further decline in krill will impact higher predators (medium confidence).
Warming of areas of the northern polar oceans has had a negative impact on the community composition, biomass and distribution of phytoplankton and zooplankton. The impact of present and future changes on higher predators, fish and fisheries, will be regionally-specific, some beneficial and some detrimental. [15.2.2.1; 15.6.3]

Already, most Arctic human communities are having to adapt to climate change (high confidence).
Indigenous People have exhibited resilience to changes in their local environments for thousands of years. Some indigenous communities are adapting through changes in wildlife management regimes and hunting practices. However, stresses in addition to climate change, together with a migration into

small remote communities and increasing involvement in employment economies and sedentary occupations, will increase vulnerability. [15.4.6]

A less severe climate in northern regions will produce positive economic benefits for some stakeholders (high confidence).
The benefits will depend on particular local conditions, but will, in places, include reduced heating costs, increased agricultural and forestry opportunities, more navigable northern sea routes and marine access to resources. [15.4.2.4]

The impacts of future climate change in the Polar Regions will produce feedbacks that in the next hundred years will have globally significant consequences (high confidence).
A continued loss of ice will add to global sea level rise. A major impact could result from a weakening of the thermohaline circulation due to a net increase in river flow into the Arctic Ocean and the resulting increased flux of freshwater into the North Atlantic. Under CO2 doubling, total river flow into the Arctic Ocean is expected to increase by up to 20%. Warming will expose more bare ground in the Arctic (Fig. TS-14) and on the Antarctic Peninsula, to be colonized by vegetation. Recent models predict a decrease in albedo due to changing vegetation and that the tundra will be a small sink for carbon although increased methane emissions from the thawing permafrost could contribute to climate warming. Annual methane emissions from Siberian wetlands are expected to increase by 6-10 million tons by 2050. [15.4.1.2; 15.4.2.3]

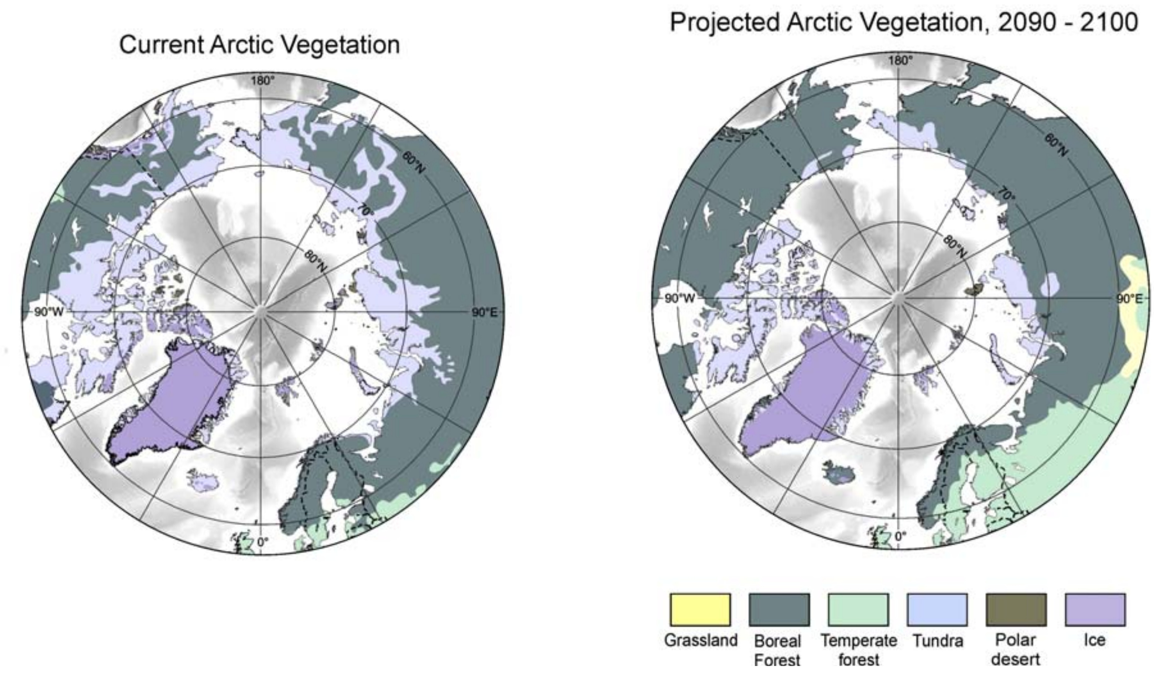


Fig. TS-14: Vegetation of the Arctic and neighbouring regions. Left: present-day based on floristic surveys. Right: modelled for 2090-2100 under the IS92a emissions scenario. [F15.2].

SMALL ISLANDS

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

Sea-level rise will exacerbate inundation, erosion and other coastal hazards, thus threatening vital infrastructure that supports the socio-economic well-being of island communities (**high confidence**).

Some studies suggest a possible reduction of island size, particularly in the Pacific, whilst others show that islands such as the Maldives are morphologically resilient and are expected to persist [16.4.2]. Island infrastructure tends to be restricted to coastal locations. In the Caribbean and Pacific Islands, more than 50% of the population live within 1.5 km of the shore. Almost without exception, every international airport in the Small Islands of Indian and Pacific Oceans and the Caribbean is sited within a few km of the coast, or on tiny coral islands [16.4.5; 16.4.7]. The threat from sea-level rise to will be amplified considerably by any changes in the occurrence of tropical storms. [16.45]

There is strong evidence that under most climate change scenarios, water resources in small islands will be seriously compromised (high confidence).
Small Islands tend to have a limited water supply. Recent studies show that many small islands in the Caribbean would be exposed to severe water stress under climate change [16.4.1]. All SRES scenarios show reduced rainfall in summer, so that it is highly likely that demand could not be met during low rainfall periods. Increased rainfall in winter would not necessarily compensate due to lack of suitable land area for dams and high runoff during storms leading to loss of freshwater to the sea. [16.4.1]

Coral reefs, fisheries and other marine-based resources in small islands will be heavily impacted by climate change (**high confidence**).
Fisheries make an important contribution to the GDP of small islands (e.g., they constitute around 10% of GDP in the Maldives) [16.4]. Any change in the occurrence and intensity of ENSO events is likely to have severe impacts on commercial fishing [16.4]. Increasing sea surface temperature and sea level, increased turbidity, nutrient and chemical pollution, damage from tropical cyclones, and decreases in growth rates due to the effects of higher carbon dioxide concentrations on ocean chemistry are very likely to affect the health of island coral reefs [16.4.3]. In tropical regions, reefs act as a natural barrier for coastlines of small islands. [16.4.2]

Subsistence and commercial agriculture on small islands will be impacted by climate change and sea-level rise, as a result of inundation, seawater intrusion into freshwater lenses, soil salinization, and a decline in water supply (high confidence).
Without adaptation, agricultural economic costs could be significant in small islands under various climate scenarios. [16.4.3]

New studies confirm previous findings that the effects of climate change on tourism in small islands will be direct and indirect, and will be largely negative (high confidence).
Tourism is the major contributor to GDP and employment in many small islands. Sea-level rise and increased sea water temperature will cause accelerated beach erosion, degradation of coral reefs including bleaching, loss of cultural heritages on the coasts by inundation and flooding, which in turn reduce attraction for coastal tourism. Water shortages and increased incidence of vector-borne diseases may steer tourists from small islands, while a warmer climate in the northern countries could also reduce the number of people visiting small islands in tropical and subtropical regions. [16.4.6]

There is growing concern that global climate change and sea-level rise are likely to impact human health in small islands, mostly in adverse ways (**medium confidence**).
Climate change is likely to result in increased incidence of climate-sensitive vector-borne diseases such as dengue fever and malaria. Other climate sensitive diseases of concern to small islands include diarrhoeal diseases, heat stress, skin diseases, acute respiratory infections, and asthma. [16.4.5]

On some islands, especially those at higher latitudes, warming has already led to the extinction of some local species (**high confidence)**.
Middle and high-latitude islands will be colonized by non-indigenous invasive species previously limited by unfavourable temperature conditions. Increases in extreme events in the short term will severely affect the adaptation responses of forests on tropical islands, where regeneration is often slow. In view of their small area, forests on island states can be easily decimated by violent cyclones or freak storms. [16.4.4]

Adaptation is urgent given that some islands are already experiencing the adverse effects of climate change (**high confidence**).
For many islands, pressures on resources are projected to increase in the future, reducing the capacity of small islands to adapt to climate change [16.2.4]. While small islands must adapt, their capacity to do so is being further eroded by internal socioeconomic changes and external factors such as globalization of economic activities. [16.5]

D. Responding by Adaptation and Mitigation

D.1 Adaptation

Adaptation can significantly reduce vulnerability to climate variability and change (high confidence).
Societies have a long record of adapting to the impacts of weather and climate through a diverse range of practices that include crop diversification, irrigation and water management, disaster risk management, infrastructure construction, and insurance. The key lesson from experience is that social and natural capital play an important role alongside technological interventions to manage climate risk. Uncertainty around climate variability has real costs for resource management and long term investment. In Sahelian Africa, pastoralist and farming economies have been shown to be adaptable to currently observed changes in climate variability. Research on the use of seasonal weather forecasts has shown that farmers, even with limited formal education and apparent risk aversion, can enhance their livelihoods and reduce livelihood risks through the use of this information. [17.2.1]

But climate change poses novel risks often outside the range of experience, such as impacts related to permafrost melt, accelerated glacier retreat and freshwater availability, and impacts of extreme events on human health and well-being and on the built environment. One example is the policy response to the 2003 heatwave in Western Europe, which demonstrates that governments, agencies and citizens were unfamiliar with risks associated with heat waves. A second example is that current building stocks in some parts of Europe are designed for comfort in present mean temperatures rather than future mean or extreme temperature situations. Given the projections of increased summer temperatures in mid-latitude countries, infrastructure and policy adaptation should take account of new parameters of risk. [17.2.1]

Adaptation to climate change is already taking place (high confidence).
Early responses by wild species, such as changes in avian migratory patterns, represent natural adaptations. [1.3.5.2]

In the past five years there has been increasing documentation of adaptation measures being implemented in both developed and developing countries in response to presently observed climate changes and to expected future climate change. Documented actions involve policies and regulations, the adoption of new or existing technologies, the private sector, and changes in behaviour and individual action. The vast majority of actions involve building generic capacity of the society to deal with a range of climate risks into the future, while a minority of adaptations at present involve changing resource use, location or infrastructure. [17.2.3]

Examples of adaptations to observed changes in climate include partial drainage of the Tsho Rolpa glacial lake in Nepal; changes in livelihood strategies in response to permafrost melt by the *Inuit* in Nunavut, Canada; and increased use of artificial snow-making by the alpine ski industry in North America and Europe. All of these have been shown to reduce risks or to keep open livelihood options. However, all of the adaptations documented were imposed by the climate risk and involve real cost and reduction of welfare in the first instance [17.2.3]. These examples also confirm the observation of attributable climate signals in impacts of change. [Section B]

A limited but growing set of adaptation measures also explicitly consider future climate change. Examples include consideration of sea level rise in design of infrastructure such as the Confederation Bridge in Canada and a coastal highway in Micronesia, as well as in shoreline management policies and flood risk measures, for example in Maine (USA), the UK, Netherlands and Norway. [17.2.3]

Adaptation measures can be no-regrets but may also entail significant costs (medium confidence).
Comprehensive estimates of costs of adaptation are limited and speculative. They are largely inferred from global damage estimates of climate change which tend to conflate estimated costs of adaptation

and those of residual impacts. Even less is known about the benefits of adaptation, in terms of damages avoided [17.2.4]. There are however a growing number of adaptation cost and benefit-cost estimates for specific sectors and projects. These studies identify a number of measures that can be implemented at low cost and/or with high benefit-cost ratios. The *transitional* and *distributional* costs of adaptation are generally not included in such estimates. [17.2]

Capacity to adapt varies across regions, societies and gender and income groups (high confidence).
There are societies and groups throughout the world with insufficient capacity to adapt to climate change. For example, women within subsistence farming communities are disproportionately burdened with the costs of recovery and coping with drought in many parts of the developing world. [17.3]

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

Multiple stresses related to HIV/AIDS, globalization, and violent conflict affect exposure to climate risks and the capacity to adapt (see Box TS-5). For example, farming communities in India are exposed to impacts of market changes and lower prices in addition to adverse climate change risks. Even high aggregate capacity however does not necessarily translate into real action on adaptation [17.3].

There are substantial limits and constraints to adaptation (high confidence).
The feasibility and success of adaptation is constrained by the magnitude and rate of climate change and sea level rise. Some examples and reasons include:

a. The large number and expansion of potentially hazardous glacial lakes due to rising temperatures in the Himalayas, for example, far exceed the capacity to countries in the region to manage such risks;
b. Bangladesh has initiated a process of development of salt tolerant rice varieties and it has achieved some successes. However, its development of the variety, field trial, commercial production and supply of seeds and convincing farmers may take decades. The new environment under climate change can complicate the situation;
c. If climate change is faster than it is anticipated, many developing countries cannot simply cope with frequent occurrence of extreme weather events as they will drain out additional resources budgeted for social sectors;
d. Climate change will occur in the life cycle of many infrastructure projects (coastal dykes, bridges, sea ports, etc.). Strengthening of these infrastructures based on new design criteria may take decades to implement**;** and
e. Due to physical constraints, adaptation measures cannot be implemented in many estuaries and delta areas.

[17.4]

Social and political structures in society can impose significant constraints to adaptation. Adaptation decisions are also often undertaken at a hierarchy of levels – actions at one level can enhance or constrain options at another. There are also significant impediments to flows of knowledge and information relevant for adaptation decisions but participatory processes are recognized as important for overcoming constraints. Early evaluation of the National Adaptation Plans of Action (NAPAs), for example, show that the guidelines for consultation and participation are in line with best practice for incorporating local knowledge and a wide range of stakeholder views. But the implementation of the Plans often deviate from the ideal and miss opportunities for participatory planning and the use of local knowledge as a valuable resource [17.4].

Box TS-5: Mapping Adaptive Capacity to Multiple Stressors

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

The map in Fig. TS-15 shows regional vulnerability to climate change, measured as a composite of adaptive capacity and climate sensitivity under exposure to climate change. The superimposed hatching indicates those areas which are doubly exposed through high vulnerability to climate change and high vulnerability to trade liberalization. The results of this mapping showed higher degrees of resilience in districts located along the Indo-Gangetic Plains (except in the state of Bihar), the south and east, and lower resilience in the interior parts of the country, particularly in the states of Bihar, Rajasthan, Madhya Pradesh, Maharashtra, Andhra Pradesh, and Karnataka. [17.3.2]

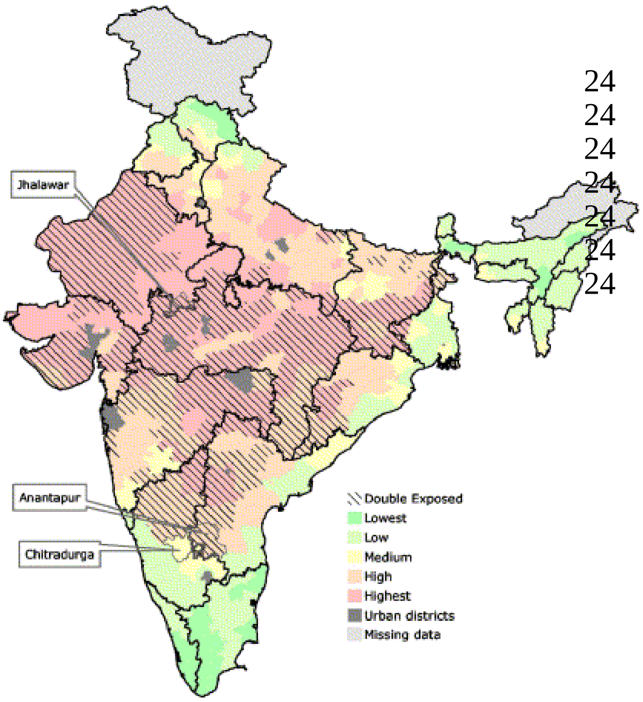


Fig. TS-15: District in India that rank in the highest in terms of climate change vulnerability and globalization vulnerability are considered to be double exposed (depicted with hatching). Source: O'Brien *et al.* (2004). [17.3.2]

D.2. Damages avoided by mitigation, and mitigation-adaptation issues

Both adaptation and mitigation help to reduce the risks of climate change to nature and society (very high confidence).
However, their effects vary over time and place. Mitigation will have global benefits but, owing to the lag times in the climate system, these will hardly be noticeable until 2040 [WG-I]. The benefits of adaptation are largely local to regional in scale but they can be immediate, especially if they also address vulnerabilities to current climate conditions [18.1.1; 18.5.2]. Given these differences between adaptation and mitigation, climate policy is not about making a choice between adapting to and mitigating climate change. If key vulnerabilities to climate change are to be addressed, adaptation is necessary because even the most stringent mitigation efforts cannot avoid further climate change in the next few decades. Mitigation is necessary because reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is possible only at very high social, environmental and economic costs. [18.4; 18.6]

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

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

Inter-relationships between adaptation and mitigation exist at each level of decision-making (see Table TS-4) (high confidence).
Adaptation actions can have (often unintended) positive or negative mitigation effects, whilst mitigation actions can have (also often unintended) positive or negative adaptation effects [18.4.2; 18.5.2]. An example of an adaptation action with a negative mitigation effect is the use of air-conditioning (if the required energy is provided by fossil fuels). An example of a mitigation action with a positive adaptation effect could be the afforestation of degraded hill slopes, which would not only sequester carbon but also control soil erosion. Other examples of such synergies between adaptation and mitigation include rural electrification based on renewable energy sources, planting trees in cities to reduce the heat-island effect and the development of agroforestry systems. [18.5.2]

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

information that explicitly considers both adaptation and mitigation makes it difficult to assess the need for and potential of synergies in climate policy. [18.7]

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

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

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

Table TS-4: Relationships between adaptation and mitigation. [F18.3]

E. Key vulnerabilities

Key vulnerabilities are found in many social, economic, biological and geophysical systems (very high confidence).

In accordance with the pertinent literature, the term "key vulnerability" is used here to denote potentially severe impacts of climate change that merit particular attention by policy makers because they endanger the lives or well-being of people or other valued attributes of climate-sensitive systems [19.1.2]. Key vulnerabilities are found in many social, economic, biological and geophysical systems. [19.3.1]

The identification of key vulnerabilities is intended to provide guidance for identifying levels and rates of climate change that, in the terminology of UNFCCC Article 2, may be considered "dangerous" by relevant decision-makers. [19.1.1] Ultimately, the definition of "dangerous anthropogenic interference with the climate system" must incorporate value judgments through a political process that is informed by the state of scientific knowledge. [19.1.2]

No single metric can adequately describe the diversity of key vulnerabilities, nor determine their ranking. The criteria used here for assessing and defining key vulnerabilities include magnitude, timing, persistence and reversibility, likelihood and confidence, potential for adaptation, unequal distribution, and importance of the vulnerable system [19.2]. Table TS-5 presents an illustrative sample of examples, categorized according to the five "reasons for concern" identified in the Third Assessment Report.

Some key vulnerabilities are associated with "systemic thresholds" in either the biogeophysical system, the socio-economic system, or coupled socio-natural systems (e.g., a level of sea surface temperature above which a coral reef would incur permanent bleaching is a threshold in the biogeophysical system). Other key vulnerabilities can be associated with "normative thresholds" defined by stakeholders or decision-makers (e.g., a magnitude of sea level rise no longer considered acceptable by low-lying coastal dwellers). [19.1.2.5]

Increasing levels of climate change will result in impacts associated with an increasing number of key vulnerabilities (Table TS-5). Some key vulnerabilities have been associated with observed climate change (very high confidence).

- Observed climate change to 2006 has been associated with some impacts that can be considered key vulnerabilities. Among these are increases in human mortality, loss of glaciers, and increases in extreme events such as intense tropical cyclones. [19.3.3, 19.3.4; 19.3.5; 19.3.6]
- Global mean temperature change of up to 2ºC above 1990 levels is projected to exacerbate current key vulnerabilities and trigger others, such as reduced food security in many low-latitude nations. However, some high latitude regions could have economic benefits. [19.3.1, 19.3.2, 19.3.3]
- Global mean temperature change of 2 to 4 ºC above 1990 is likely to result in impacts associated with an increasing number of key vulnerabilities at all scales, such as widespread loss of biodiversity, triggering of widespread deglaciation of major ice sheets, and net economic damages. [19.3.1, 19.3.5]
- Global mean temperature changes greater than 4ºC above 1990 are likely to lead to major increases in key vulnerabilities, exceeding the adaptive capacity of many systems. [19.3.1]
- Regions that are already at high risk from current climate variability are more likely to be adversely affected by anthropogenic climate change in the near future due to increases in the magnitude and frequency of extreme events. [19.3.6 19.4.1]

Adaptation and Mitigation Can Reduce the Risk from Key Vulnerabilities (very high confidence)

Planned adaptation can reduce many potentially dangerous impacts of climate change and reduce the risk from many key vulnerabilities. However, the technical and financial resources and political motivation necessary for planning and implementing effective adaptations are currently quite limited in many regions, in particular in developing countries. In addition, the risk-reducing potential of planned adaptation is very limited for some key vulnerabilities, such as loss of biodiversity, melting of mountain glaciers or disintegration of major ice sheets, especially for large temperature increases. The net effect of adaptation on reducing vulnerability is uncertain. [19.3.3, 19.4.1]

Mitigation of climate change, i.e. reductions in net greenhouse gas emissions, would reduce the risk of triggering additional key vulnerabilities. Postponement of emissions reductions, in contrast, increases the risk of triggering additional key vulnerabilities. In some cases, adaptation and mitigation may have synergistic effects. [19.4.2, 19.4.3]

Some key vulnerabilities occur at lower temperature than indicated in the TAR (high confidence)

The five "reasons for concern" identified in the TAR remain relevant for characterizing key vulnerabilities of climate change. Based on the recent literature, the relationship between global mean temperature increase and the reasons for concern is updated as follows:

1. *Unique and Threatened Systems.* There is new and much stronger evidence of the adverse impacts of observed climate change to date on several unique and threatened systems. Confidence has increased that a 1 to 2°C increase in global mean temperature above 1990 levels will pose significant risks to many unique and threatened systems, including many biodiversity hotspots. [19.3.7]
2. *Extreme Events*. Recent extreme climate events have caused significant loss of life and property damage in developed as well as developing countries. Recent research has shown that human influence is likely to have already significantly increased the risk from certain extreme events (e.g., heat waves, tropical cyclones). [19.3.7]
3. *Distribution of Impacts*. There is still high confidence that the distribution of climate impacts will be uneven, and that low-latitude less-developed areas are generally at greatest risk. However, recent work has shown that vulnerability to climate change is also highly variable within individual countries. As a consequence, some population groups in developed countries are also highly vulnerable. [19.3.7]
4. *Aggregate Impacts*. Episodic impacts previously unaccounted for in assessments of aggregate impacts, such as damages from increased extreme events, may impose potentially large costs. On the other hand, positive impacts sometimes have been overlooked and the potential of adaptation underestimated. In summary, there is now lower confidence in most assessments of aggregate effects than in the TAR, in particular there is uncertainty about how aggregate benefits change up to a few degrees of global warming [19.3.7]
5. *Large-Scale Singularities.* Thresholds for partial deglaciation of the West Antarctic Ice Sheet (WAIS) and Greenland may be lower than reported in the TAR. Partial deglaciation of both ice sheets leading to global sea level rise of 4-6 metres could begin with global warming of 1-2°C above 1990 levels, with an upper limit of ~1m/century on the rate of sea level rise from WAIS. [19.3.5]

Table TS-5: Candidate key vulnerabilities (not net impacts), classified according to the TAR reasons for concern. Note that all criteria for inclusion are not listed and that this table is not quantitative. It is a reflection of the scientific judgement of the authors in light of the literature, taking account of critical comments received. Temperature increases are global mean, relative to 1990. [T19.1]

Sector/activity	Criteria for "key" vulnerability	Critical level, timings and confidence
Risks to unique and threatened systems		
Terrestrial ecosystems	Bounded ecosystems such as coastal, mountain and remnants already threatened	Many ecosystems already being affected and widespread disruption at 1-2ºC or more (high confidence)
Ocean ecosystems	Vulnerable to increased acidification, warming and decreased vertical mixing, notably coral reefs	Coral reefs threatened at 1ºC warming (high confidence). Effects of acidification complex and poorly understood.
Risks from extreme events		
Coastal communities	Sea-level rise (SLR) and increased storm surge threatens infrastructure, protective barrier dunes, mangroves and levees.	Vulnerability under present climate variability will increase non-linearly as design criteria exceeded (high confidence). Population and economic growth will increase exposure, but vulnerability can be partially offset by adaptation.
Infrastructure	Non-linear impacts due to design criteria being exceeded by increased intensity and/or frequency of extreme events.	Rapidly increasing damages (high confidence), though much can be reduced by more stringent zoning, design criteria and retrofitting.
Distribution of impacts		
Indigenous, poor or isolated communities	Water supply, health and infrastructure vulnerable to extreme events, disease, sea-level rise, etc., with low adaptive capacity.	Some communities already affected (e.g., Arctic, low-lying islands) (high confidence). Thresholds are site-specific.
Regional systems	Many Arctic systems vulnerable to permafrost melting, sea –ice retreat etc. Africa vulnerable to decreased food production and extreme events. Europe vulnerable to increased drought in south and floods in the centre and north. Low-lying islands and coasts highly vulnerable.	Varying regional vulnerability likely to increase inequities and cause pressures for internal and external migration, external aid etc. (high confidence). Implementation of adaptive potential for Arctic and particularly Africa are uncertain.
Aggregate impacts		
Crops and food supplies	Vital welfare measure. Large regional differences in impacts. Welfare outcome depends on aid and trade capacity.	Initial negative impacts at small warmings in warm regions, wider negative impacts at large warmings (low confidence). High adaptive capacity in many regions; tends to be lower in poorer regions.
Risks from large-scale discontinuities and irreversible changes		
Greenland Ice Sheet, West Antarctic Ice Sheet (WAIS)	Triggering of partial deglaciation possible at 1-2ºC. Potential for 10 or more metres SLR over several centuries to millennium above 2.5-5°C.	Much debate about rapidity of onset. Ongoing Greenland melting likely this century. WAIS disintegration more uncertain, with models of new mechanisms not yet available. Because of long time frame, adaptation potential uncertain, but may require massive relocation of coastal populations and loss of coastal ecosystems.

F. Effects on future sustainability

The aggregate global impacts of climate change are expected to be negative even though specific estimates are uncertain and should therefore be interpreted very carefully (high confidence).

The SAR reported that the net cost of a doubling of greenhouse gas concentrations would be about 1.5% to 3.5% of gross global product; corresponding estimates of (marginal) social cost of carbon ranged from $5 to $125 per tonne of carbon (in 1990 prices). The TAR reported comparable estimates. Across more than 100 estimates from 28 studies now available, the 5% to 95% range of estimates runs from -$10 to $350 per tonne of carbon; the median estimate is $14 per tonne and the mean is $93 per tonne. Climate sensitivity, the discount rate, the treatment of global equity, and estimates of economic and non-economic damages explain much of the variation across this range. [20.6]

The social cost of carbon and all greenhouse gases will rise over time, the best estimate being between 2% and 3% per year [20.6].

Global estimates of the number of people adversely affected by climate change are now available. By 2080 1.1 to 3.2 billions could be experiencing water scarcity (depending on the SRES scenario); 200 to 600 millions, hunger; 2-7 millions or more, coastal flooding [20.6].

The impacts of climate change are expected to be most significant where they occur in the context of multiple stresses from other sources such as poverty, unequal access to resources, food insecurity, and environmental degradation (high confidence).

The intensities of these interactions vary from place to place and over time along specific development pathways [20.3.1; 20.4; 20.3.3].

Increased vulnerability to climate change is expected to impede nations' abilities to achieve sustainable development pathways, as measured for example as progress toward Millennium Development Goals (high confidence).

Climate change, *per se,* will not be a serious impediment to reaching the 2015 targets in most cases. Climate change will, though, erode our ability to achieve goals calibrated in terms of reducing poverty and otherwise improving equity by 2050, particularly in Africa and parts of Asia [20.7.1].

Sustainable development can encourage adaptation to climate change, increase adaptive capacity and *vice versa* [20.3.3]. Some development activities can, however, exacerbate climate-related vulnerabilities [20.3.3; 20.7.1; 20.8.3].

Uneven geographic distributions of climate change impacts will produce varying degrees of vulnerability according to nations' capacities to adapt as shown in Fig. TS-16 (high confidence).

Through 2050, some developing countries are expected to experience significant increases in vulnerability even along low climate sensitivity futures. If climate sensitivity turns out to be high, then the adaptive capacities of most developing countries may be overwhelmed and even some developed countries may experience significant vulnerability [20.7.2].

Through 2100, developed and developing countries could be vulnerable even if climate sensitivity turns out to be low, but developing countries would feel the largest stress. If climate sensitivity turns out to be high, then this unequal distribution of vulnerability would disappear well before 2100 because adaptive capacity would be overwhelmed almost everywhere [20.7.3].

Through 2050 with low climate sensitivity, global mitigation efforts (e.g., restricting concentrations to 550 ppm) would benefit developing countries (in terms of reducing an aggregate vulnerability index) more than developed countries. By 2100, or earlier if climate sensitivity is high, unfettered climate change would overwhelm adaptive capacity nearly everywhere and mitigation would reduce the vulnerability of developed countries more than developing countries [20.7.4].

Reducing vulnerability to the hazards of current climate variability, through specific programs, individual initiatives, and participatory planning processes and other community approaches can reduce vulnerability to climate change, *per se* [20.5; 20.8.1; 20.8.2]. These opportunities will not be sufficient to eliminate damages associated with climate change, and they can be counterproductive if the signal drawn from variability produces false impressions of long-term trends [20.5; 20.8.2]

Discussions about promoting development and improving environmental quality have seldom explicitly included adapting to climate impacts and/or promoting adaptive capacity [20.8.3]. Most of the scholars and practitioners of development who recognize that climate change is a significant issue at local, national, regional and/or global levels focus their attention almost exclusively on mitigation. [20.4; 20.8.3]

Efforts to cope with the impacts of climate change and attempts to promote sustainable development share common goals and determinants including, for example, access to resources, equity in the distribution of resources, stocks of human and social capital, access to risk spreading mechanisms, abilities of decision-support mechanisms to cope with uncertainty [20.2; 20.3.2]

Significant synergies could be exploited with high confidence if progress were made in bringing climate change to the development community and critical development issues to the climate change community (high confidence).

Dialogue processes in assessment, appraisal and action are becoming important tools both in participatory governance and in identifying productive areas for shared learning initiatives [20.3.3; 20.8.2; 20.8.3].

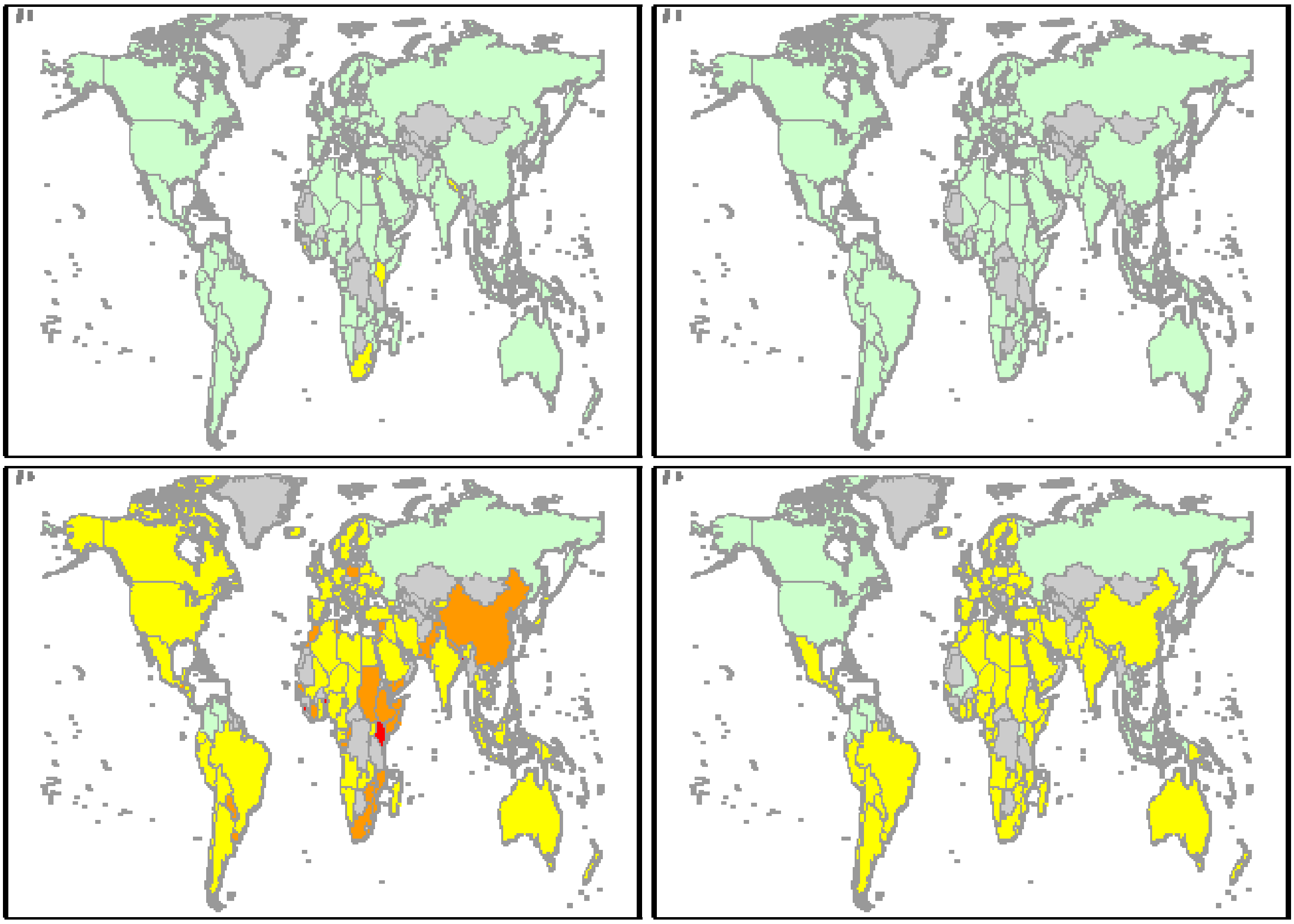


Fig. TS-16: Geographical distributions of vulnerability in 2050 for climate sensitivities of 1.5°C (upper maps) and 5.5°C (lower maps), and without (left-hand maps) and with (right-hand maps) enhanced adaptive capacity. Grey = no data available. Light green = little or modest vulnerability. Yellow = moderate vulnerability. Orange = significant vulnerability. Red = nations where adaptive capacity would be overwhelmed by exposure. [F20.6]

G. Advances in the AR4, knowledge gaps and uncertainties

G.1 Advances in the Fourth Assessment

Since the TAR, the principle advances have been:

- Much improved coverage of the impacts of climate change on developing regions, through studies such as the AIACC project (Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors), although further research is still required, especially in Latin America and Africa [9.ES; 10.ES; 13.ES].
- More studies of adaptation to climate change, with improved understanding of current practice, adaptive capacity, the options, barriers and limits to adaptation [17.ES].
- Much more monitoring of observed effects [1.ES; F1.1].
- Some standardization of the scenarios of future climate change underpinning impact studies, facilitated by centralized data provision through organizations such as the IPCC Data Distribution Centre, thus allowing comparison between sectors and regions [2.2.2].

However, there has been little advance on:

- Costing the impacts of climate change;
- The costs of adaptation to climate change;
- Impacts under different assumptions about how the world will evolve in future – societies, governance, technology, economic development etc.; and,
- Damages avoided by different levels of emissions reduction.

G.2 Future research needs

Costing the impacts
Only a small amount of literature on the costs of climate change impacts could be found for assessment [5.6; 6.5.3; 7.5]. Debate still surrounds the topic of how to measure impacts, and which metrics should be used to ensure comparability [2.2.3; 19.3.2.3; 20.9].

Costs of adaptation to climate change
The literature on adaptation costs and benefits is limited and fragmented [17.2.3]. It focuses on sea level rise and agriculture, with more limited assessments for energy demand, water resources and transport. There is an emphasis on the US and other OECD countries, with only a few studies for developing countries. [17.2.3]

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

Impacts under different assumptions about future development pathways
Here, AR4 studies of future climate change are based on a small number of studies using SRES scenarios, especially the A2 and B2 families [2.3.1]. This has allowed some limited, but incomplete, characterization of the potential range of futures and their impacts [see section 4 on key future impacts in all core chapters]. Climate change scenarios are required for a wide range of development pathways, for abrupt climate change such as the collapse of the North Atlantic thermohaline circulation [6.8], and beyond 2100 (especially for sea level rise) [6.8; 11.8.1].

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

Damages avoided by different levels of emissions reduction

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

Climate science-related research needs

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

i. The first is that our understanding of the likely future impacts of climate change is hampered by lack of knowledge regarding the nature of future changes, particularly at the regional scale and particularly with respect to precipitation changes and changes in extreme events. [T2.5; 3.3.1; 3.4.1; 4.3].

ii. The second relates to abrupt climate change. Policymakers require understanding of the impacts of such events as the collapse of the North Atlantic thermohaline circulation. However, without a better understanding of the likely manifestation of such events at the regional scale, it is not possible to carry out impacts assessments. [6.8; 7.6; 8.8; 10.8.3]

Observations and monitoring

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

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

Multiple stresses and vulnerable people and places

It has become clear in the AR4 that the impacts of climate change are most damaging when they occur in the context of multiple stresses arising from the effects, for example, of globalization, poverty and poor governance. Considerable progress has been made towards understanding which people and which locations may expect to be disproportionately impacted by negative aspects of climate change. It is important to understand what characteristics enhance vulnerability, and what characteristics strengthen the adaptive capacity of some people and places [7.1; B7.4; 9.1; 9.ES].

Climate change and sustainable development

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

Appendix 1

The IPCC Fourth Assessment

The Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environment Programme in 1988, in response to the widespread recognition that human-influenced emissions of greenhouse gases have the potential to alter the climate system. Its role is to provide an assessment of the understanding of all aspects of climate change.

At its first session, the IPCC was organized into three Working Groups. The current remits of the three Working Groups are for Working Group I to examine the scientific aspects of the climate system and climate change, Working Group II to address vulnerabilities to, impacts of and adaptations to climate change, and Working Group III to explore the options for mitigation of climate change. The three previous assessment reports were produced in 1990, 1996 and 2001.

The Working Group II Fourth Assessment

The decision to produce a Fourth Assessment Report (AR4) was taken by the 19th Session of the IPCC at Geneva in April 2002. The report was to be more focussed and shorter than before. The Working Group II AR4 was to be finalized in mid-2007.

At the 20th session of the IPCC, in February 2003, four key questions were identified as central to the Working Group II assessment. These were:

- What is the current state of knowledge on impacts of climate change?
- What is the state of knowledge on impacts under different levels of adaptation?
- What are the impacts under different levels of mitigation?
- What is the state of knowledge concerning observed effects?

These questions are central to the structure and content of the Working Group II AR4.

Two meetings were held in 2003 to scope the Fourth Assessment, from which emerged the outline for the Working Group II AR4 submitted to IPCC Plenary 21 in November 2003 for approval and subsequent acceptance. This outline was designed in full knowledge of the four key questions above. It provides the framework for the preparation, writing and final presentation of the final AR4.

The Report has twenty chapters which together provide a comprehensive assessment of the climate change literature as it addresses the four key questions posed above.