Intergovernmental Panel on Climate Change
Fourth Assessment Report

Climate Change 2007: Synthesis Report

Summary for Policymakers

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References in curly brackets { } in this Summary for Policymakers refer to sections, tables and figures in the longer report of the Synthesis Report.

1. Observed changes in climate and their effects

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (Figure SPM.1). {1.1}

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 1906-2005 linear trend of global surface temperature was 0.74 [0.56 to 0.92]°C [1] warming per century (Figure SPM.1). The temperature increase is widespread over the globe, and is greater at higher northern latitudes. Land regions have warmed at a faster rate than the oceans (Figure SPM.2). {1.1, 1.2}

Observed decreases in snow and ice extent are consistent with warming (Figure SPM.1). Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres. {1.1}

Rising sea level is also consistent with warming (Figure SPM.1). Global average sea level has risen since 1961 at an average rate of 1.8 [1.3 to 2.3] mm/yr and since 1993 at 3.1 [2.4 to 3.8] mm/yr, with contributions from thermal expansion, melting glaciers and ice caps, and the polar ice sheets. Whether the faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer-term trend is unclear. {1.1}

From 1900 to 2005, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia but declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. The area affected by drought has *likely*[2] increased in many regions since the 1970s. {1.1}

Cold days, cold nights and frosts have *very likely* become less frequent over most land areas, while hot days and hot nights have become more frequent. It is *likely* that heat waves have become more frequent over most land areas, that the frequency of heavy precipitation events has increased over most areas, and that the incidence of extreme high sea level (excluding tsunamis) has increased worldwide since 1975. {1.1}

There is observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, but there is no clear trend in the annual numbers of tropical cyclones. {1.1, 1.4}

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[1] Numbers in square brackets indicate a 90% uncertainty interval around a best estimate, i.e., there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range. Uncertainty intervals are not necessarily symmetric around the corresponding best estimate.

[2] Words in italics represent calibrated expressions of uncertainty and confidence. Relevant terms are explained in the Box 'Treatment of uncertainty' in the Introduction of the longer report.

Changes in temperature, sea level and Northern Hemisphere snow cover

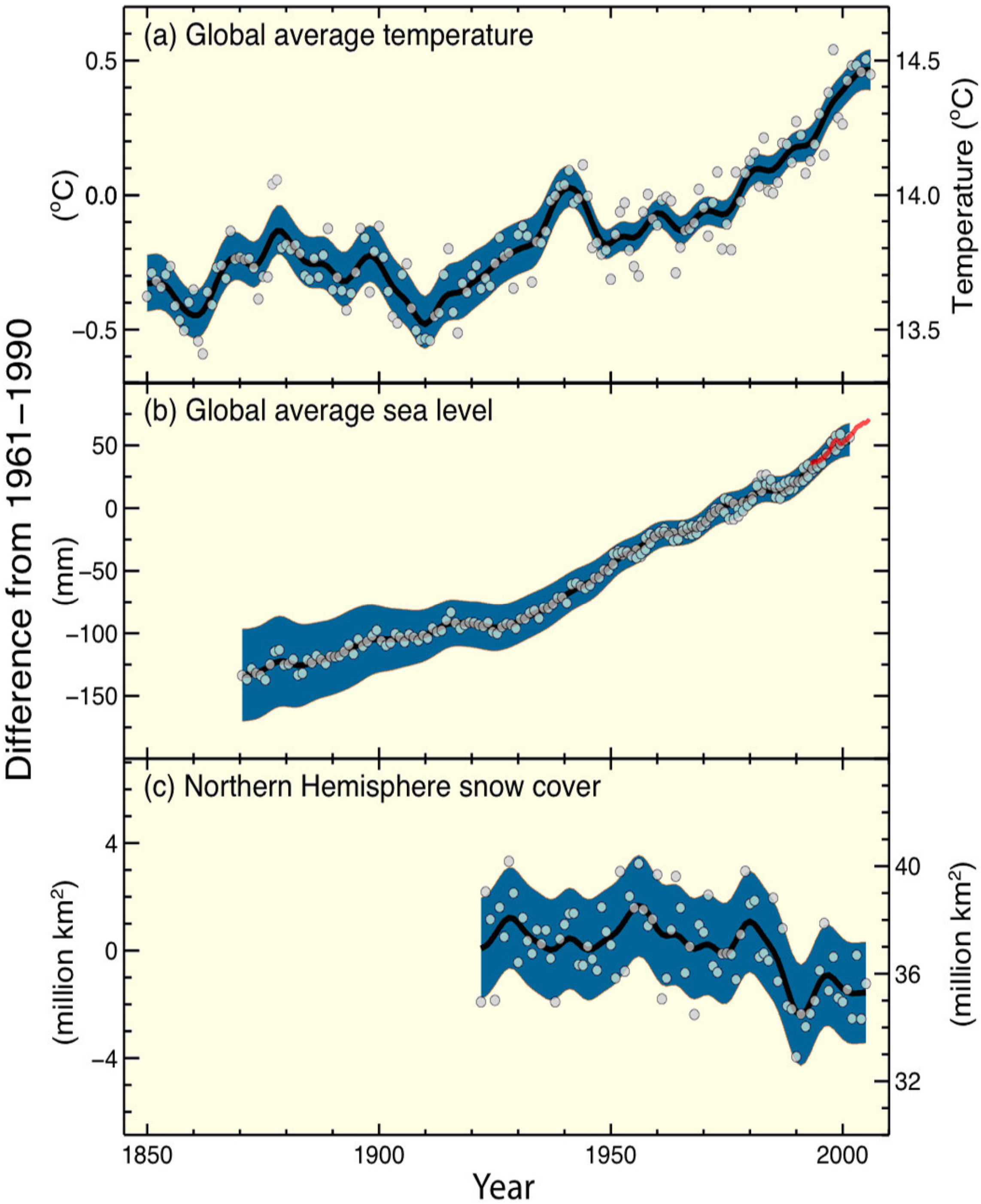


Figure SPM.1. Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {Figure 1.1}

Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years. {1.1}

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. {1.2}

Changes in snow, ice and frozen ground have with *high confidence* increased the number and size of glacial lakes, increased ground instability in mountain and other permafrost regions, and led to changes in some Arctic and Antarctic flora and fauna. {1.2}

There is *high confidence* that some hydrological systems have also been affected through increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers and changing thermal structure and water quality of warming rivers and lakes. {1.2}

In terrestrial ecosystems, earlier timing of spring events and poleward and upward shifts in plant and animal ranges are with *very high confidence* linked to recent warming. In marine and freshwater systems, shifts in ranges and changes in algal, plankton and fish abundance are with *high confidence* associated with rising water temperatures. {1.2}

Of the more than 29,000 observational data series, from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming (Figure SPM.2). However, there is a lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries. {1.3}

Changes in physical and biological systems and surface temperature 1970-2004

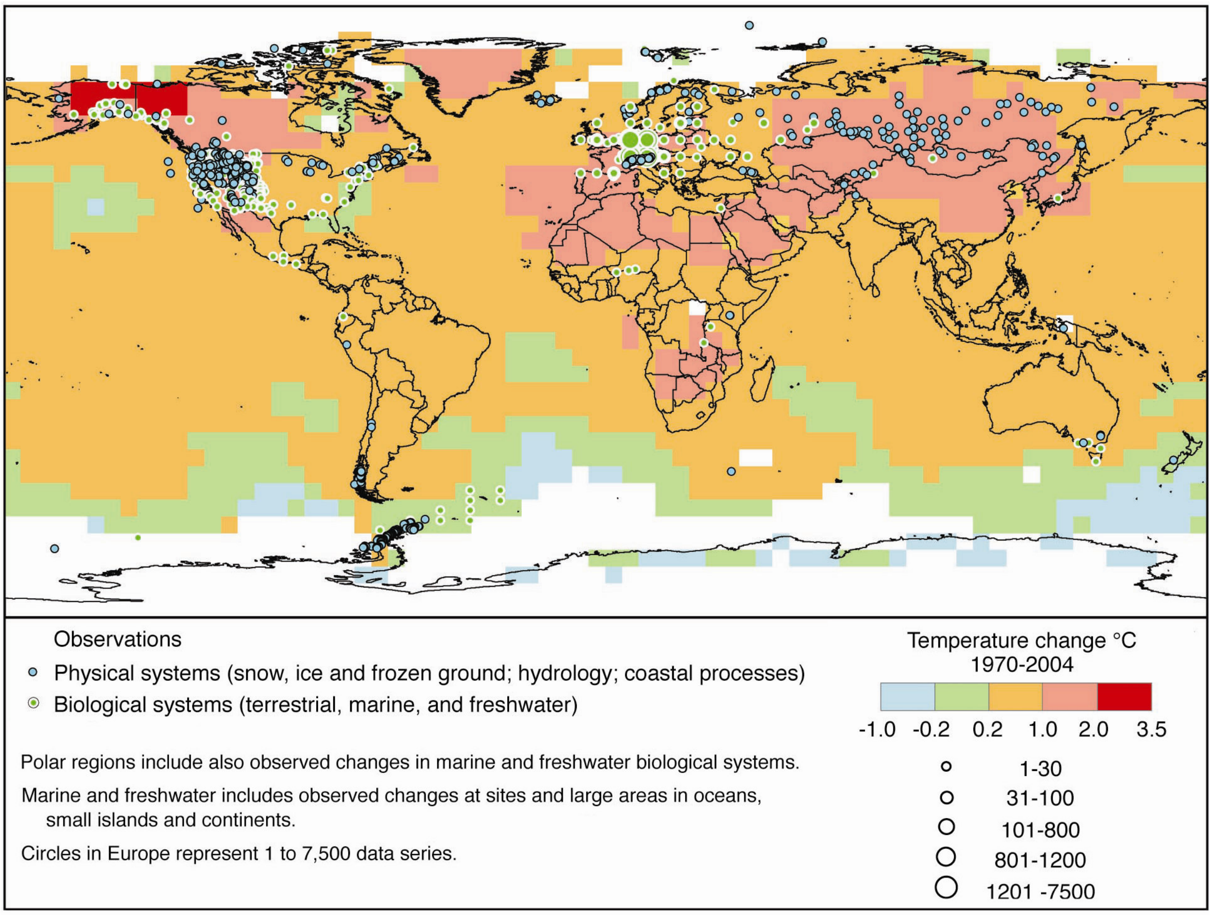


Figure SPM.2. Locations of statistically significant changes in observations of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine, and freshwater biological systems) are shown together with surface temperature changes over the period 1970-2004 (from the GHCN-ERSST dataset). White regions do not contain sufficient observational climate data to estimate a temperature trend. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. The selected subset is from about 75 studies (of which ~70 are new since the Third Assessment Report); about 28,000 data series are from European studies. Regions without dots have no time-series that meet the criteria; in these regions physical and biological systems may or may not be changing but are not documented. {Figure 1.2}

There is *medium confidence* that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. They include: {1.2}

- agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbance regimes of forests due to fires and pests
- some aspects of human health, such as heat-related mortality in Europe, changes in infectious disease vectors in some areas, and allergenic pollen in Northern Hemisphere high and mid-latitudes
- some human activities in the Arctic (e.g. hunting and travel over snow and ice) and in lower-elevation alpine areas (such as mountain sports).

2. Causes of change

Global total annual anthropogenic greenhouse gas (GHG) emissions have grown by 70% between 1970 and 2004, from 28.7 to 49 GtCO_2-equivalent (Figure SPM.3).[3] {2.1}

Carbon dioxide (CO_2) is the dominant anthropogenic GHG. Its annual emissions grew by about 80% between 1970 and 2004 despite a decrease in global energy intensity. The long-term trend of a declining carbon intensity of energy supply reversed after 2000. {2.1}

Global anthropogenic GHG emissions

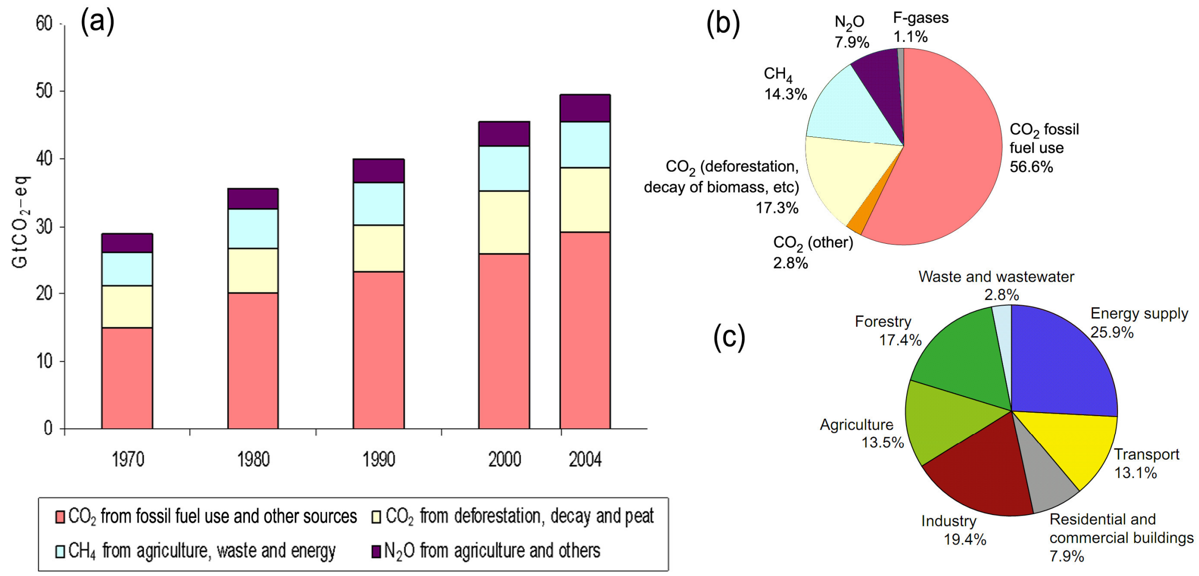


Figure SPM.3. (a) Global emissions of principal anthropogenic GHGs between 1970 to 2004. (b) Share of different anthropogenic GHGs in total emissions in 2004 in CO_2-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in CO_2-eq (forestry includes deforestation). {Figure 2.1}

Global atmospheric concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. {2.2}

The global increases in CO_2 concentration are due primarily to fossil fuel use and land-use change. The atmospheric concentration of CO_2 in 2005 exceeds by far the natural range over the last 650,000 years. Increases in CH_4 and N_2O are primarily due to agriculture. {2.2}

Changes in the atmospheric concentrations of GHGs and aerosols, land-cover and solar radiation alter the energy balance of the climate system. While anthropogenic aerosols produce a net cooling effect, there is *very high confidence* that the global net effect of human activities since 1750 has been one of warming. {2.2}

[3] GHG emissions have been weighted by their 100-year Global Warming Potentials, using values consistent with the UNFCCC.

Most of the observed increase in globally-averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations.[4] It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica (Figure SPM.4).[5] {2.4}

During the past 50 years, the sum of solar and volcanic forcings would *likely* have produced cooling, not warming. The observed patterns of warming and their changes over time are only simulated by models that include both natural and anthropogenic forcings. However, difficulties remain in reliably simulating and attributing observed temperature changes at smaller than continental scales. {2.4}

Global and continental temperature change

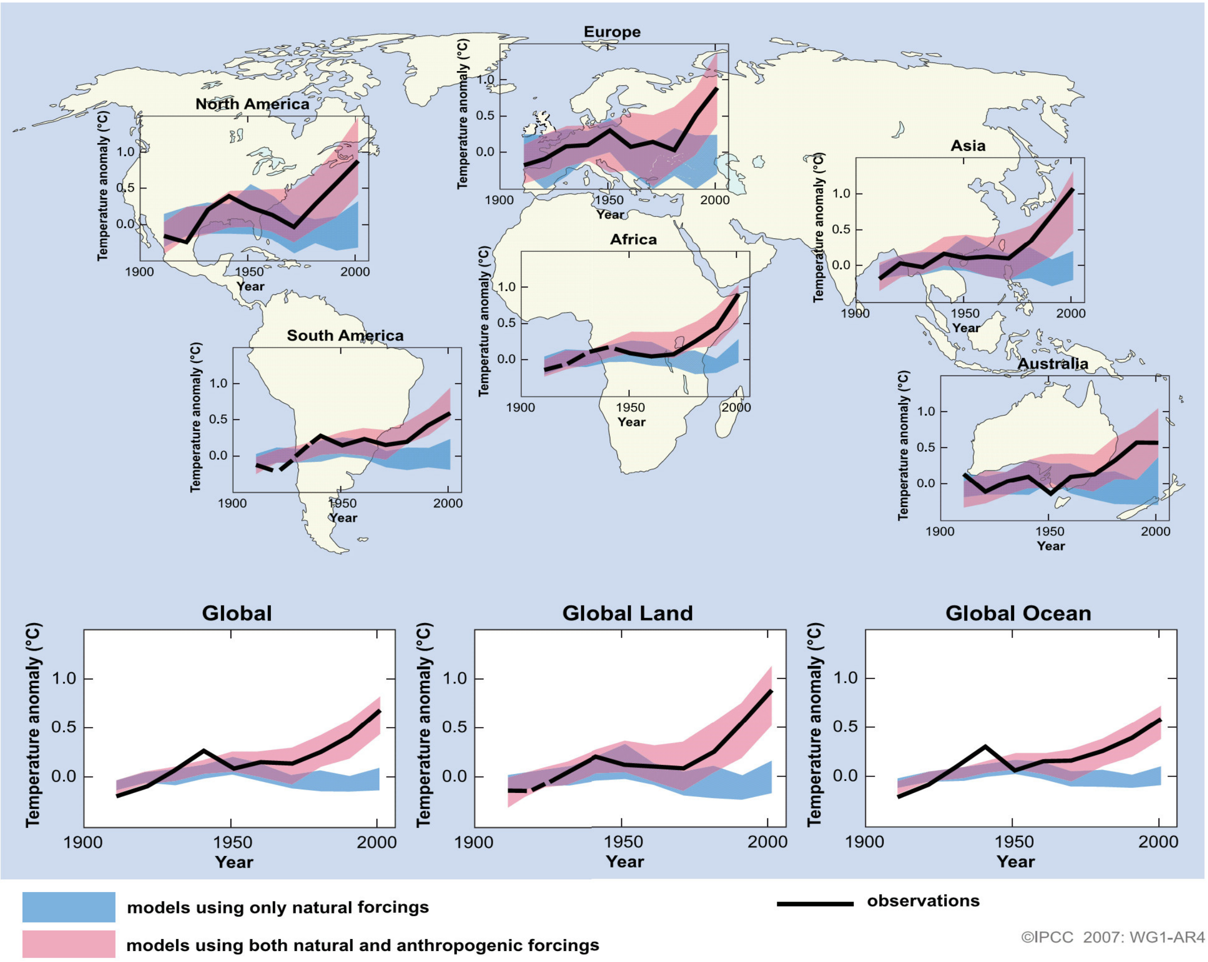


Figure SPM.4. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the period 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5-95% range for 19 simulations from 5 climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5-95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. {Figure 2.5}

[4] Consideration of remaining uncertainty is based on current methodologies.

[5] Antarctica had insufficient observational coverage to make a continental-scale assessment.

Discernible human influences also extend to other aspects of climate. {2.4}

Human influences have: {2.4}

- *very likely* contributed to sea level rise during the latter half of the 20th century
- *likely* contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns
- *likely* increased temperatures of the most extreme hot nights, cold nights and cold days
- *more likely than not* increased the risk of heat waves and the area affected by drought since the 1970s.

At the global scale, anthropogenic warming over the last three decades has *likely* had a discernible influence on observed changes in many physical and biological systems. {2.4}

The spatial agreement between regions of significant warming across the globe and the locations of significant observed changes in many systems consistent with warming is *very unlikely* to be due solely to natural variability. In addition, a few modelling studies have linked some specific responses in physical and biological systems directly to anthropogenic warming. {2.4}

More complete attribution of observed natural system responses to anthropogenic warming is prevented by short time scales of many impact studies, greater natural climate variability at regional scales, and possible contributions of non-climate factors in some regions. {2.4}

3. Projected climate change and its impacts

There is *high agreement* and *much evidence* that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. {3.1}

Non-mitigation scenarios from the IPCC Special Report on Emission Scenarios (SRES)[6] project an increase of global GHG emissions by 25-90% (CO_2-eq) between 2000 and 2030, with fossil fuels maintaining their dominant position in the global energy mix to 2030 and beyond. More recent non-mitigation scenarios are comparable in range. {3.1}

Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century (Table SPM.1, Figure SPM.5). {3.2.1}

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. Beyond the next few decades, projections increasingly depend on future GHG emission scenarios. {3.2}

[6] For an explanation of SRES emission scenarios, see Box 'SRES scenarios' and Figure 3.1 in topic 3 of the longer report.

Table SPM.1. Projected global averaged surface warming and sea level rise at the end of the 21st century. {Table 3.1}

	Temperature change (°C at 2090-2099 relative to 1980-1999) [a, d]		Sea level rise (m at 2090-2099 relative to 1980-1999)
Case	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations [b]	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:
a) Temperatures are assessed best estimates and *likely* uncertainty ranges from a hierarchy of models of varying complexity.
b) Year 2000 constant composition is derived from AOGCMs only.
c) All scenarios above are six SRES marker scenarios.
d) Add about half a degree C to the temperature ranges shown to obtain warming relative to pre-industrial.

The range of projections is broadly consistent with the Third Assessment Report (TAR), but assessed uncertainties and upper ranges for temperature projections are larger mainly because the broader range of models now available suggests stronger climate-carbon cycle feedbacks. Warming tends to reduce terrestrial ecosystem and ocean uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions that remains in the atmosphere. The strength of this feedback effect varies markedly among models. {2.3, 3.2.1}

Because understanding of some important effects which determine sea level rise is too limited, this report does not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise. Instead, Table SPM.1 shows model-based projections of global average sea level rise at the end of the 21st century (2090-2099). The projections do not include uncertainties in climate-carbon cycle feedbacks nor the full effects of changes in ice sheet flow. They do include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flow rates could increase or decrease in the future. {3.2.1}

Projections of surface temperatures

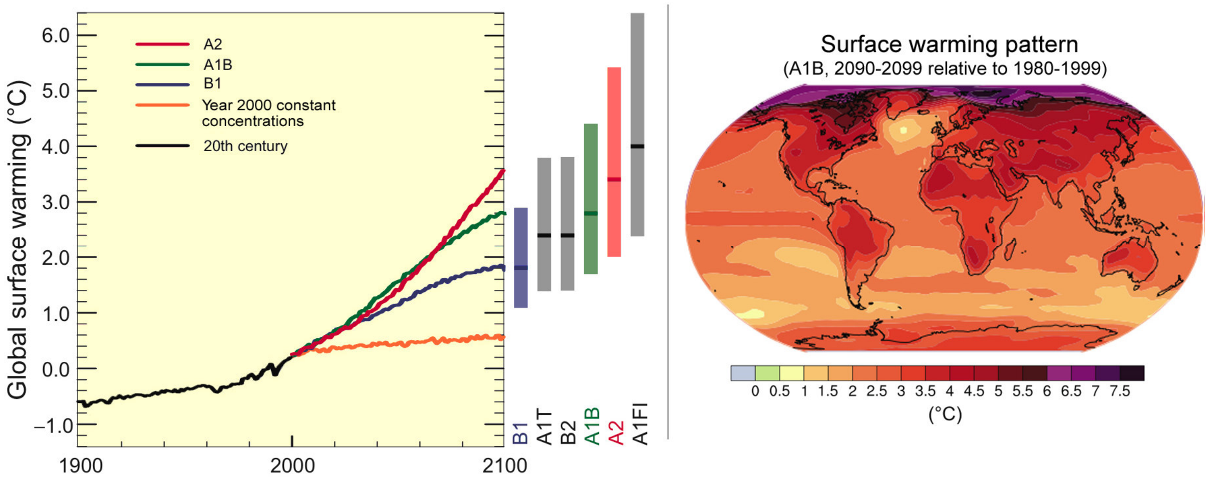


Figure SPM.5. Left panel: Solid lines are multi-model global averages of surface warming for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for an experiment where concentrations were held constant at year 2000 values. The bars in middle of figure indicate the best estimate (solid line within each bar) and the *likely* range assessed for the six SRES marker scenarios at 2090-2999. Right panel: Projected surface temperature changes for the late 21st century (2090-2099). The map shows the multi-AOGCM average projection for the A1B SRES scenario. All temperatures are relative to the period 1980-1999. {Figure 3.2}

There is now higher confidence in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation, and some aspects of extremes and of sea ice. {3.2.2}

Projected regional-scale changes include: {3.2.2}

- geographical patterns of warming similar to those observed in recent decades
- contraction of snow cover area, increases in thaw depth over most permafrost regions, and decrease in sea ice extent; in some projections using SRES scenarios, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century
- *very likely* increase in frequency of hot extremes, heat waves, and heavy precipitation
- *likely* increase in tropical cyclone intensity; less confidence in projected global decrease of tropical cyclone numbers
- poleward shift of extra-tropical storm tracks with consequent changes in wind, precipitation, and temperature patterns
- *very likely* precipitation increases in high latitudes and *likely* decreases in most subtropical land regions, continuing observed patterns in recent trends.

Studies since the TAR have enabled a more systematic understanding of the timing and magnitude of impacts related to differing amounts and rates of climate change. {3.3.1, 3.3.2}

Figure SPM.6 presents examples of this new information for systems and sectors. Entries have been selected which are judged to be relevant for people and the environment and for which there is *high confidence* in the assessment. Adaptation is not included in these estimations. Region-specific projections of impacts are provided in topic 3.3.2 of the longer report. {3.3.1, 3.3.2}

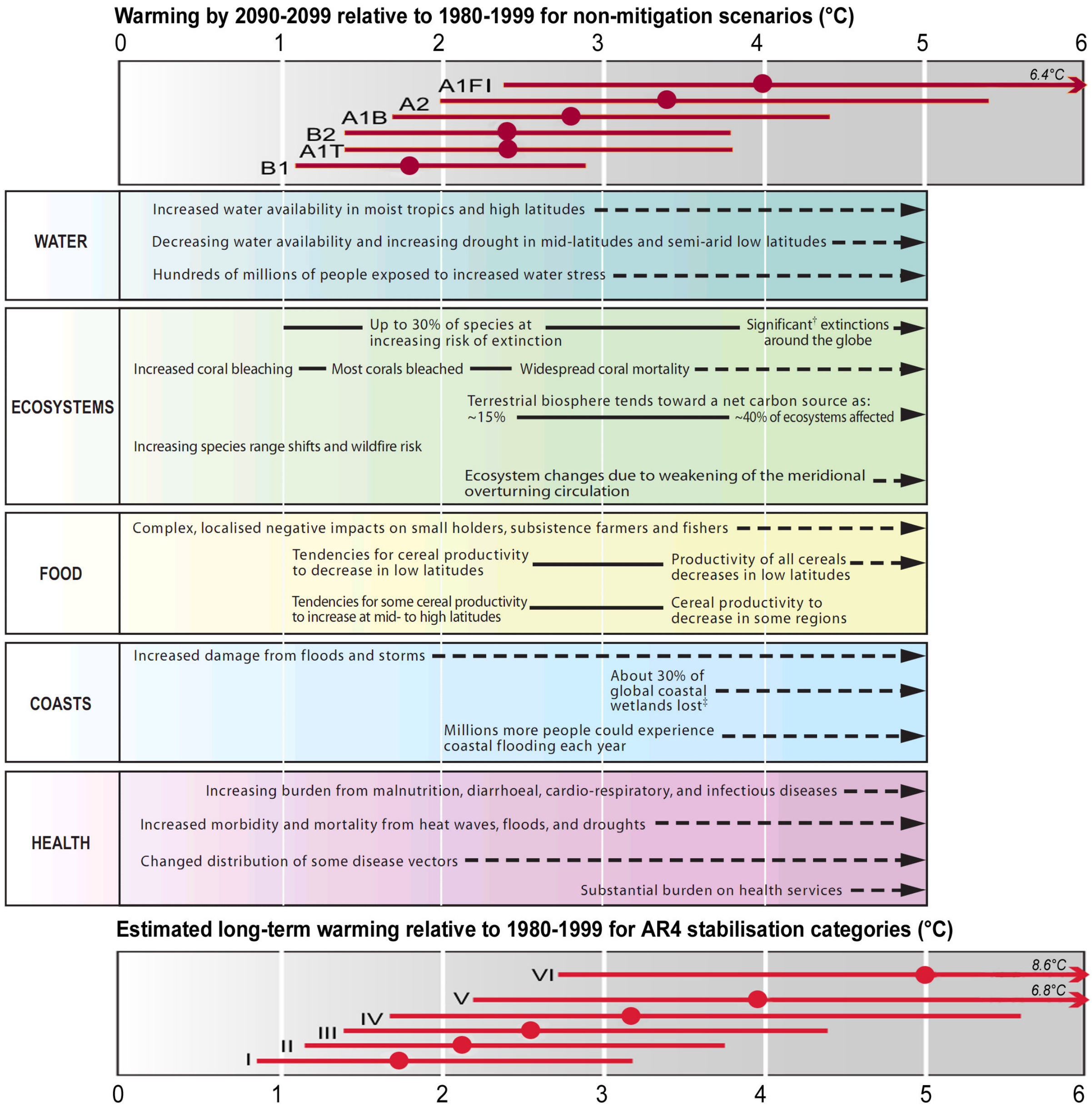
The magnitude and timing of impacts will vary with the amount and timing of climate change, development pathway and, in some cases, the capacity to adapt. {3.3.1, 3.3.2}

Even under the most stringent mitigation scenarios, further warming and some associated impacts over the 21st century are already unavoidable. {3.3.1}

Examples of projected impacts that, even with adaptation, appear unavoidable, include increases in (see Figure SPM.6): {3.3.1}

- coral bleaching
- species range shifts
- water scarcity and drought risk in some regions of the dry tropics and subtropics
- risk of wildfire
- coastal damage from floods combined with sea level rise.

Examples of impacts associated with projected global average surface warming



† Significant is defined here as more than 40%. ‡ Based on average rate of sea level rise of 4.2mm/year from 2000 to 2080.

Figure SPM.6. Examples of impacts associated with projected global average surface warming. **Upper panel:** Dots and bars indicate the best estimate and likely ranges of warming assessed for the six SRES marker scenarios for 2090-2099 relative to 1980-1999. Together, the upper and middle parts of this figure demonstrate the influence of different SRES emission scenarios on the severity of the impacts shown. **Middle panel:** Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts, broken-line arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left hand side of text indicates the approximate level of warming that is associated with the onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. Confidence levels for all statements are *high*. **Lower panel:** Estimated long term (multi-century) warming corresponding to the six AR4 WG III stabilisation categories (Table SPM.3). Warming is reduced by half a degree C compared to Table SPM.3 to account approximately for the warming between pre-industrial and 1980-1999. {Figure 3.5}

Since the TAR, confidence has increased that some weather events and extremes will become more frequent, more widespread and/or more intense during the 21st century. {3.3.3}

The projected changes in extremes are expected to have mostly adverse effects on natural and human systems. {Table 3.2}

Some systems, sectors and regions are *likely* to be especially affected by climate change. {3.3.4}

Regarding systems and sectors, these are: {3.3.4}

- particular ecosystems:
  - terrestrial: tundra, boreal forest, mountain, mediterranean-type ecosystems
  - coastal: mangroves and salt marshes
  - marine: coral reefs and the sea ice biome
- low-lying coastal regions
- water resources in the dry tropics and subtropics
- agriculture in low-latitude regions
- human health in areas with low adaptive capacity.

Regarding regions, these are: {3.3.4}

- the Arctic, because of the impacts of high rates of projected warming on natural systems
- Africa, especially the sub-Saharan region, because of projected climate change impacts and low adaptive capacity
- small islands, due to high exposure of population and infrastructure to sea level rise and increased storm surges
- Asian megadeltas, due to large populations and high exposure to sea level rise, storm surges and river flooding.

In all regions there are certain areas, sectors and communities which are particularly at risk, for example the poor, young children, the elderly and the ill. {3.3.4}

Anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if GHG concentrations were to be stabilised. {3.2.3}

Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7 m if global average warming were sustained for millennia in excess of 1.9 to 4.6ºC relative to pre-industrial values. The corresponding future temperatures in Greenland are comparable to those inferred for the last interglacial period 125,000 years ago, when paleoclimatic information suggests reductions of polar land ice extent and 4 to 6 m of sea level rise. {3.2.3}

Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and is expected to gain mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance. {3.2.3}

Human activities could lead to abrupt or irreversible climate changes and impacts. The risks are related to the rate and magnitude of the climate change. {3.4}

Based on current model simulations, the meridional overturning circulation (MOC) of the Atlantic Ocean will *very likely* slow down during the 21st century, but it is *very unlikely* to undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence. Impacts of large-scale and persistent changes in the MOC are *likely* to include changes in marine ecosystem productivity, fisheries, ocean CO_2 uptake, oceanic oxygen concentrations and terrestrial vegetation. These changes may then feed back on the climate system. {3.4}

Partial deglaciation of polar ice sheets would imply major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands. Current models project that such changes would occur over millennial time scales, but rapid sea level rise on century time scales cannot be excluded. {3.4}

Climate change is *likely* to lead to some irreversible impacts. There is *medium confidence* that approximately 20-30% of species assessed so far would be at increasing risk of extinction if increases in global average warming exceed 1.5-2.5°C, and *high confidence* of significant (>40%) extinctions around the globe for warming above 4°C. {3.4}

4. Adaptation and mitigation options

Adaptation reduces vulnerability, especially in the short-term. {4.2}

Societies have a long record of managing the impacts of weather- and climate-related events such as floods, droughts and storms. Regardless of the scale of mitigation undertaken up to 2030, additional adaptation measures will be required to reduce the adverse impacts of projected climate change and variability. However, non-climate stresses (e.g. poverty, unequal access to resources, food insecurity, trends in economic globalisation, conflict, and incidence of diseases) can exacerbate vulnerability and reduce the capacity to respond to climate change. {4.2}

Some planned adaptation to climate change is already occurring on a limited basis, often embedded in broader development initiatives. There is *high confidence* that there are viable adaptation options that can be implemented in some sectors at low cost, and/or with high benefit-cost ratios. However, comprehensive estimates of global costs and benefits of adaptation are limited. {4.2, Table 4.1}

Adaptive capacity is intimately connected to social and economic development but is unevenly distributed across and within societies. {4.2}

A range of barriers limit both the implementation and effectiveness of adaptation measures. Many societies have high adaptive capacity but remain vulnerable to climate change, variability and extremes. {4.2}

There is *high agreement* and *much evidence* from both bottom-up and top-down studies that there is substantial economic potential for the mitigation of global GHG emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels. {4.3}

While top-down and bottom-up studies agree at the global level (Table SPM.2) there are considerable differences at the sectoral level. Bottom-up sectoral estimates are shown in Figure SPM.7. No one technology can provide all of the mitigation potential in any sector, and the economic potential, which is generally greater than the market potential, can only be achieved when adequate government policies are in place. {4.3, Table 4.2}

Table SPM.2. Global economic mitigation potential in 2030 estimated from bottom-up and top-down studies. {Table 4.2}

Carbon price	Economic mitigation potential	Reduction relative to SRES A1B projection of 68 $GtCO_2$-eq in 2030	Reduction relative to SRES B2 projection of 49 $GtCO_2$-eq in 2030
US$/$tCO_2$-eq	$GtCO_2$-eq/yr	percent	percent
estimated from bottom-up studies:			
0	5-7	7-10	10-14
20	9-17	14-25	19-35
50	13-26	20-38	27-52
100	16-31	23-46	32-63
estimated from top-down studies:			
20	9-18	13-27	18-37
50	14-23	21-34	29-47
100	17-26	25-38	35-53

Note: 50 US$/$tCO_2$-eq equals: ~25 US$/bbl crude oil, or ~0.12 US$/litre gasoline (~0.50 US$/gallon), or ~5 US cents/kWh electricity from coal, or ~1.5 US cents/kWh electricity from gas.

Economic mitigation potential by sector in 2030 estimated from bottom-up studies

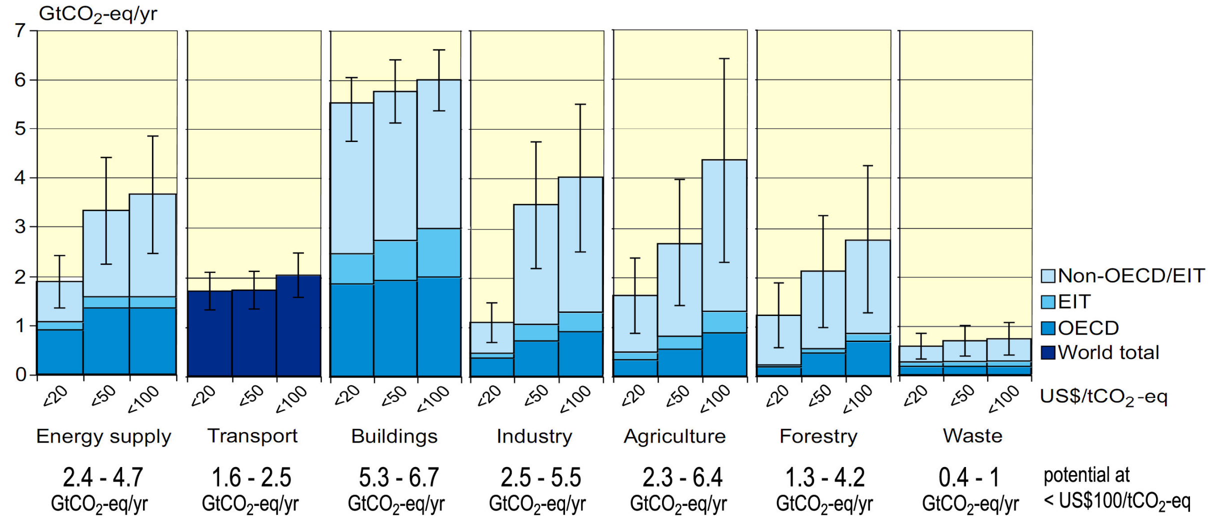


Figure SPM.7. Estimated economic mitigation potential by sector in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments. The potentials do not include non-technical options such as lifestyle changes. {Figure 4.1} Notes:

a) The ranges for global economic potentials as assessed in each sector are shown by vertical lines. The ranges are based on end-use allocations of emissions, meaning that emissions of electricity use are counted towards the end-use sectors and not to the energy supply sector.
b) The estimated potentials have been constrained by the availability of studies particularly at high carbon price levels.
c) Only global totals for transport are shown because international aviation is included.
d) Categories excluded are: non-CO_2 emissions in buildings and transport, part of material efficiency options, heat production and cogeneration in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10-15%.

Future energy infrastructure investment decisions, expected to exceed 20 trillion US$[7] up to 2030, will have long-term impacts on GHG emissions, because of the long life-times of energy plants and other infrastructure capital stock. Initial estimates show that returning global energy-related CO_2 emissions to 2005 levels by 2030 would require a large shift in investment patterns, although the net additional investment required ranges from negligible to 5-10%. {4.3}

A wide variety of national policies and instruments are available to governments to create the incentives for mitigation action. {4.3}

They include integrating climate policies in wider development policies, regulations and standards, taxes and charges, tradable permits, financial incentives, voluntary agreements, information instruments, and research, development and demonstration (RD&D). Their applicability depends on national circumstances. {4.3}

An effective carbon-price signal could realise significant mitigation potential in all sectors. Modelling studies show carbon prices rising to 20-80 US$/t$CO_2$-eq by 2030 are consistent with stabilisation at around 550 ppm CO_2-eq by 2100. For the same stabilisation level, studies

[7] 20 trillion = 20,000 billion = 20×10^{12}

since the TAR that take into account induced technological change lower these price ranges to 5-65 US$/t$CO_2$-eq in 2030. {4.3}

There is *high agreement* and *much evidence* that mitigation actions can result in near-term co-benefits (e.g. improved health due to reduced air pollution) that may offset a substantial fraction of mitigation costs. {4.3}

There is *high agreement* and *medium evidence* that Annex I countries' actions may affect the global economy and global emissions, although the scale of carbon leakage remains uncertain. {4.3}

The literature identifies many options for reducing global GHG emissions through international cooperation. There is *high agreement* and *much evidence* that notable achievements of the UNFCCC and its Kyoto protocol are the establishment of a global response to climate change, stimulation of an array of national policies, and the creation of an international carbon market and new institutional mechanisms that may provide the foundation for future mitigation and adaptation efforts. {4.5}

Greater cooperative efforts and expansion of market mechanisms will help to reduce global costs for achieving a given level of mitigation, or will improve environmental effectiveness. Efforts can include diverse elements such as emissions targets; sectoral, local, sub-national and regional actions; RD&D programmes; adopting common policies; implementing development oriented actions; or expanding financing instruments. {4.5}

Climate response options in several sectors can be implemented to realise synergies and avoid conflicts with other dimensions of sustainable development. Decisions about macroeconomic and other non-climate policies can significantly affect emissions, adaptive capacity and vulnerability. {4.4, 5.8}

Both synergies and trade-offs exist between adaptation and mitigation. Examples of synergies include properly designed biomass production, formation of protected areas, land management, energy use in buildings, and forestry. Potential trade-offs include increased GHG emissions due to increased energy consumption related to adaptive responses. {4.4}

Climate change will interact at all scales with other trends in global environmental and natural resource concerns, including water, soil and air pollution, health hazards, disaster risk, and deforestation. Making development more sustainable can enhance mitigative and adaptive capacities, reduce emissions, and reduce vulnerability, but there may be barriers to implementation. On the other hand, it is *very likely* that climate change can slow the pace of progress towards sustainable development and could impede achievement of the mid-century Millennium Development Goals. {5.8}

5. The long-term perspective

Determining what constitutes "dangerous anthropogenic interference with the climate system" involves value judgements. Science can support informed decisions by offering explicit criteria for judging which vulnerabilities might be labeled "key". {Box 'Key Vulnerabilities and Article 2 of the UNFCCC', topic 5}

More specific information on key vulnerabilities[8] shows that there are sharp differences across regions and that those in the weakest economic and/or political position are frequently the most susceptible to climate change. {Box 'Key Vulnerabilities and Article 2 of the UNFCCC', topic 5}

The five "reasons for concern" identified in the TAR remain a viable framework to consider key vulnerabilities and are assessed here to be stronger, with larger risks at lower temperature increases. {5.2}

This is due to better understanding of impacts and risks, more precise identification of especially vulnerable systems, sectors, and regions, and growing evidence of the risks of very large impacts on multiple century time scales. Some key vulnerablities may be linked to thresholds that cause a system to shift from one state to another, while others have thresholds that are defined subjectively. {5.2}

- **Risks to unique and threatened systems.** Predominantly negative effects on biodiversity are projected if global average temperature increase exceeds 1.5-2.5^{o}C above 1980-1999, with the risk of significant extinctions of species and damage to coral reefs increasing with temperature.
- **Risks of extreme weather events.** Recent extreme events have exposed a higher level of vulnerability. Higher confidence in projected changes in many regions are assessed to bring higher impacts and risks than were assessed in the TAR.
- **Distribution of impacts and vulnerabilities.** Substantial improvements in the projection of patterns of climate change and impacts have clarified and expanded the identification of systems, sectors and regions that are particularly vulnerable.
- **Net aggregate impacts.** There is some evidence that initial market benefits from climate change will peak at a lower magnitude of warming and sooner than was assumed in the TAR, and global risks calibrated in other aggregate metrics have been better quantified.
- **Risks of large scale singularities: abrupt or irreversible changes.** The risks of large sea level rise on many century time scales and species extinction within this century have been identified.

Neither adaptation nor mitigation alone can avoid significant climate change impacts, however, they can complement each other and together can significantly reduce the risks of climate change. {5.3}

[8] Key Vulnerabilities can be identified based on a number of criteria in the literature, including magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts.

Adaptation is necessary in the short and longer term even for the lowest stabilisation scenarios assessed, but there are significant barriers, limits and costs. Mitigation is necessary because unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. The time at which such limits could be reached will vary between sectors and regions. Early mitigation actions would avoid locking in carbon intensive infrastructure and reduce climate change and associated adaptation needs. {5.2, 5.3}

Mitigation efforts and investments over the next two to three decades have a large impact on opportunities to achieve lower stabilisation levels. These efforts determine to a large extent which long-term risks for vulnerable systems can be reduced, avoided or delayed. {5.3, 5.4, 5.7}

In order to stabilise the concentration of GHGs in the atmosphere, emissions would need to peak and decline thereafter. The lower the stabilisation level, the more quickly this peak and decline would need to occur. {5.4}

Table SPM.3 and Figure SPM.8 summarise the required emission levels for different groups of stabilisation concentrations and the associated equilibrium global average temperature increase and long-term sea level rise due to thermal expansion only.[9] Specific examples of risks that would be reduced by limiting global average warming below any given level can be derived from Figure SPM.6. {5.4, 5.7}

Sea level rise from thermal expansion would continue for many centuries after GHG concentrations have stabilised, causing an eventual sea level rise much larger than projected for the 21st century, for any of the stabilisation levels assessed. The eventual contributions from Greenland ice sheet loss, should global temperature increases in excess of 1.9-4.6°C above pre-industrial be sustained over many centuries, could be much larger than from thermal expansion. The long time scales of thermal expansion and ice sheet response to warming imply that stabilisation of GHG concentrations at or above present levels would not stabilise sea level for many centuries. {5.3, 5.4}

[9] Estimates for transient temperature over the course of this century are not available in the AR4 for the stabilisation scenarios. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For the much lower stabilisation scenarios with overshoot of GHG concentrations above the stabilisation level (category I and II, Figure SPM.8), the equilibrium temperature may be reached earlier.

Table SPM.3. Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and sea level rise from thermal expansion only. {Table 5.1}

Category	CO_2 concentration [a]	CO_2-equivalent concentration [a]	Peaking year for CO_2 emissions [b]	Change in global CO_2 emissions in 2050 (% of 2000 emissions) [b]	Global average temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity [c], [d]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only [e]	Number of assessed scenarios
	ppm	ppm	year	percent	℃	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Notes:
a) Atmospheric CO_2 concentrations have increased by about 100 ppm since pre-industrial times, reaching 379 ppm in 2005. The best estimate of total CO_2-eq concentration in 2005 for all long-lived GHGs is about 455 ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375 ppm CO_2-eq.
b) Ranges correspond to the 15th to 85th percentile of the post-TAR scenario distribution. CO_2 emissions are shown so multi-gas scenarios can be compared with CO_2-only scenarios.
c) The best estimate of climate sensitivity is 3℃.
d) Global average temperature at equilibrium is different from expected global average temperature at the time of stabilisation of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150.
e) Equilibrium sea level rise is for the contribution from thermal expansion only and does not reach equilibrium for at least many centuries. These values have been estimated using relatively simple climate models (one low resolution AOGCM and several EMICs based on the best estimate of 3℃ climate sensitivity) and do not include contributions from ice sheets, glaciers and ice caps. Long-term thermal expansion is projected to result in 0.2 to 0.6 m per degree of global average warming above present temperatures.

CO_2 emissions and equilibrium temperature increases for a range of stabilisation levels

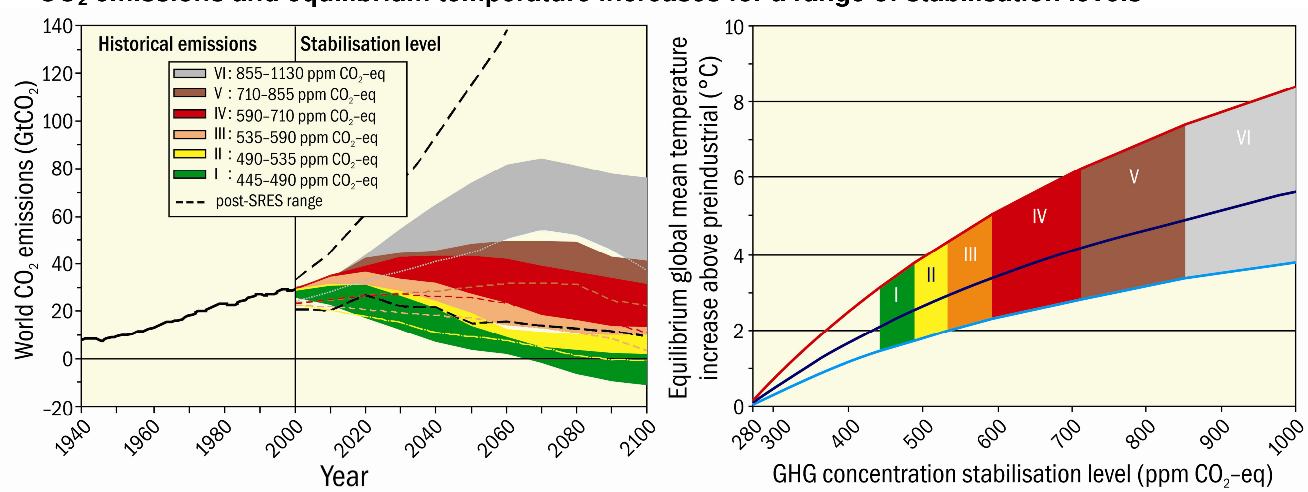


Figure SPM.8. Global CO_2 emissions for 1940 to 2000 and emissions ranges for groups of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the likely equilibrium global average temperature increase above pre-industrial (right-hand panel). Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilisation. Coloured shadings show stabilisation scenarios grouped according to different targets (stabilisation category I to VI). Right-hand panel shows ranges of global average temperature change above pre-industrial, using (i) "best estimate" climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of *likely* range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of *likely* range of climate sensitivity of 2°C (blue line at bottom of shaded area). Black dashed lines in the left panel give the emissions range of post-SRES baseline scenarios. Emissions ranges of the stabilisation scenarios correspond to the 10^{th}-90^{th} percentile of the full scenario distribution. {Figure 5.1}

The stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming incentives are in place and barriers addressed. {5.6}

All assessed stabilisation scenarios indicate that 60-80% of the reductions would come from energy supply and use, and industrial processes, with energy efficiency playing a key role in many scenarios. Low stabilisation levels require early investments and substantially more rapid commercialisation of advanced low-emissions technologies. {5.6}

The macro-economic costs of mitigation generally rises with the stringency of the stabilisation target (Table SPM.4). For specific countries and sectors, costs vary considerably from the global average.[10] {5.5}

The reduction of average annual global GDP growth rates ranges from less than 0.12 to less than 0.06 percentage points per annum for the 445-535 and 590-710 CO_2-eq stabilisation scenario ranges, respectively. {5.5}

[10] Studies on mitigation portfolios and macro-economic costs assessed in this report are based on top-down modelling. Most models use a global least cost approach to mitigation portfolios and with universal emissions trading, assuming transparent markets, no transaction cost, and thus perfect implementation of mitigation measures throughout the 21st century. Costs are given for a specific point in time. Global modelled costs will increase if some regions, sectors (e.g. land-use), options or gases are excluded. Global modelled costs will decrease with lower baselines, use of revenues from carbon taxes and auctioned permits, and if induced technological learning is included. These models do not consider climate benefits and generally also co-benefits of mitigation measures, or equity issues. In models that consider induced technological change projected costs for a given stabilisation level are reduced; the reductions are greater at lower stabilisation level.

Table SPM.4. Estimated global macro-economic costs in 2030 and 2050. Costs are relative to the baseline for least-cost trajectories towards different long-term stabilisation levels. {Table 5.2}

Stabilisation levels (ppm CO_2-eq)	Median GDP reduction [(a)] (%)		Range of GDP reduction [(b)] (%)		Reduction of average annual GDP growth rates (percentage points) [(b), (c)]	
	2030	2050	2030	2050	2030	2050
590 – 710	0.2	0.5	-0.6 to 1.2	-1 to 2	< 0.06	< 0.05
535 – 590	0.6	1.3	0.2 to 2.5	slightly negative to 4	< 0.1	< 0.1
445 – 535 [(d)]	Not available		< 3	< 5.5	< 0.12	< 0.12

Notes: Values given in this table correspond to the full literature across all baselines and mitigation scenarios that provide GDP numbers.
a) Global GDP based market exchange rates.
b) The 10th and 90th percentile range of the analysed data are given. Negative values indicate GDP gain.
c) The calculation of the reduction of the annual growth rate is based on the average reduction during the assessed period that would result in the indicated GDP decrease by 2030 and 2050 respectively.
d) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.

Decision-making about responding to climate change involves an iterative risk management process that includes both adaptation and mitigation and takes into account climate change impacts, co-benefits, sustainability, equity, and attitudes to risk. {5.1}

Impacts of climate change are *very likely* to impose net annual costs which will increase over time as global temperatures increase. Estimates of the social cost of carbon in 2005 average US$12 per tonne of CO_2, but the range around this mean is large (-$3 to $95/t$CO_2$ in a survey of 100 estimates). These estimates are very sensitive to assumptions about climate sensitivity, discounting, and the treatment of equity and catastrophic risks. They also mask significant differences in impacts across sectors, regions and populations and *very likely* underestimate damage costs because they do not include many non-monetised impacts. {5.7}

Limited and early analytical results from integrated analyses of the costs and benefits of mitigation indicate that they are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilisation level where benefits exceed costs. {5.7}

Climate sensitivity is a key uncertainty for mitigation scenarios that aim to meet specific temperature levels. If climate sensitivity were high, then the required mitigation is earlier and more stringent than if climate sensitivity were lower. {5.4}

Mitigation studies to date have not incorporated the full range of climate-carbon cycle feedbacks. As a consequence, the emission reductions to meet a particular stabilisation level (Table SPM.3, Figure SPM.8) might be underestimated. {5.4}

6. Robust findings, key uncertainties

A selection of policy-relevant robust findings and key uncertainties is provided in topic 6 of the longer report. {6.1, 6.2, 6.3}