

## Introduction

This Synthesis Report is based on the assessment carried out by the three Working Groups of the IPCC. It provides an integrated view of climate change as the final part of the IPCC's Fourth Assessment Report.

A complete elaboration of the topics covered in this summary can be found in this Synthesis Report and in the underlying reports of the three Working Groups.

### 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 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92]<sup>1</sup>°C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) given in the Third Assessment Report (TAR) (Figure SPM.1). The temperature increase is widespread over the globe, and is greater at higher northern latitudes. Land regions have warmed faster than the oceans (Figures SPM.2, SPM.4). {1.1, 1.2}

Rising sea level is 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}

Observed decreases in snow and ice extent are also 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}

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. Globally, the area affected by drought has *likely*<sup>2</sup> increased since the 1970s. {1.1}

It is *very likely* that over the past 50 years: cold days, cold nights and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent. It is *likely* that: heat waves have become more frequent over most land areas, the frequency of heavy precipitation events has increased over most areas, and since 1975 the incidence of extreme high sea level<sup>3</sup> has increased worldwide. {1.1}

There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, with limited evidence of increases elsewhere. There is no clear trend in the annual numbers of tropical cyclones. It is difficult to ascertain longer term trends in cyclone activity, particularly prior to 1970.

Average Northern Hemisphere temperatures during the second half of the 20<sup>th</sup> 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}

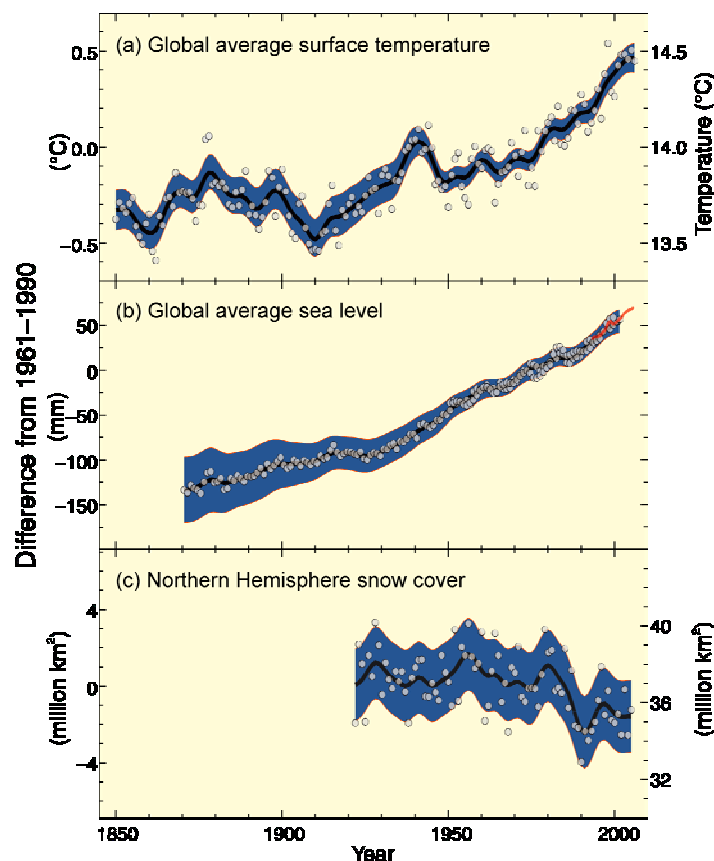
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<sup>1</sup> Numbers in square brackets indicate a 90% uncertainty interval around a best estimate, i.e., there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be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

<sup>2</sup> Words in italics represent calibrated expressions of uncertainty and confidence. Relevant terms are explained in the Box 'Treatment of uncertainty' in the Introduction of this Synthesis Report.

<sup>3</sup> Excluding tsunamis, which are not due to climate change. Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.

### 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 from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences 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}

**Observational evidence<sup>4</sup> 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 ecosystems. {1.2}

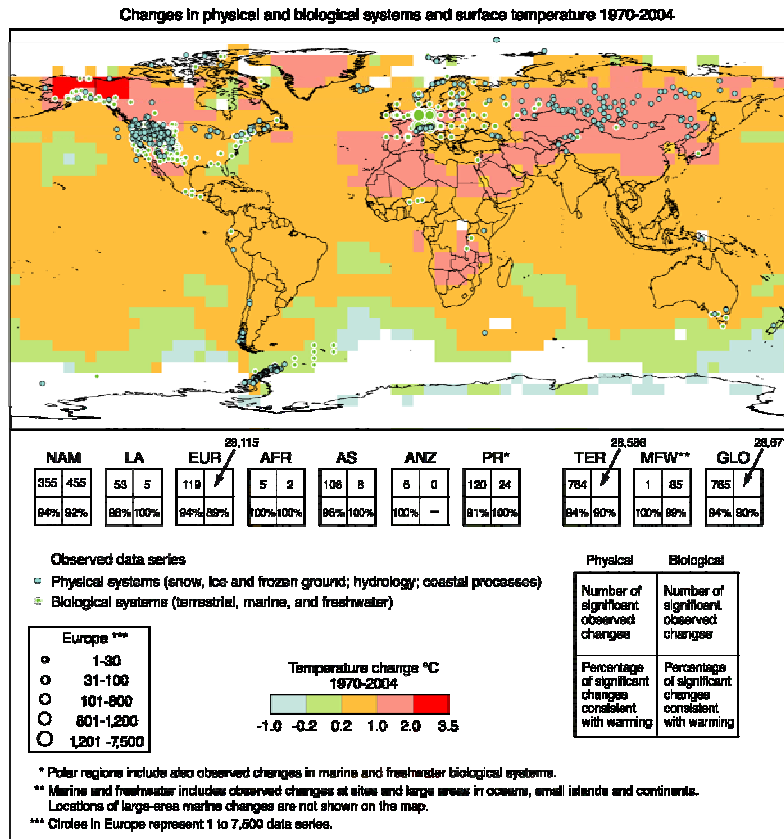
There is *high confidence* that some hydrological systems have also been affected through increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and effects on thermal structure and water quality of warming rivers and lakes. {1.2}

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 some marine and freshwater systems, shifts in ranges and changes in algal, plankton and fish abundance are with *high confidence* associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation. {1.2}

<sup>4</sup> Based largely on data sets that cover the period since 1970.

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 notable 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 significant changes in data series of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine, and freshwater biological systems), are shown together with surface air temperature changes over the period 1970-2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (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. These data series are from about 75 studies (of which about 70 are new since the Third Assessment) and contain about 29,000 data series, of which about 28,000 are from European studies. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2 x 2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). The numbers of studies from the seven regional boxes (NAM, EUR, AFR, AS, ANZ, PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFW) systems. Locations of large-area marine changes are not shown on the map. {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 effects of temperature increases on {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).

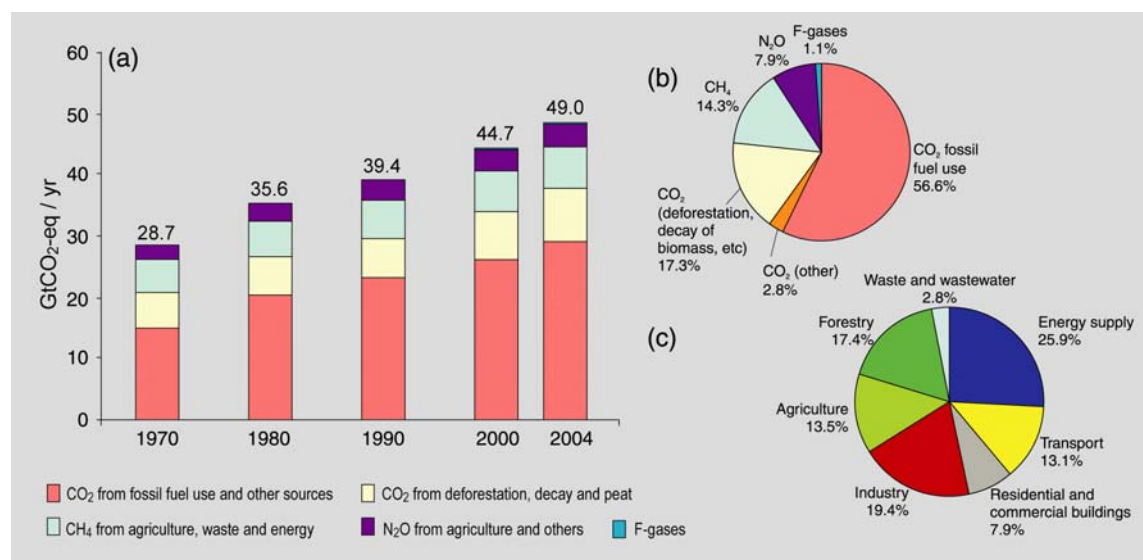
## 2. Causes of change

Changes in atmospheric concentrations of greenhouse gases (GHGs) and aerosols, land-cover and solar radiation alter the energy balance of the climate system.

**Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (Figure SPM.3).<sup>5</sup> {2.1}**

Carbon dioxide (CO<sub>2</sub>) is the most important anthropogenic GHG. Its annual emissions grew by about 80% between 1970 and 2004. The long-term trend of declining CO<sub>2</sub> emissions per unit of energy supplied reversed after 2000. {2.1}

### Global anthropogenic GHG emissions



**Figure SPM.3.** (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.<sup>5</sup> (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO<sub>2</sub>-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO<sub>2</sub>-eq. (Forestry includes deforestation). {Figure 2.1}

**Global atmospheric concentrations of CO<sub>2</sub>, methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) 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}**

Atmospheric concentrations of CO<sub>2</sub> (379ppm) and CH<sub>4</sub> (1774 ppb) in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO<sub>2</sub> concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is *very likely* that the observed increase in CH<sub>4</sub> concentration is predominantly due to agriculture and fossil fuel use. Methane growth rates have declined since the early 1990s, consistent with total emission (sum of anthropogenic and natural sources) being nearly constant during this period. The increase in N<sub>2</sub>O concentration is primarily due to agriculture. {2.2}

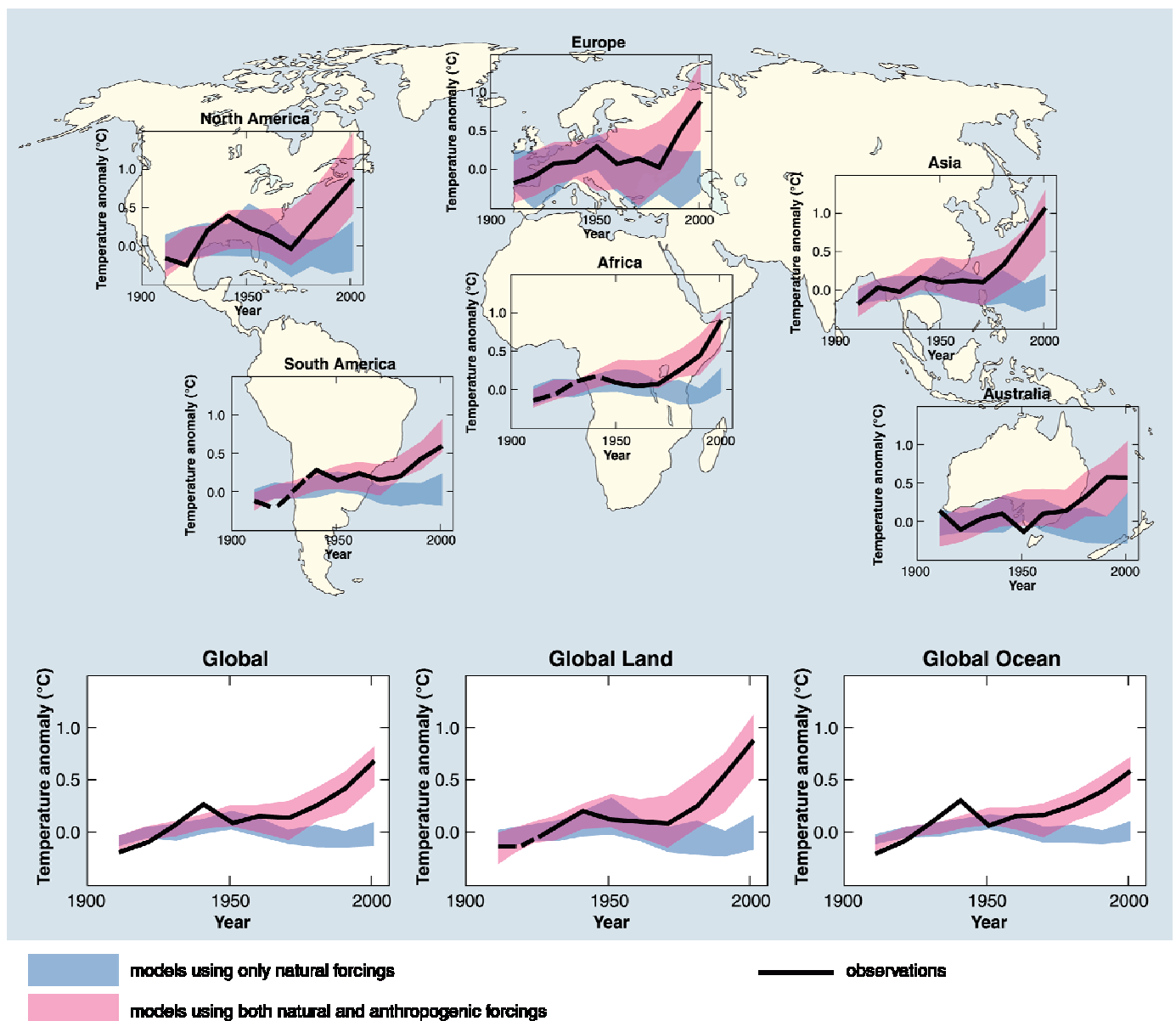
There is *very high confidence* that the net effect of human activities since 1750 has been one of warming.<sup>6</sup> {2.2}

<sup>5</sup> Includes only CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs and SF<sub>6</sub> whose emissions are covered by the UNFCCC. These GHGs are weighted by their 100-year Global Warming Potentials, using values consistent with reporting under the UNFCCC.

Most of the observed increase in globally-averaged temperatures since the mid-20<sup>th</sup> century is *very likely* due to the observed increase in anthropogenic GHG concentrations.<sup>7</sup> It is *likely* there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica) (Figure SPM.4). {2.4}

During the past 50 years, the sum of solar and volcanic forcings would *likely* have produced cooling. Observed patterns of warming and their changes are simulated only by models that include anthropogenic forcings. Difficulties remain in simulating and attributing observed temperature changes at smaller than continental scales. {2.4}

### Global and continental temperature change



<sup>6</sup> Increases in GHGs tend to warm the surface while the net effect of increases in aerosols tends to cool it. The net effect due to human activities since the pre-industrial era is one of warming (+1.6 [+0.6 to +2.4]W/m<sup>2</sup>). In comparison, changes in solar irradiance are estimated to have caused a small warming effect (+0.12 [+0.06 to +0.30]W/m<sup>2</sup>).

<sup>7</sup> Consideration of remaining uncertainty is based on current methodologies.

**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}

**Advances since the TAR show that discernible human influences extend beyond average temperature 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 20<sup>th</sup> century
- *likely* contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns
- *likely* increased temperatures of extreme hot nights, cold nights and cold days
- *more likely than not* increased risk of heat waves, area affected by drought since the 1970s and frequency of heavy precipitation events.

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

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

More complete attribution of observed natural system responses to anthropogenic warming is currently prevented by the short time scales of many impact studies, greater natural climate variability at regional scales, contributions of non-climate factors and limited spatial coverage of studies. {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}**

The IPCC Special Report on Emission Scenarios (SRES, 2000) projects an increase of global GHG emissions by 25-90% (CO<sub>2</sub>-eq) between 2000 and 2030 (Figure SPM.5), with fossil fuels maintaining their dominant position in the global energy mix to 2030 and beyond. More recent scenarios without additional emissions mitigation are comparable in range. <sup>8,9</sup> {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 21<sup>st</sup> century that would *very likely* be larger than those observed during the 20<sup>th</sup> century (Table SPM.1, Figure SPM.5). {3.2.1}**

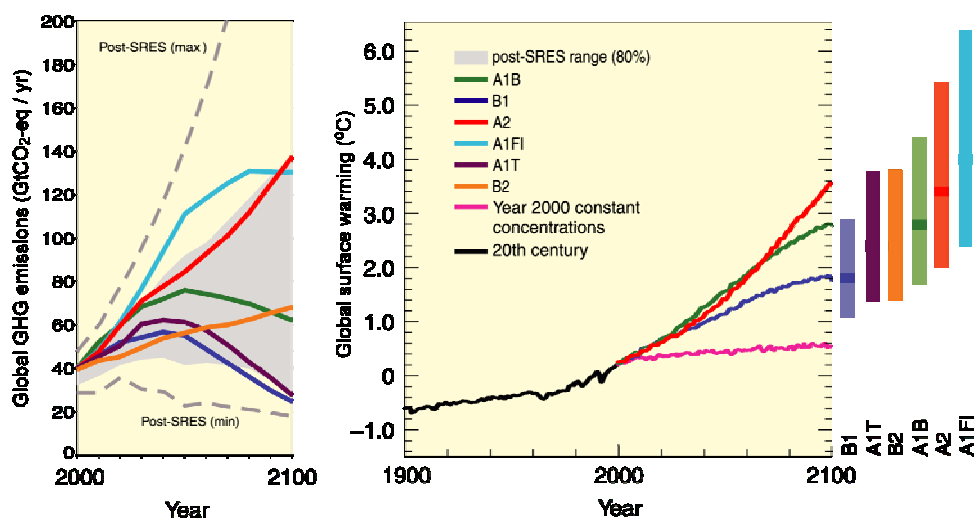
For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Afterwards, temperature projections increasingly depend on specific emission scenarios. {3.2}

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<sup>8</sup> For an explanation of SRES emission scenarios, see Box 'SRES scenarios' of this Synthesis Report. These scenarios do not include additional climate policy above current ones; more recent studies differ with respect to UNFCCC and Kyoto Protocol inclusion.

<sup>9</sup> Emission pathways of mitigation scenarios are discussed in Section 5.

### Scenarios for GHG emissions from 2000 to 2100 (in the absence of additional climate policies) and projections of surface temperatures



**Figure SPM-5.** Left Panel: Global GHG emissions (in CO<sub>2</sub>-eq) in the absence of climate policies: six illustrative SRES marker scenarios (coloured lines) and the 80<sup>th</sup> percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions cover CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, and F-gases. Right Panel: Solid lines are multi-model global averages of surface warming for scenarios A2, A1B and B1, shown as continuations of the 20<sup>th</sup> century simulations. These projections also take into account emissions of short-lived GHGs and aerosols. The pink line is not a scenario, but is for AOGCM simulations where atmospheric concentrations are held constant at year 2000 values. The bars at the right of the figure indicate the best estimate (solid line within each bar) and the *likely* range assessed for the six SRES marker scenarios at 2090-2099. All temperatures are relative to the period 1980-1999. {Figure 3.1, Figure 3.2}

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

Case	Temperature change (°C at 2090-2099 relative to 1980-1999) <sup>a, d</sup>		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	Likely range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations <sup>b</sup>	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 as well as observational constraints.
- b) Year 2000 constant composition is derived from Atmosphere-Ocean General Circulation Models (AOGCMs) only.
- c) All scenarios above are six SRES marker scenarios. Approximate carbon dioxide equivalent concentrations corresponding to the computed radiative forcing due to anthropogenic GHGs and aerosols in 2100 (see p. 823 of the TAR) for the SRES B1, A1T, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550 ppm, respectively.
- d) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5 °C.

The range of projections (Table SPM.1) is broadly consistent with the TAR, but uncertainties and upper ranges for temperature are larger mainly because the broader range of available models suggests stronger climate-carbon cycle feedbacks. Warming reduces terrestrial and ocean uptake of atmospheric CO<sub>2</sub>, increasing the fraction of anthropogenic emissions remaining in the atmosphere. The strength of this feedback effect varies markedly among models. {2.3, 3.2.1}

Because understanding of some important effects driving 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. Table SPM.1 shows model-based projections of global average sea level rise for 2090-2099.<sup>10</sup> The projections do not include uncertainties in climate-carbon cycle feedbacks nor the full effects of changes in ice sheet flow, therefore the upper values of the ranges are not to be considered upper bounds for sea level rise. They include a contribution from increased Greenland and Antarctic ice flow at the rates observed for 1993-2003, but this could increase or decrease in the future.<sup>11</sup> {3.2.1}

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

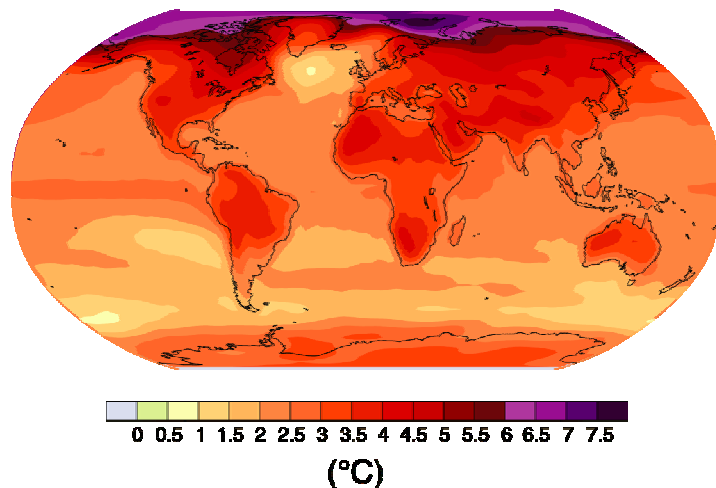
Regional-scale changes include: {3.2.2}

- warming greatest over land and at most high northern latitudes and least over Southern Ocean and parts of the North Atlantic Ocean, continuing recent observed trends (Figure SPM.6) in 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 21<sup>st</sup> century
- *very likely* increase in frequency of hot extremes, heat waves, and heavy precipitation
- *likely* increase in tropical cyclone intensity; less confidence in 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 recent trends

There is *high confidence* that by mid-century, annual river runoff and water availability are projected to increase at high latitudes (and in some tropical wet areas) and decrease in some dry regions in the mid-latitudes and tropics. There is also *high confidence* that many semi-arid areas (e.g. Mediterranean basin, western United States, southern Africa and northeast Brazil) will suffer a decrease in water resources due to climate change. {3.2; Figure 3.4}

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**Geographical pattern of surface warming**



**Figure SPM. 6.** Projected surface temperature changes for the late 21<sup>st</sup> 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}

<sup>10</sup> TAR projections were made for 2100, whereas the projections for this report are for 2090-2099. The TAR would have had similar ranges to those in Table SPM.1 if it had treated uncertainties in the same way.

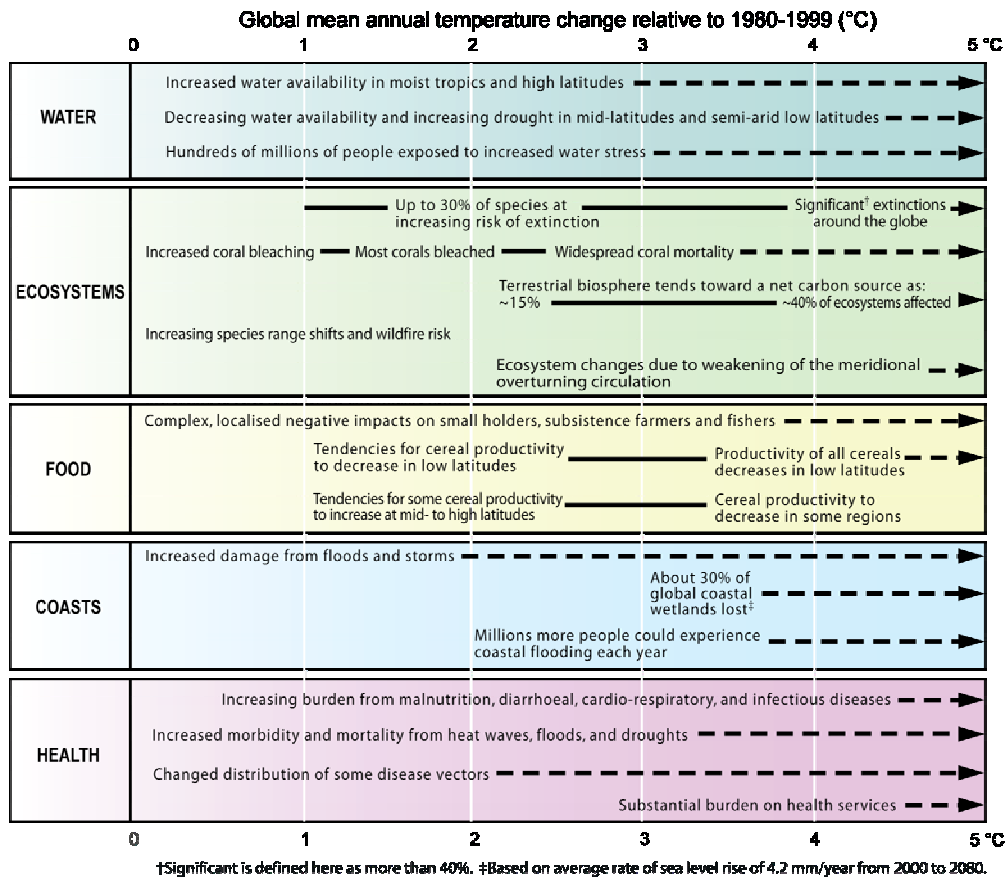
<sup>11</sup> For discussion of the longer term see material below.



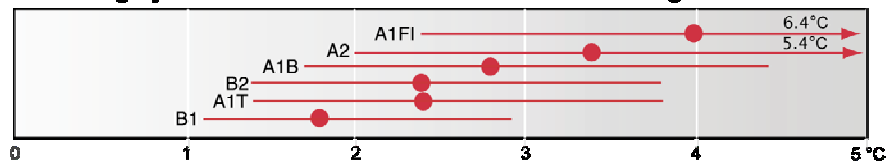
Studies since the TAR have enabled more systematic understanding of the timing and magnitude of impacts related to differing amounts and rates of climate change. {3.3.1, 3.3.2}

Figure SPM.7 presents examples of this new information for systems and sectors. The top panel shows impacts increasing with increasing temperature change. Their estimated magnitude and timing is also affected by development pathway (lower panel). {3.3.1, 3.3.2}

**Examples of impacts associated with global average temperature change**  
 (Impacts will vary by extent of adaptation, rate of temperature change, and socio-economic pathway)



**Warming by 2090-2099 relative to 1980-1999 for non-mitigation scenarios**



**Figure SPM.7.** Examples of impacts associated with projected global average surface warming. Upper panel: Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO<sub>2</sub> where relevant) associated with different amounts of increase in global average surface temperature in the 21<sup>st</sup> 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: 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. {Figure 3.5}

Examples of some projected impacts for different regions are given in Table SPM.2.

**Table SPM.2.** Examples of some projected regional impacts\*

<b>Africa</b>	<ul style="list-style-type: none"> <li>• By 2020, between 75 and 250 million of people are projected to be exposed to increased water stress due to climate change;</li> <li>• By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition;</li> <li>• Towards the end of the 21st century, projected sea-level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5-10% of Gross Domestic Product (GDP);</li> <li>• By 2080, an increase of 5-8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (TS).</li> </ul>
<b>Asia</b>	<ul style="list-style-type: none"> <li>• By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease;</li> <li>• Coastal areas, especially heavily-populated megadelta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers;</li> <li>• Climate change is projected to compound the pressures on natural resources and the environment, associated with rapid urbanization, industrialization and economic development;</li> <li>• Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle.</li> </ul>
<b>Australia and New Zealand</b>	<ul style="list-style-type: none"> <li>• By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites including the Great Barrier Reef and Queensland Wet Tropics;</li> <li>• By 2030, water security problems are projected to intensify in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions;</li> <li>• By 2030, production from agriculture and forestry is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in some other regions.;</li> <li>• By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding.</li> </ul>
<b>Europe</b>	<ul style="list-style-type: none"> <li>• Climate change is expected to magnify regional differences in Europe's natural resources and assets. Negative impacts will include increased risk of inland flash floods, and more frequent coastal flooding and increased erosion (due to storminess and sea-level rise);</li> <li>• Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extensive species losses (in some areas up to 60% under high emissions scenarios by 2080);</li> <li>• In Southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity;</li> <li>• Climate change is also projected to increase the health risks due to heat-waves, and the frequency of wildfires.</li> </ul>
<b>Latin America</b>	<ul style="list-style-type: none"> <li>• By mid century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation.</li> <li>• There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America;</li> <li>• Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase (TS; <i>medium confidence</i>).</li> <li>• Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation.</li> </ul>
<b>North America</b>	<ul style="list-style-type: none"> <li>• Warming in western mountains is projected to cause decreased snowpack, more winter flooding, and reduced summer flows, exacerbating competition for over-allocated water resources;</li> <li>• In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5-20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilized water resources;</li> <li>• During the course of this century, cities that currently experience heatwaves are expected to be further challenged by an increased number, intensity and duration of heatwaves during the course of the century, with potential for adverse health impacts;</li> <li>• Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution.</li> </ul>
<b>Polar Regions</b>	<ul style="list-style-type: none"> <li>• The main projected biophysical effects are reductions in thickness and extent of glaciers and ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators;</li> <li>• For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions are projected to be mixed;</li> <li>• Detrimental impacts would include those on infrastructure and traditional indigenous ways of life;</li> <li>• In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered.</li> </ul>

**Table SPM.2.** (cont.)

<b>Small Islands</b>	<ul style="list-style-type: none"><li>• Sea-level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities;</li><li>• Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching is expected to affect local resources;</li><li>• By mid-century, climate change is expected to reduce water resources in many small islands, e.g., in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods.</li><li>• With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands.</li></ul>
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*\*Unless stated explicitly, all entries are from WGII SPM text, and are either very high confidence or high confidence statements, reflecting different sectors (Agriculture, Ecosystems, Water, Coasts, Health, Industry and Settlements). The WGII SPM refers to the source of the statements, timelines and temperatures. The magnitude and timing of impacts that will ultimately be realized will vary with the amount and rate of climate change, emission scenarios, development pathways and adaptation.*

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Some systems, sectors and regions are *likely* to be especially affected by climate change.<sup>12</sup>

Systems and sectors: {3.3.4}

- particular ecosystems:
  - terrestrial: tundra, boreal forest and mountain regions because of sensitivity to warming; mediterranean-type ecosystems because of reduction in rainfall; and tropical rainforests where precipitation declines
  - coastal: mangroves and salt marshes, due to multiple stresses
  - marine: coral reefs due to multiple stresses; the sea ice biome because of sensitivity to warming
- water resources in some dry regions at mid-latitudes<sup>13</sup> and in the dry tropics, due to changes in rainfall and evapotranspiration, and in areas dependent on snow and ice melt
- agriculture in low-latitudes, due to reduced water availability
- low-lying coastal systems, due to threat of sea level rise and increased risk from extreme weather events
- human health in populations with low adaptive capacity.

Regions: {3.3.4}

- the Arctic, because of the impacts of high rates of projected warming on natural systems and human communities
- Africa, because of low adaptive capacity and projected climate change impacts
- small islands, where there is high exposure of population and infrastructure to projected climate change impacts
- Asian and African megadeltas, due to large populations and high exposure to sea level rise, storm surges and river flooding.

Within other areas, even those with high incomes, some people (such as the poor, young children, and the elderly) can be particularly at risk, and also some areas and some activities. {3.3.4}

### **Ocean Acidification**

The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units. Increasing atmospheric CO<sub>2</sub> concentrations lead to further acidification. Projections based on SRES scenarios give a reduction in average global surface ocean pH of between 0.14 and 0.35 units over the 21<sup>st</sup> century. While the effects of observed ocean acidification on the marine biosphere are as yet undocumented, the progressive acidification of oceans is expected to have negative impacts on marine shell-forming organisms (e.g. corals) and their dependent species. {3.3.1}

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<sup>12</sup> Identified on the basis of expert judgement of the assessed literature and considering the magnitude, timing and projected rate of climate change, sensitivity and adaptive capacity.

<sup>13</sup> Including arid and semi-arid regions.

**Altered frequencies and intensities of extreme weather, together with sea level rise, are expected to have mostly adverse effects on natural and human systems. {3.3.3}**

Examples for selected extremes and sectors are shown in Table SPM.3. {Table 3.2}

**Table SPM.3.** Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid- to late 21<sup>st</sup> century. These do not take into account any changes or developments in adaptive capacity. The likelihood estimates in column 2 relate to the phenomena listed in column 1. {WGII Table SPM.1}

Phenomenon <sup>a</sup> and direction of trend	Likelihood of future trends based on projections for 21 <sup>st</sup> century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems {WGII 4.4, 5.4}	Water resources {WGII 3.4}	Human health {WGII 8.2, 8.4}	Industry, settlement and society {WGII 7.4}
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	<i>Virtually certain<sup>b</sup></i>	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snowmelt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increased over most land areas	<i>Very likely</i>	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g. algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	<i>Very likely</i>	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	<i>Likely</i>	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water-and food-borne diseases	Water shortage for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	<i>Likely</i>	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers, potential for population migrations, loss of property
Increased incidence of extreme high sea level (excludes tsunamis) <sup>c</sup>	<i>Likely<sup>d</sup></i>	Salinisation of irrigation water, estuaries and freshwater systems	Decreased freshwater availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

Notes:

a) See WGI Table 3.7 for further details regarding definitions.

b) Warming of the most extreme days and nights each year.

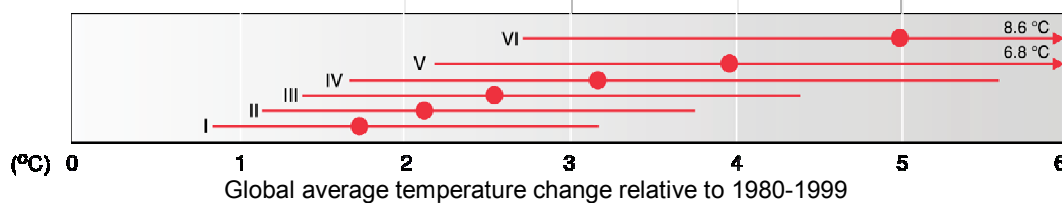
c) Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.

d) In all scenarios, the projected global average sea level at 2100 is higher than in the reference period {WGI 10.6}. The effect of changes in regional weather systems on sea level extremes has not been assessed.

**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}**

Estimated long term (multi-century) warming corresponding to the six AR4 WG III stabilisation categories is shown in Figure SPM.8.

**Estimated multi-century warming relative to 1980-1999 for AR4 stabilisation categories**



**Figure SPM.8.** Estimated long term (multi-century) warming corresponding to the six AR4 WGIII stabilisation categories (Table SPM.3). Temperature scale has been shifted by  $-0.5^{\circ}\text{C}$  compared to Table SPM.3 to account approximately for the warming between pre-industrial and 1980-1999. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For GHG emission scenarios that lead to stabilisation by 2100 at levels comparable to SRES B1 and A1B (600 and 850  $\text{CO}_2\text{-eq. ppm}$ ; category IV and V) assessed models project that about 65-70% of the estimated global equilibrium temperature increase assuming a climate sensitivity of  $3^{\circ}\text{C}$  would be realised at the time of stabilisation (WGI 10.7.2). For the much lower stabilisation scenarios (category I and II), the equilibrium temperature may be reached earlier (Figure SPM.11).

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  $4.6^{\circ}\text{C}$  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 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}

**Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change. {3.4}**

Partial loss of ice sheets on polar land could imply metres of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands. Such changes are projected to occur over millennial time scales, but more 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 are *likely* to be at increased risk of extinction if increases in global average warming exceed  $1.5\text{-}2.5^{\circ}\text{C}$  (relative to 1980-1999). As global average temperature increase exceeds about  $3.5^{\circ}\text{C}$ , model projections suggest significant extinctions (40-70% of species assessed) around the globe. {3.4}

Based on current model simulations, the meridional overturning circulation (MOC) of the Atlantic Ocean will *very likely* slow down during the 21<sup>st</sup> century; nevertheless temperatures over the Atlantic and Europe are projected to increase. The MOC is *very unlikely* to undergo a large abrupt transition during the 21<sup>st</sup> century. Longer-term MOC changes 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  $\text{CO}_2$  uptake, oceanic oxygen concentrations and terrestrial vegetation. Changes in terrestrial and ocean  $\text{CO}_2$  uptake may feed back on the climate system. {3.4}

#### **4. Adaptation and mitigation options<sup>14</sup>**

**A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood. {4.2}**

Societies have a long record of managing the impacts of weather- and climate-related events. Nevertheless, additional adaptation measures will be required to reduce the adverse impacts of projected climate change and variability, regardless of the scale of mitigation undertaken over the next two to three decades. Moreover, vulnerability to climate change can be exacerbated by other stresses. These arise from, for example, current climate hazards, poverty and unequal access to resources, food insecurity, trends in economic globalisation, conflict and incidence of diseases such as HIV/AIDS. {4.2}

Some planned adaptation to climate change is already occurring on a limited basis. Adaptation can reduce vulnerability especially when it is embedded within broader sectoral initiatives (Table SPM.4). 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. The capacity to adapt is dynamic and is influenced by a society's productive base including: natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health and technology. Even societies with high adaptive capacity remain vulnerable to climate change, variability and extremes. {4.2}

**Both bottom-up and top-down studies indicate that there is *high agreement and much evidence of 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 (Figure SPM.9, SPM.10)*<sup>15</sup>. While top-down and bottom-up studies are in line at the global level (Figure SPM.9) there are considerable differences at the sectoral level. {4.3}**

No single technology can provide all of the mitigation potential in any sector. The economic mitigation potential, which is generally greater than the market mitigation potential, can only be achieved when adequate policies are in place and barriers removed (Table SPM.5).

Bottom-up studies suggest that mitigation opportunities with net negative costs have the potential to reduce emissions by around 6 GtCO<sub>2</sub>-eq/yr in 2030, realizing which requires dealing with implementation barriers. {4.3}

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<sup>14</sup> While this section deals with adaptation and mitigation separately, these responses can be complementary. This theme is discussed in section 5.

<sup>15</sup> The concept of "**mitigation potential**" has been developed to assess the scale of GHG reductions that could be made, relative to emission baselines, for a given level of carbon price (expressed in cost per unit of carbon dioxide equivalent emissions avoided or reduced). Mitigation potential is further differentiated in terms of "market mitigation potential" and "economic mitigation potential".

**Market mitigation potential** is the mitigation potential based on private costs and private discount rates (reflecting the perspective of private consumers and companies), which might be expected to occur under forecast market conditions, including policies and measures currently in place, noting that barriers limit actual uptake.

**Economic mitigation potential** is the mitigation potential, which takes into account social costs and benefits and social discount rates (reflecting the perspective of society; social discount rates are lower than those used by private investors), assuming that market efficiency is improved by policies and measures and barriers are removed.

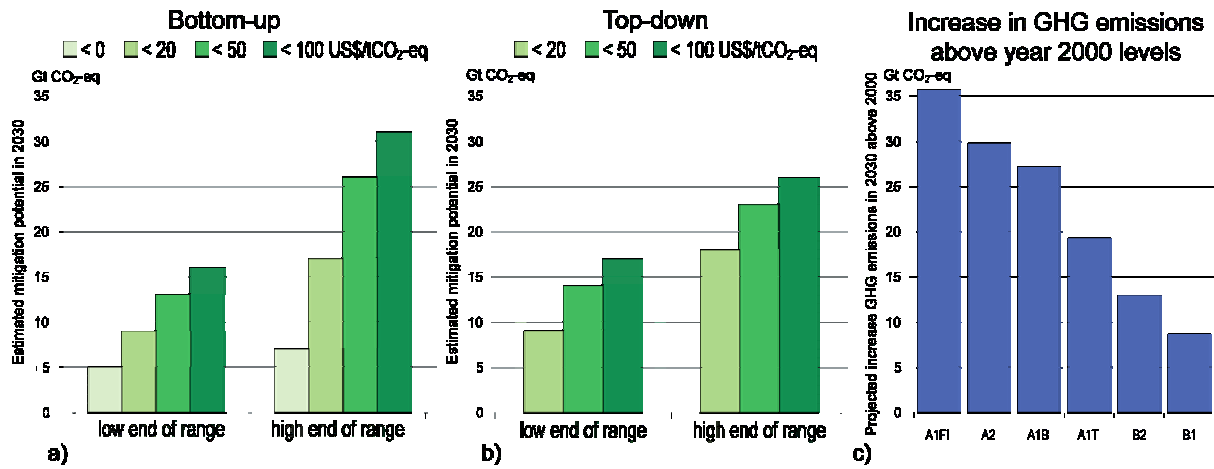
Mitigation potential is estimated using different types of approaches. **Bottom-up studies** are based on assessment of mitigation options, emphasizing specific technologies and regulations. They are typically sectoral studies taking the macro-economy as unchanged. **Top-down studies** assess the economy-wide potential of mitigation options. They use globally consistent frameworks and aggregated information about mitigation options and capture macro-economic and market feedbacks.

**Table SPM-4.** Selected examples of planned adaptation by sector.

Sector	Adaptation option/strategy	Underlying policy framework	Key constraints and opportunities to implementation (Normal font = constraints; <i>italics = opportunities</i> )
<b>Water</b>	Expanded rainwater harvesting; water storage and conservation techniques; water re-use; desalination; water-use and irrigation efficiency	National water policies and integrated water resources management; water-related hazards management	Financial, human resources and physical barriers; <i>integrated water resources management; synergies with other sectors</i>
<b>Agriculture</b>	Adjustment of planting dates and crop variety; crop relocation; improved land management, e.g. erosion control and soil protection through tree planting	R&D policies; institutional reform; land tenure and land reform; training; capacity building; crop insurance; financial incentives, e.g. subsidies and tax credits	Technological & financial constraints; access to new varieties; markets; <i>longer growing season in higher latitudes; revenues from 'new' products</i>
<b>Infrastructure/settlement (including coastal zones)</b>	Relocation; seawalls and storm surge barriers; dune reinforcement; land acquisition and creation of marshlands/wetlands as buffer against sea level rise and flooding; protection of existing natural barriers	Standards and regulations that integrate climate change considerations into design; land use policies; building codes; insurance	Financial and technological barriers; availability of relocation space; <i>integrated policies and managements; synergies with sustainable development goals</i>
<b>Human health</b>	Heat-health action plans; emergency medical services; improved climate-sensitive disease surveillance and control; safe water and improved sanitation	Public health policies that recognise climate risk; strengthened health services; regional and international cooperation	Limits to human tolerance (vulnerable groups); knowledge limitations; financial capacity; <i>upgraded health services; improved quality of life</i>
<b>Tourism</b>	Diversification of tourism attractions & revenues; shifting ski slopes to higher altitudes and glaciers; artificial snow-making	Integrated planning (e.g. carrying capacity; linkages with other sectors); financial incentives, e.g. subsidies and tax credits	Appeal/marketing of new attractions; financial and logistical challenges; potential adverse impact on other sectors (e.g. artificial snow-making may increase energy use); <i>revenues from 'new' attractions; involvement of wider group of stakeholders</i>
<b>Transport</b>	Realignment/relocation; design standards and planning for roads, rail, and other infrastructure to cope with warming and drainage	Integrating climate change considerations into national transport policy; investment in R&D for special situations, e.g. permafrost areas	Financial & technological barriers; availability of less vulnerable routes; <i>improved technologies and integration with key sectors (e.g. energy)</i>
<b>Energy</b>	Strengthening of overhead transmission and distribution infrastructure; underground cabling for utilities; energy efficiency; use of renewable sources; reduced dependence on single sources of energy	National energy policies, regulations, and fiscal and financial incentives to encourage use of alternative sources; incorporating climate change in design standards	Access to viable alternatives; financial and technological barriers; acceptance of new technologies; <i>stimulation of new technologies; use of local resources</i>

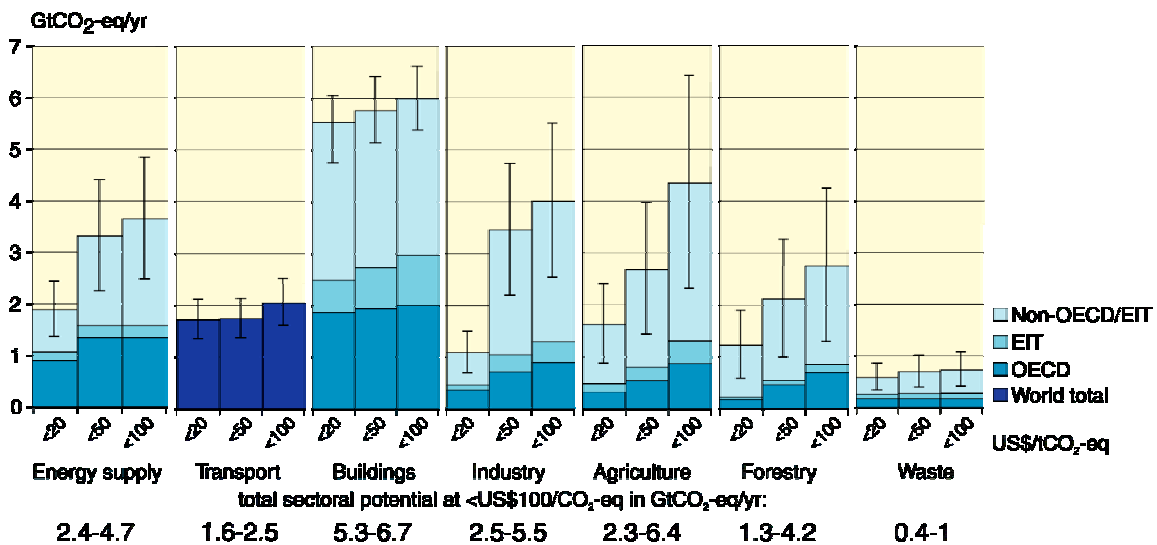
Note: Other examples from many sectors would include early warning systems.

### Comparison between global economic mitigation potential and projected emissions increase in 2030



**Figure SPM.9.** Global economic mitigation potential in 2030 estimated from bottom-up (Panel a) and top-down (Panel b) studies, compared with the projected emission increases from SRES scenarios relative to 2000 GHG emissions of 40.8 GtCO<sub>2</sub>-eq (Panel c). Note: GHG emissions in 2000 are exclusive of emissions of decay of above ground biomass that remains after logging and deforestation and from peat fires and drained peat soils, to ensure consistency with the SRES emission results.

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



**Figure SPM.10.** 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) Sectors used different baselines. For industry the SRES B2 baseline was taken, for energy supply and transport the WEO 2004 baseline was used; the building sector is based on a baseline in between SRES B2 and A1B; for waste, SRES A1B driving forces were used to construct a waste specific baseline; agriculture and forestry used baselines that mostly used B2 driving forces.
- d) Only global totals for transport are shown because international aviation is included.
- e) Categories excluded are: non-CO<sub>2</sub> 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



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energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10-15%.

**Table SPM-5.** Selected examples of key sectoral mitigation technologies, policies and measures, constraints and opportunities. {WGIII, Tables SPM.3, SPM.7}

Sector	Key mitigation technologies and practices currently commercially available. Key mitigation technologies and practices projected to be commercialised before 2030 shown in italics.	Policies, measures and instruments shown to be environmentally effective	Key constraints or opportunities (Normal font = constraints; italics = opportunities)
Energy Supply	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of Carbon Dioxide Capture and Storage (CCS) (e.g. storage of removed CO <sub>2</sub> from natural gas); <i>CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and wave energy, concentrating solar, and solar photovoltaics</i>	Reduction of fossil fuel subsidies; Taxes or carbon charges on fossil fuels	Resistance by vested interests may make them difficult to implement
		Feed-in tariffs for renewable energy technologies; Renewable energy obligations; Producer subsidies	<i>May be appropriate to create markets for low emissions technologies</i>
Transport	More fuel efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning*; <i>Second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries</i>	Mandatory fuel economy, biofuel blending and CO <sub>2</sub> standards for road transport	Partial coverage of vehicle fleet may limit effectiveness
		Taxes on vehicle purchase, registration, use and motor fuels, road and parking pricing	Effectiveness may drop with higher incomes
		Influence mobility needs through land use regulations, and infrastructure planning; Investment in attractive public transport facilities and non-motorised forms of transport	<i>Particularly appropriate for countries that are building up their transportation systems</i>
Buildings	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycling of fluorinated gases; <i>Integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar photovoltaics integrated in buildings</i>	Appliance standards and labelling	Periodic revision of standards needed
		Building codes and certification	<i>Attractive for new buildings.</i> Enforcement can be difficult
		Demand-side management programmes	Need for regulations so that utilities may profit
		Public sector leadership programmes, including procurement	<i>Government purchasing can expand demand for energy-efficient products</i>
		Incentives for energy service companies (ESCOs)	<i>Success factor: Access to third party financing</i>
Industry	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO <sub>2</sub> gas emissions; and a wide array of process-specific technologies; <i>Advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture</i>	Provision of benchmark information; Performance standards; Subsidies, tax credits	<i>May be appropriate to stimulate technology uptake.</i> Stability of national policy important in view of international competitiveness
		Tradable permits	Predictable allocation mechanisms and stable price signals important for investments
		Voluntary agreements	Success factors include: clear targets, a baseline scenario, third party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry
Agriculture	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH <sub>4</sub> emissions; improved nitrogen fertiliser application techniques to reduce N <sub>2</sub> O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency; <i>Improvements of crop yields</i>	Financial incentives and regulations for improved land management, maintaining soil carbon content, efficient use of fertilisers and irrigation	<i>May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation</i>

**Table SPM-5.** (cont.)

Sector	Key mitigation technologies and practices currently commercially available. <i>Key mitigation technologies and practices projected to be commercialised before 2030 shown in italics.</i>	Policies, measures and instruments shown to be environmentally effective	Key constraints or opportunities (Normal font = constraints; <i>italics = opportunities</i> )
<b>Forestry/ forests</b>	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use; <i>Tree species improvement to increase biomass productivity and carbon sequestration. Improved remote sensing technologies for analysis of vegetation/ soil carbon sequestration potential and mapping land use change</i>	Financial incentives (national and international) to increase forest area, to reduce deforestation, and to maintain and manage forests; Land-use regulation and enforcement	Constraints include lack of investment capital and land tenure issues. <i>Can help poverty alleviation.</i>
<b>Waste</b>	Landfill CH <sub>4</sub> recovery; waste incineration with energy recovery; composting of organic waste; controlled waste water treatment; recycling and waste minimisation; <i>biocovers and biofilters to optimise CH<sub>4</sub> oxidation</i>	Financial incentives for improved waste and wastewater management	<i>May stimulate technology diffusion</i>
		Renewable energy incentives or obligations	Local availability of low-cost fuel
		Waste management regulations	Most effectively applied at national level with enforcement strategies

Future energy infrastructure investment decisions, expected to exceed 20 trillion US\$<sup>16</sup> between 2005 and 2030, will have long-term impacts on GHG emissions, because of the long life-times of energy plants and other infrastructure capital stock. The widespread diffusion of low-carbon technologies may take many decades, even if early investments in these technologies are made attractive. Initial estimates show that returning global energy-related CO<sub>2</sub> 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 policies and instruments are available to governments to create the incentives for mitigation action. Their applicability depends on national circumstances and sectoral context (Table SPM5). {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). {4.3}

An effective carbon-price signal could realise significant mitigation potential in all sectors. Modelling studies show global carbon prices rising to 20-80 US\$/tCO<sub>2</sub>-eq by 2030 are consistent with stabilisation at around 550 ppm CO<sub>2</sub>-eq by 2100. For the same stabilisation level, induced technological change may lower these price ranges to 5-65 US\$/tCO<sub>2</sub>-eq in 2030.<sup>17</sup> {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.<sup>18</sup> {4.3}

<sup>16</sup> 20 trillion = 20,000 billion = 20×10<sup>12</sup>

<sup>17</sup> 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, with universal emissions trading, assuming transparent markets, no transaction cost, and thus perfect implementation of mitigation measures throughout the 21<sup>st</sup> 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. Significant progress has been achieved in applying approaches based on induced technological change to stabilisation studies; however, conceptual issues remain. In the models that consider induced technological change, projected costs for a given stabilisation level are reduced; the reductions are greater at lower stabilisation level.

<sup>18</sup> Further details may be found in Topic 4 of the Synthesis Report.

Fossil fuel exporting nations (in both Annex I and non-Annex I countries) may expect, as indicated in the TAR, lower demand and prices and lower GDP growth due to mitigation policies. The extent of this spill over depends strongly on assumptions related to policy decisions and oil market conditions.

There is also *high agreement* and *medium evidence* that changes in lifestyle, behaviour patterns and management practices can contribute to climate change mitigation across all sectors. {4.3}

**Many options for reducing global GHG emissions through international cooperation exist. 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 efforts. Progress has also been made in addressing adaptation within the UNFCCC and additional international initiatives have been suggested. {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}

**In several sectors, climate response options 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}**

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. Over the next half-century, climate change could impede achievement of the Millennium Development Goals. {5.8}

## **5. The long-term perspective**

**Determining what constitutes “dangerous anthropogenic interference with the climate system” in relation to Article 2 of the UNFCCC involves value judgements. Science can support informed decisions on this issue, including by providing criteria for judging which vulnerabilities might be labelled “key”. {Box ‘Key Vulnerabilities and Article 2 of the UNFCCC’, topic 5}**

Key vulnerabilities<sup>19</sup> may be associated with many climate sensitive systems including food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets, and modes of oceanic and atmospheric circulation. {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. These “reasons” are assessed here to be stronger than in the TAR. Many risks are identified with higher confidence. Some risks are projected to be larger or to occur at lower increases in temperature. Understanding about the relationship between impacts (the basis for “reasons for concern” in the TAR) and vulnerability (that includes the ability to adapt to impacts) has improved. {5.2}**

This is due to more precise identification of the circumstances that make systems, sectors and regions especially vulnerable, and growing evidence of the risks of very large impacts on multiple century time scales. {5.2}

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<sup>19</sup> 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.

- **Risks to unique and threatened systems.** There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase further. An increasing risk of species extinction and coral reef damage is projected with higher confidence than in the TAR as warming proceeds. There is *medium confidence* that approximately 20-30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5-2.5°C over 1980-1999 levels. Confidence has increased that a 1-2°C increase in global mean temperature above 1990 levels (about 1.5-2.5°C above pre-industrial) poses significant risks to many unique and threatened systems including many biodiversity hotspots. Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1-3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatization by corals. Increasing vulnerability of indigenous communities in the Arctic and small island communities to warming is projected.
- **Risks of extreme weather events.** Responses to some recent extreme events reveal higher levels of vulnerability than the TAR. There is now higher confidence in the projected increases in droughts, heatwaves, and floods as well as their adverse impacts.
- **Distribution of impacts and vulnerabilities.** There are sharp differences across regions and those in the weakest economic position are often the most vulnerable to climate change. There is increasing evidence of greater vulnerability of specific groups such as the poor and elderly in not only developing but also developed countries. Moreover, there is increased evidence that low-latitude and less-developed areas generally face greater risk, for example in dry areas and mega-deltas.
- **Aggregate impacts.** Compared to the TAR, initial net market-based benefits from climate change are projected to peak at a lower magnitude of warming, while damages would be higher for larger magnitudes of warming. The net costs of impacts of increased warming are projected to increase over time.
- **Risks of large-scale singularities.** There is *high confidence* that global warming over many centuries would lead to a sea level rise contribution from thermal expansion alone which is projected to be much larger than observed over the 20<sup>th</sup> century, with loss of coastal area and associated impacts. There is better understanding than in the TAR that the risk of additional contributions to sea level rise from both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century time scales. This is because ice dynamical processes seen in recent observations but not fully included in ice sheet models assessed in AR4 could increase the rate of ice loss.

**There is *high confidence* that neither adaptation nor mitigation alone can avoid all climate change impacts; however, they can complement each other and together can significantly reduce the risks of climate change. {5.3}**

Adaptation is necessary in the short and longer term to address impacts resulting from the warming that would occur even for the lowest stabilisation scenarios assessed. There are barriers, limits and costs, but these are not fully understood. 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 further locking in carbon intensive infrastructure and reduce climate change and associated adaptation needs. {5.2, 5.3}

**Many impacts can be reduced, delayed or avoided by mitigation. Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels. Delayed emission reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. {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.<sup>20</sup> {5.4}

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<sup>20</sup> For the lowest mitigation scenario category assessed, emissions would need to peak by 2015 and for the highest by 2090 (see Table SPM.3). Scenarios that use alternative emission pathways show substantial differences in the rate of global climate change.

Table SPM.6 and Figure SPM.11 summarise the required emission levels for different groups of stabilisation concentrations and the resulting equilibrium global warming and long-term sea level rise due to thermal expansion only.<sup>21</sup> The timing and level of mitigation to reach a given temperature stabilisation level is earlier and more stringent if climate sensitivity is high than if it is low. {5.4, 5.7}

Sea level rise under warming is inevitable. Thermal expansion would continue for many centuries after GHG concentrations have stabilised, for any of the stabilisation levels assessed, causing an eventual sea level rise much larger than projected for the 21<sup>st</sup> century. The eventual contributions from Greenland ice sheet loss could be several metres, and larger than from thermal expansion, should warming in excess of 1.9-4.6°C above pre-industrial be sustained over many centuries. 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}

**Table SPM.6.** Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only. {Table 5.1}<sup>a</sup>

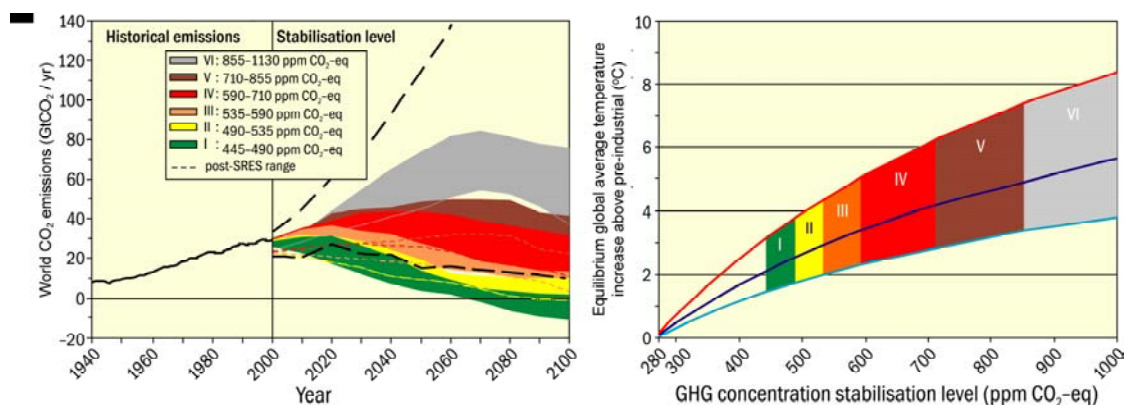
Category	CO <sub>2</sub> concentration at stabilization (2005 = 379 ppm) <sup>(b)</sup>	CO <sub>2</sub> -equivalent Concentration at stabilization including GHGs and aerosols (2005 = 375 ppm) <sup>(b)</sup>	Peaking year for CO <sub>2</sub> emissions <sup>(a, c)</sup>	Change in global CO <sub>2</sub> emissions in 2050 (% of 2000 emissions) <sup>(a, c)</sup>	Global average temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity <sup>(d), (e)</sup>	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only <sup>(f)</sup>	Number of assessed scenarios
	ppm	ppm	Year	Percent	°C	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) The emission reductions to meet a particular stabilization level reported in the mitigation studies assessed here might be underestimated due to missing carbon cycle feedbacks (see also Topic 2).
- b) Atmospheric CO<sub>2</sub> concentrations were 379 ppm in 2005. The best estimate of total CO<sub>2</sub>-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<sub>2</sub>-eq.
- c) Ranges correspond to the 15th to 85th percentile of the post-TAR scenario distribution. CO<sub>2</sub> emissions are shown so multi-gas scenarios can be compared with CO<sub>2</sub>-only scenarios (see Figure SPM.3).
- d) The best estimate of climate sensitivity is 3°C.
- e) Note that global average temperature at equilibrium is different from expected global average temperature at the time of stabilization 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 (see also Footnote 9).
- f) Equilibrium sea level rise is for the contribution from ocean 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°C climate sensitivity) and do not include contributions from melting ice sheets, glaciers and ice caps. Long-term thermal expansion is projected to result in 0.2 to 0.6 m per degree Celsius of global average warming above preindustrial. (AOGCM refers to Atmosphere Ocean General Circulation Models and EMICs to Earth System Models of Intermediate Complexity.)

<sup>21</sup> Estimates for the evolution of 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 (category I and II, Figure SPM.11), the equilibrium temperature may be reached earlier.

## CO<sub>2</sub> emissions and equilibrium temperature increases for a range of stabilisation levels



**Figure SPM.11.** Global CO<sub>2</sub> emissions for 1940 to 2000 and emissions ranges for categories 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 recent baseline scenarios published since the SRES (2000). Emissions ranges of the stabilisation scenarios comprise CO<sub>2</sub>-only and multigas scenarios and correspond to the 10th-90th percentile of the full scenario distribution. Note: CO<sub>2</sub> emissions in most models do not include emissions from decay of above ground biomass that remains after logging and deforestation, and from peat fires and drained peat soils. {Figure 5.1}

There is *high agreement and much evidence* that all 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 appropriate and effective incentives are in place for their development, acquisition, deployment and diffusion and addressing related barriers. {5.5}

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. Including non-CO<sub>2</sub> and CO<sub>2</sub> land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Low stabilisation levels require early investments and substantially more rapid diffusion and commercialisation of advanced low-emissions technologies.

Without substantial investment flows and effective technology transfer, it may be difficult to achieve emission reduction at a significant scale. Mobilizing financing of incremental costs of low-carbon technologies is important. {5.5}

The macro-economic costs of mitigation generally rise with the stringency of the stabilisation target (Table SPM.7). For specific countries and sectors, costs vary considerably from the global average.<sup>22</sup> {5.6}

In 2050, global average macro-economic costs for mitigation towards stabilisation between 710 and 445ppm CO<sub>2</sub>-eq are between a 1% gain and 5.5% decrease of global GDP (Table SPM.7). This corresponds to slowing average annual global GDP growth by less than 0.12 percentage points. {5.6}

<sup>22</sup> See footnote 17 for more detail on cost estimates and model assumptions.

**Table SPM.7.** 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 <sub>2</sub> -eq)	Median GDP reduction <sup>(a)</sup> (%)		Range of GDP reduction <sup>(b)</sup> (%)		Reduction of average annual GDP growth rates (percentage points) <sup>(c)</sup> ( <sup>(e)</sup> )	
	2030	2050	2030	2050	2030	2050
445 – 535 <sup>(d)</sup>	Not available		< 3	< 5.5	< 0.12	< 0.12
535 – 590	0.6	1.3	0.2 to 2.5	slightly negative to 4	< 0.1	< 0.1
590 – 710	0.2	0.5	-0.6 to 1.2	-1 to 2	< 0.06	< 0.05

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 on market exchange rates.
- b) The 10th and 90th percentile range of the analysed data are given where applicable. Negative values indicate GDP gain. The first row (445-535 ppm CO<sub>2</sub>-eq) gives the upper bound estimate of the literature only.
- 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.
- e) The values correspond to the highest estimate for GDP reduction shown in column three.

**Responding to climate change involves an iterative risk management process that includes both adaptation and mitigation and takes into account climate change damages, co-benefits, sustainability, equity, and attitudes to risk. {5.1}**

Impacts of climate change are *very likely* to impose net annual costs which will increase over time as global temperatures increase. Peer-reviewed estimates of the social cost of carbon<sup>23</sup> in 2005 average US\$12 per tonne of CO<sub>2</sub>, but the range from 100 estimates is large (-\$3 to \$95/tCO<sub>2</sub>). This is due in large part to differences in assumptions regarding climate sensitivity, response lags, the treatment of risk and equity, economic and non-economic impacts, the inclusion of potentially catastrophic losses, and discount rates. Aggregate estimates of costs mask significant differences in impacts across sectors, regions and populations and *very likely* underestimate damage costs because they cannot include many non-quantifiable 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 for specific temperature levels.

Choices about the scale and timing of GHG mitigation involve balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay. {5.4}

<sup>23</sup> Net economic costs of damages from climate change aggregated across the globe and discounted to the specified year.