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**IPCC FOURTH ASSESSMENT REPORT "CLIMATE CHANGE 2007"**

**DRAFT SYNTHESIS REPORT**

**Longer Report**

(Submitted by the Chairman)

| The draft longer report is submitted to the Twenty-Seventh Session for adoption. |
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# Intergovernmental Panel on Climate Change
# Fourth Assessment Report

## Climate Change 2007: Synthesis Report

# Longer Report

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References in curly brackets { } in the Longer Report of the Synthesis Report refer to the Summaries for Policymakers (SPMs), Technical Summaries (TS), Chapters, Tables and Figures of the contributions of Working Groups I, II and III (WGI, WGII, WGIII) to the Fourth Assessment Report (AR4), and to Special Reports (SROC: Special Report on Safeguarding the Ozone Layer and the Global Climate System; SRES: Special Report on Emission Scenarios).

# Introduction
**(31 August 2007)**

This Synthesis Report is based on the assessment carried out by the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC). It provides an integrated view of climate change as the final part of the IPCC's Fourth Assessment Report (AR4).

Topic 1 summarises observed changes in climate and their effects on natural and human systems, regardless of their causes, while topic 2 assesses the causes of the observed changes. Topic 3 presents projections of future climate change and related impacts under different scenarios.

Topic 4 discusses adaptation and mitigation options over the next few decades and their interactions with sustainable development. Topic 5 assesses the relationship between adaptation and mitigation on a more conceptual basis and takes a longer-term perspective. Topic 6 summarises the major robust findings and remaining key uncertainties in this assessment.

A schematic framework representing anthropogenic drivers, impacts of, and responses to climate change and their linkages, is shown in Figure I.1. At the time of the Third Assessment Report (TAR) in 2001, information was mainly available to describe the linkages clockwise, i.e. to derive climatic changes and impacts from socio-economic information and emissions. With increased understanding of these linkages, it is now possible to assess the linkages also counterclockwise, i.e. to evaluate possible development pathways and global emissions constraints that would reduce the risk of future impacts that society may wish to avoid.

**Schematic framework of anthropogenic climate change drivers, impacts and responses**

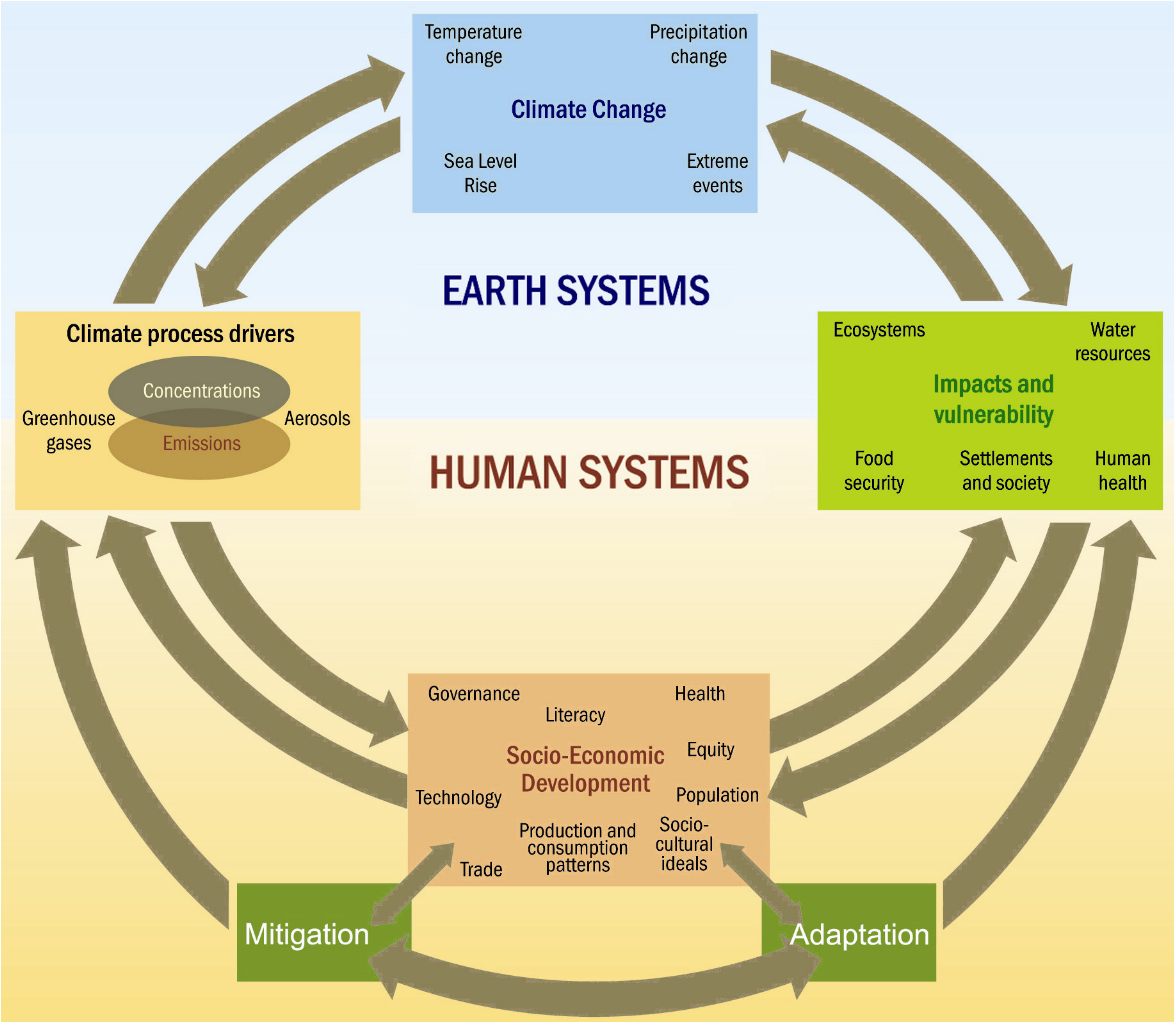



**Figure I.1.** Schematic framework representing anthropogenic drivers, impacts of, and responses to climate change, and their linkages.

## Treatment of uncertainty

The IPCC uncertainty guidance note[1] defines a framework for the treatment of uncertainties across all Working Groups (WGs) and in this Synthesis Report. This framework is broad because the WGs assess material from different disciplines and cover a diversity of approaches to the treatment of uncertainty drawn from the literature. The nature of data, indicators and analyses used in the natural sciences is generally different from that used in assessing technology development or the social sciences. WG I focuses on the former, WG III on the latter, and WG II covers aspects of both.

Three different approaches are used to describe uncertainties each with a distinct form of language. Choices among and within these three approaches depend both on the nature of the information available and the authors' expert judgment of the correctness and completeness of current scientific understanding.

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

Where uncertainty is assessed qualitatively, it is characterised by providing a relative sense of the amount and quality of evidence (that is, information from theory, observations or models indicating whether a belief or proposition is true or valid) and the degree of agreement (that is, the level of concurrence in the literature on a particular finding). This approach is used by WG III through a series of self-explanatory terms such as: *high agreement, much evidence; high agreement, medium evidence; medium agreement, medium evidence; etc*.

Where uncertainty is assessed more quantitatively using expert judgement of the correctness of underlying data, models or analyses, then the following scale of confidence levels is used to express the assessed chance of a finding being correct: v*ery high confidence* at least 9 out of 10; *high confidence* about 8 out of 10; *medium confidence* about 5 out of 10; *low confidence* about 2 out of 10; and *very low confidence* less than 1 out of 10.

Where uncertainty in specific outcomes is assessed using expert judgment and statistical analysis of a body of evidence (e.g. observations or model results), then the following likelihood ranges are used to express the assessed probability of occurrence: *virtually certain* >99%; *extremely likely* >95%; *very likely* >90%; *likely* >66%; *more likely than not* > 50%; *about as likely as not* 33% to 66%; *unlikely* <33%; *very unlikely* <10%; *extremely unlikely* <5%; *exceptionally unlikely* <1%.

WG II have used a combination of confidence and likelihood assessments and WG I have predominantly used likelihood assessments.

The Synthesis Report follows the uncertainty assessment of the underlying WGs. Where synthesised findings are based on information from more than one WG, the description of uncertainty used is consistent with that for the components drawn from the respective WG reports.

Unless otherwise stated, numerical ranges given in square brackets in this report indicate 90% uncertainty intervals (i.e. the true value is *very likely* to lie within the stated range). Uncertainty intervals are not necessarily symmetric around the best estimate.

# Topic 1 – Observed changes in climate and its effects
**(31 August 2007)**

## 1.1 Observations of climate change

Since the TAR, progress in understanding how climate is changing in space and time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. {WGI SPM}

**Definitions of climate change**

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

**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 1.1). {WGI 3.2, 4.8, 5.2, SPM}**

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 per century (Figure 1.1). The linear warming trend over the 50 years 1956-2005 (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the 100 years 1906-2005. {WGI 3.2, SPM}

The temperature increase is widespread over the globe, and is greater at higher northern latitudes (Figure 1.2). Average Arctic temperatures have increased at almost twice the global average rate in the past 100 years. Land regions have warmed at a faster rate than the oceans. Surface air temperatures over land have increased at about 0.27ºC per decade in the past two decades, with the greatest warming in winter and spring in the Northern Hemisphere. Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been taking up over 80% of the heat being added to the climate system. New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates similar to those observed in surface temperature. {WGI 3.2, 3.4, 5.2, 5.5, SPM}

Observed decreases in snow and ice extent are consistent with warming (Figure 1.1). 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. The maximum areal extent of seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with decreases in spring of up to 15%. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic by up to 3°C. {WGI 3.2, 4.5, 4.6, 4.7, 4.8, 5.5, SPM}

Increases in sea level are also consistent with warming (Figure 1.1). Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003 and at an average rate of about 3.1 [2.4 to 3.8] mm per year from 1993 to 2003. Whether this faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer term trend is unclear. Since 1993 thermal expansion of the oceans has contributed about 57% of the sum of the estimated individual contributions to the sea level rise, with decreases in glaciers and ice-caps contributing about 28% and losses from the polar ice sheets contributing the remainder. From 1993 to 2003 the sum of these climate contributions is consistent within uncertainties with the total sea level rise that is directly observed. {WGI 4.6, 4.8, 5.5, SPM, Table SPM.1}

**Changes in temperature, sea level and Northern Hemisphere snow cover**

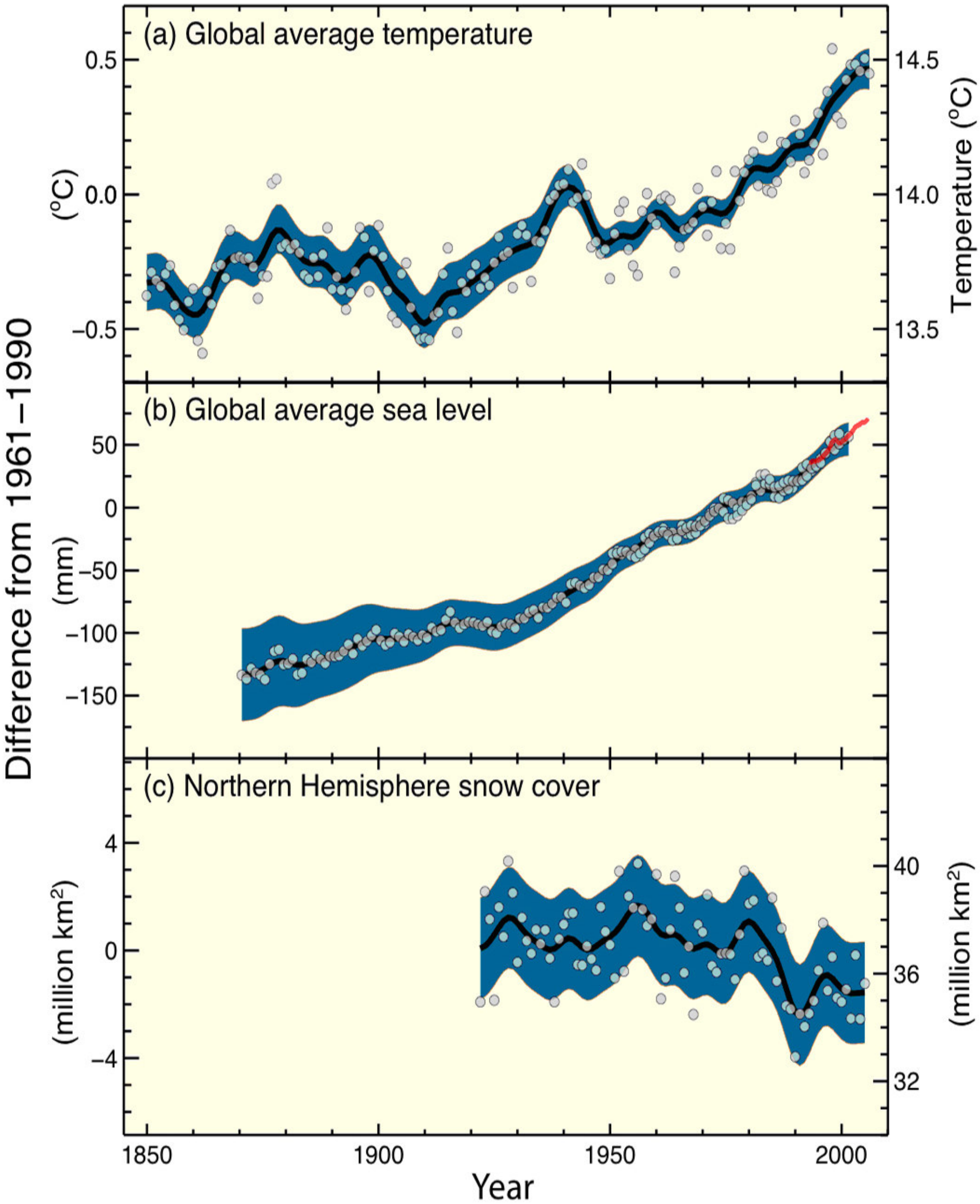



**Figure 1.1.** Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves 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). {WGI FAQ 3.1 Figure 1, Figure 4.2 and Figure 5.13, Figure SPM.3}

At continental, regional, and ocean basin scales, numerous changes in other aspects of climate have also been observed. Trends from 1900 to 2005 have been observed in precipitation amount in many large regions. Over this period, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia whereas precipitation 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. {WGI 3.3, 3.9, SPM}

Some extreme weather events have changed in frequency or intensity:
- It is *very likely* that cold days, cold nights and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent. {WGI 3.8, SPM}
- It is *likely* that heat waves have become more frequent over most land areas. {WGI 3.8, SPM}
- It is *likely* that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas. {WGI 3.8, 3.9, SPM}
- It is *likely* that the incidence of extreme high sea level (excluding tsunamis) has increased at a broad range of sites worldwide since 1975. {WGI 5.5, SPM}

There is observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, and suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. {WGI 3.8, SPM}

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. {WGI 6.6, SPM}

## 1.2 Observed effects of climate changes

The statements presented here are based largely on data sets that cover the period since 1970. The number of studies of observed trends in the physical and biological environment and their relationship to regional climate changes has increased greatly since the TAR. The quality of the data sets has also improved. There is a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries. {WGII SPM}

These studies have allowed a broader and more confident assessment of the relationship between observed warming and impacts than was made in the TAR. That Assessment concluded that "there is *high confidence*[2] that recent regional changes in temperature have had discernible impacts on physical and biological systems". {WGII SPM}

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

There is *high confidence* that natural systems related to snow, ice and frozen ground (including permafrost) are affected. Examples are:
- enlargement and increased numbers of glacial lakes {WGII 1.3, SPM}

[2] Likelihood and confidence statements in italics represent calibrated expressions of uncertainty and confidence. See Box 'Treatment of uncertainty' in the Introduction for an explanation of these terms.

- increasing ground instability in permafrost regions, and rock avalanches in mountain regions {WGII 1.3, SPM}
- changes in some Arctic and Antarctic flora and fauna, including those in sea-ice biomes, and predators at high levels of the food web. {WGII 1.3, 4.4, 15.4, SPM}

Based on growing evidence, there is *high confidence* that the following effects on hydrological systems are occurring: increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers; and warming of lakes and rivers in many regions, with effects on thermal structure and water quality. {WGII 1.3, 15.2, SPM}

There is *very high confidence*, based on more evidence from a wider range of species, that recent warming is strongly affecting terrestrial biological systems**,** including such changes as: earlier timing of spring events, such as leaf-unfolding, bird migration and egg-laying; and poleward and upward shifts in ranges in plant and animal species. Based on satellite observations since the early 1980s, there is *high confidence* that there has been a trend in many regions towards earlier 'greening' of vegetation in the spring linked to longer thermal growing seasons due to recent warming. {WGII 1.3, 8.2, 14.2, SPM}

There is *high confidence*, based on substantial new evidence, that observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels, and circulation. These include: shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans; increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; and range changes and earlier fish migrations in rivers. While there is increasing evidence for climate change impacts on coral reefs, separating the impacts of climate-related stresses from other stresses (e.g. over-fishing and pollution) is difficult. {WGII 1.3, SPM}

Increasing atmospheric carbon dioxide ($CO_2$) concentrations lead to increasing acidification of the oceans. The average pH of near-surface seawater has fallen by 0.1 units since pre-industrial times, i.e. a 30% increase in the concentration of hydrogen ions in the near-surface seawater. However, the effects of observed ocean acidification on the marine biosphere are as yet undocumented. {WGI SPM, 5.4; WGII 1.3, SPM}

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

Effects of temperature increases have been documented with *medium confidence* in the following managed and human systems:
- agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbances of forests due to fires and pests {WGII 1.3, SPM}
- some aspects of human health, such as increased heat-related mortality in Europe, changes in infectious disease vectors in parts of Europe, and earlier onset of and increases in seasonal production of allergenic pollen season in Northern Hemisphere high and mid-latitudes {WGII 1.3, 8.2, 8.ES, SPM}
- some human activities in the Arctic (e.g. hunting and shorter travel seasons over snow and ice) and in lower-elevation alpine areas (such as limitations in mountain sports). {WGII 1.3, SPM}

Sea level rise and human development are together contributing to losses of coastal wetlands and mangroves and increasing damage from coastal flooding in many areas. However, based on the published literature, the impacts have not yet become established trends. {WGII 1.3, 1.ES, SPM}

## 1.3 Consistency of changes in physical and biological systems with warming

Changes in the ocean and on land, including observed decreases in snow cover and Northern Hemisphere sea ice extent, thinner sea ice, shorter freezing seasons of lake and river ice, glacier melt, decreases in permafrost extent, increases in soil temperatures and borehole temperature profiles, and sea level rise, provide additional evidence that the world is warming. {WGI 3.9}

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 1.2 and Table 1.1). {WGII 1.4, SPM}

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

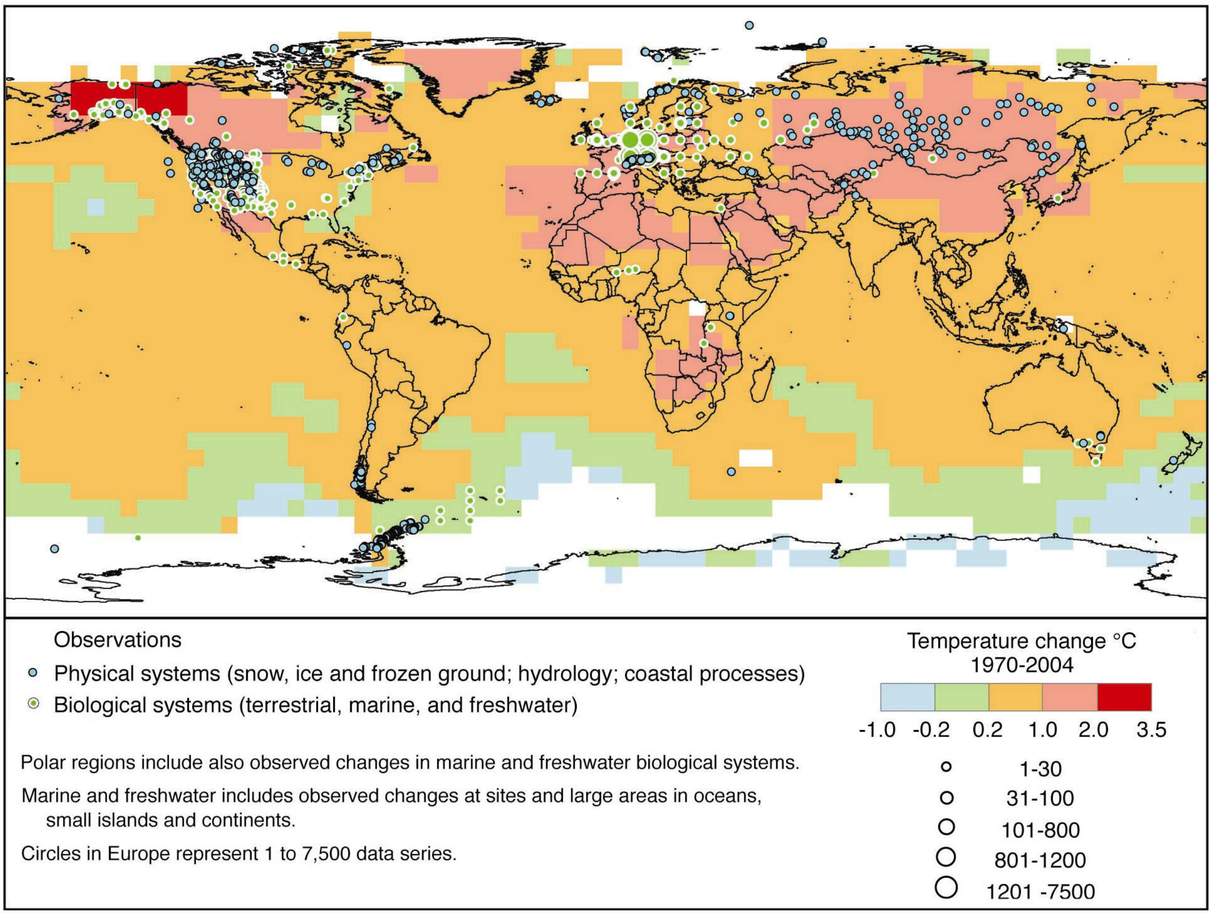



**Figure 1.2.** Locations of statistically significant changes in observations of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine, and freshwater biological systems) are shown together with surface temperature changes over the 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 TAR); 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. {WGII Figure SPM.1, 1.4, Figure 1.8}

**Table 1.1.** Number of physical and biological data series with significant changes and the percentage of those consistent with warming for terrestrial systems, and marine and freshwater systems. {WGII SPM, Figure SPM.1, 1.4, Figure 1.9}

| | physical data series | | biological data series | |
|---|---|---|---|---|
| | number of significant data series | % consistent with warming | number of significant data series | % consistent with warming |
| Terrestrial systems | 764 | 94 | 28,586 | 90 |
| Marine and freshwater systems | 1 | 100 | 85 | 99 |

## 1.4 Some aspects of climate have not been observed to change

Some aspects of climate appear not to have changed, and for some data inadequacies mean that it cannot be determined if they are changing. Antarctic sea ice extent shows inter-annual variability and localised changes but no statistically significant average multi-decadal trend, consistent with the lack of rise in near-surface atmospheric temperatures averaged across the continent. There is insufficient evidence to determine whether trends exist in some other variables, for example the meridional overturning circulation of the global ocean or small-scale phenomena such as tornadoes, hail, lightning and dust-storms. There is no clear trend in the annual numbers of tropical cyclones. {WGI 3.2, 3.8, 4.4, 5.3, SPM}

# Topic 2 – Causes of change
**(31 August 2007)**

This topic considers both natural and anthropogenic drivers of climate change including the chain from greenhouse gas (GHG) emissions to atmospheric concentrations to radiative forcing[3] to climate responses and effects.

## 2.1 Emissions of long lived GHGs

The radiative forcing of the climate system is dominated by the long-lived GHGs, and this section considers those whose emissions are covered by the UNFCCC.

**Global total anthropogenic GHG emissions have grown by 70% between 1970 and 2004, from 28.7 to 49 $GtCO_2$-equivalent (weighted by their 100-year Global Warming Potentials). {WGIII 1.3, SPM}**

$CO_2$ emissions have grown between 1970 and 2004 by about 80%, from 21 to 38 Gt per annum, and represented 77% of total anthropogenic GHG emissions in 2004 (Figure 2.1). The rate of growth of $CO_2$-eq emissions was much higher during the recent ten year period of 1995-2004 (0.92 $GtCO_2$-eq per year) than during the previous period of 1970-1994 (0.43 $GtCO_2$-eq per year). {WGIII 1.3, TS.1, SPM}

**Carbon dioxide-equivalent ($CO_2$-eq) emissions and concentrations**

GHGs differ in their warming influence (radiative forcing) on the global climate system due to their radiative properties and their different lifetimes in the atmosphere. These warming influences may be expressed through a common metric based on the radiative forcing of $CO_2$.

- **$CO_2$-equivalent emission** is the amount of $CO_2$ emission that would cause the same time-integrated radiative forcing, over a given time horizon, as an emitted amount of a long-lived GHG or a mixture of GHGs. The equivalent $CO_2$ emission is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP) for the given time horizon.[4] For a mix of GHGs it is obtained by summing the equivalent $CO_2$ emissions of each gas. Equivalent $CO_2$ emission is a standard and useful metric for comparing emissions of different GHGs but does not imply the same climate change responses (see WGI 2.10).
- **$CO_2$-equivalent concentration** is the concentration of $CO_2$ that would cause the same amount of radiative forcing as a given mixture of $CO_2$ and other forcing components.

[3] *Radiative forcing* is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. In this report radiative forcing values are for changes relative to pre-industrial conditions defined at 1750 and are expressed in watts per square metre ($W/m^2$).

[4] This report uses 100-year GWPs and numerical values consistent with the UNFCCC.

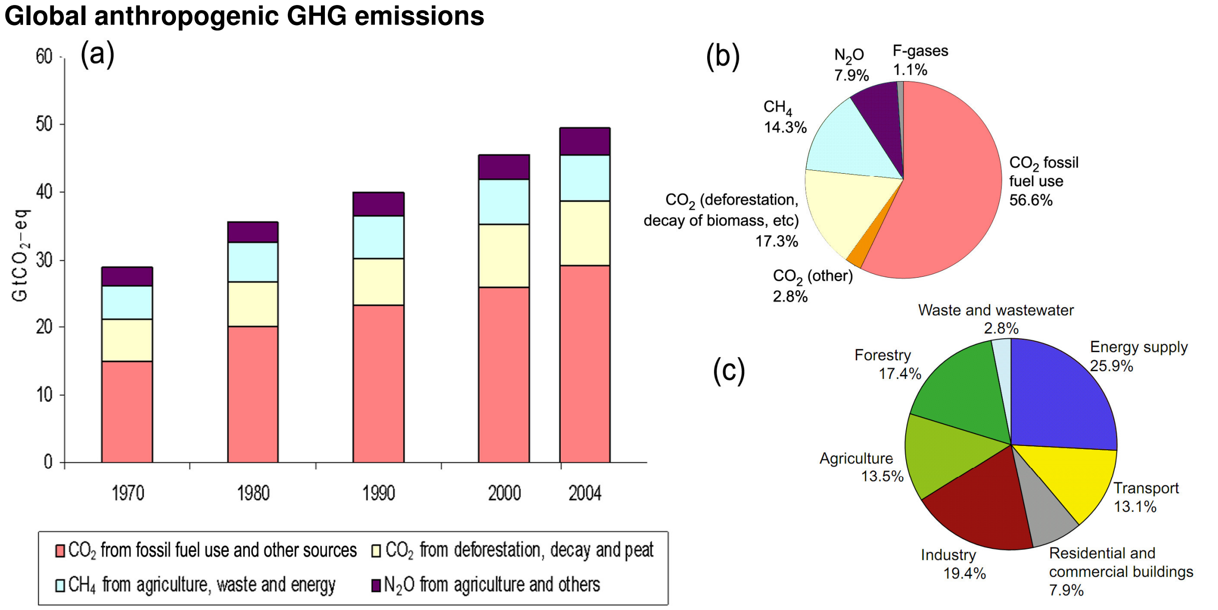



**Figure 2.1.** (a) Global emissions of principal anthropogenic GHGs between 1970 and 2004. (b) Share of different anthropogenic GHGs in total emissions in 2004 in $CO_2$-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in $CO_2$-eq (forestry includes deforestation). {WGIII Figures TS 1a, TS 1b, TS 2b}

The largest growth in GHG emissions between 1970 and 2004 has come from energy supply, transport and industry, while residential and commercial buildings, forestry (including deforestation) and agriculture sectors have been growing at a lower rate. The sectoral sources of GHGs in 2004 are considered in Figure 2.1c. { WGIII 1.3, SPM}

The effect on global emissions of the decrease in global energy intensity (-33%), during 1970 to 2004 has been smaller than the combined effect of global income growth (77%) and global population growth (69%); both drivers of increasing energy-related $CO_2$ emissions. The long-term trend of a declining carbon intensity of energy supply reversed after 2000. {WGIII 1.3, Figure SPM 2, SPM}

Differences in terms of per capita income, per capita emissions, and energy intensity among countries remain significant. In 2004, UNFCCC Annex I countries held a 20% share in world population, produced 57% of world Gross Domestic Product based on Purchasing Power Parity ($GDP_{ppp}$), and accounted for 46% of global GHG emissions (Figure 2.2). {WGIII 1.3, SPM}

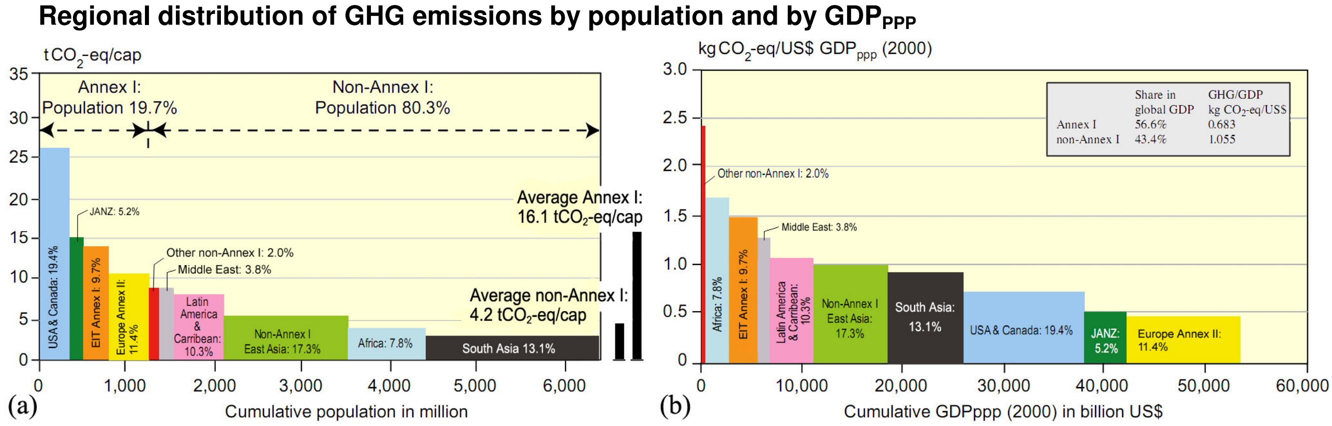



**Figure 2.2.** (a) Distribution of regional per capita GHG emissions according to the population of different country groupings in 2004 (see appendix for definitions of country groupings). (b) Distribution of regional GHG emissions per US$ of $GDP_{PPP}$ over the GDP of different country groupings in 2004. {WGIII Figures SPM 3a, b}

## 2.2 Drivers of climate change

Changes in the atmospheric concentration of GHGs and aerosols, in solar radiation and in land surface properties are drivers of climate change. They affect the absorption, scattering and emission of radiation within the atmosphere and at the Earth's surface. The resulting positive or negative changes in energy balance due to these factors are expressed as radiative forcing[3], which is used to compare warming or cooling influences on global climate (Figure 2.4). {WGI TS.2}

Human activities result in emissions of four long-lived GHGs: $CO_2$, methane ($CH_4$), nitrous oxide ($N_2O$) and halocarbons (a group of gases containing fluorine, chlorine or bromine). Atmospheric concentrations of GHGs increase when emissions are larger than natural removal processes.

**Global atmospheric concentrations of $CO_2$, $CH_4$ and $N_2O$ 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 (Figure 2.3). The atmospheric concentration of $CO_2$ in 2005 exceeds by far the natural range over the last 650,000 years. The global increases in $CO_2$ concentrations are due primarily to fossil fuel use and land-use change, while those of $CH_4$ and $N_2O$ are due primarily to agriculture. {WGI 2.3, 7.3, SPM}**

The global atmospheric concentration of $CO_2$ increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005. The annual $CO_2$ concentration growth-rate was larger during the last 10 years (1995-2005 average: 1.9 ppm per year), than it has been since the beginning of continuous direct atmospheric measurements (1960-2005 average: 1.4 ppm per year) although there is year-to-year variability in growth rates. {WGI 2.3, 7.3, SPM; WGIII 1.3}

The global atmospheric concentration of $CH_4$ has increased from a pre-industrial value of about 715 ppb to 1732 ppb in the early 1990s, and was 1774 ppb in 2005. Growth rates have declined since the early 1990s. {WGI 2.3, 7.4, SPM}

The global atmospheric $N_2O$ concentration increased from a pre-industrial value of about 270 ppb to 319 ppb in 2005. {WGI 2.3, 7.4, SPM}

Many halocarbons (including hydrofluorocarbons) have increased from a near zero pre-industrial background concentration, primarily due to human activities. {WGI 2.3, SPM; SROC SPM }

**Changes in GHGs from ice core and modern data**

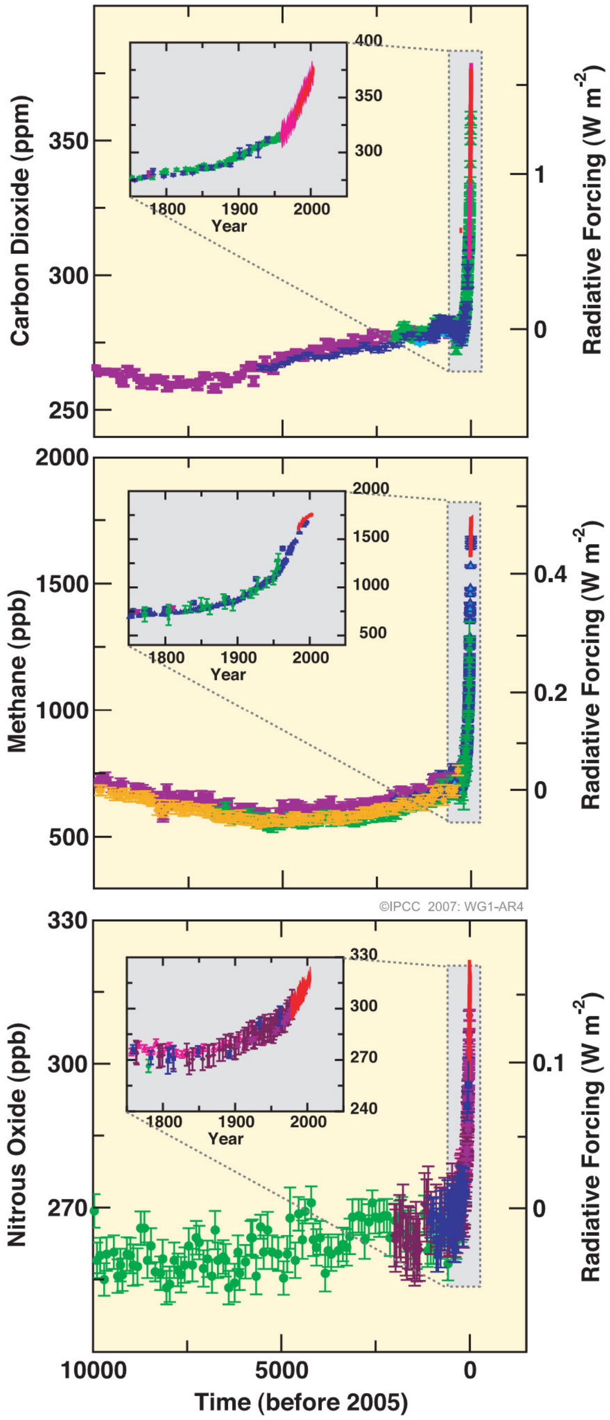



**Figure 2.3.** Atmospheric concentrations of $CO_2$, $CH_4$ and $N_2O$ over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings relative to 1750 are shown on the right hand axes of the large panels. {WGI Figure SPM.1}

**There is *very high confidence* that the globally averaged net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W/m$^2$ (Figure 2.4). {WGI 2.3, 6.5, 2.9, SPM}**

The combined radiative forcing due to increases in $CO_2$, $CH_4$ and $N_2O$ is +2.3 [+2.1 to +2.5] W/m$^2$, and its rate of increase during the industrial era is *very likely* to have been unprecedented in more than 10,000 years (Figures 2.3 and 2.4). The $CO_2$ radiative forcing increased by 20% from 1995 to 2005, the largest change for any decade in at least the last 200 years. {WGI 2.3, 6.4, SPM}

Anthropogenic contributions to aerosols (primarily sulphate, organic carbon, black carbon, nitrate and dust) together produce a cooling effect, with a total direct radiative forcing of -0.5 [-0.9 to -0.1] W/m$^2$ and an indirect cloud albedo forcing of -0.7 [-1.8 to -0.3] W/m$^2$. Aerosols also influence cloud lifetime and precipitation but these are considered to be part of the climate response rather than radiative forcings. {WGI 2.4, 2.9, 7.5, SPM}

Changes in solar irradiance since 1750 are estimated to have caused a radiative forcing of +0.12 [+0.06 to +0.30] W/m$^2$, which is less than half the estimate given in the TAR. {WGI 2.7, SPM}

**Radiative forcing components**

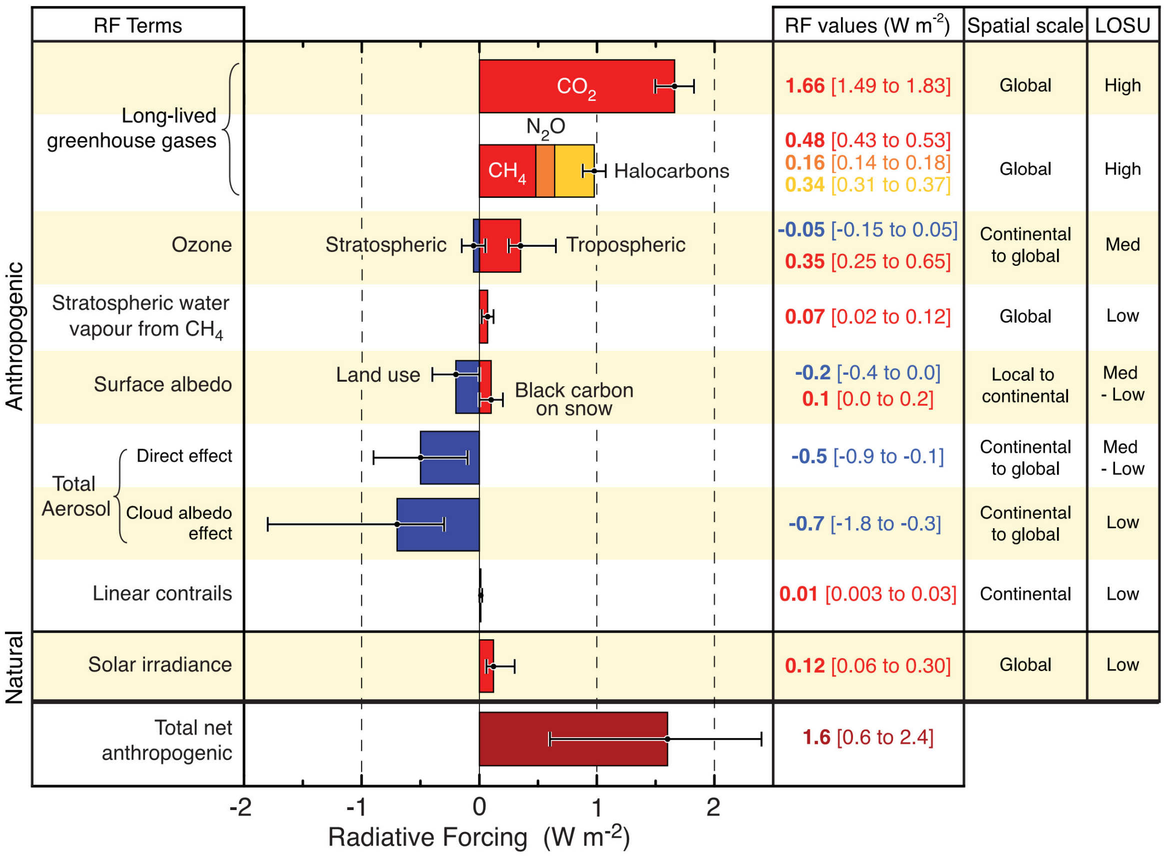



**Figure 2.4.** Global-average radiative forcing (RF) in 2005 (best estimates and 5-95% uncertainty ranges) with respect to 1750 for $CO_2$, $CH_4$, $N_2O$ and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). Aerosols from explosive volcanic eruptions contribute an additional episodic cooling term for a few years following an eruption. {WGI Figure SPM.2}

## 2.3 Climate sensitivity and feedbacks

The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is defined as the equilibrium global average surface warming following a doubling of $CO_2$ concentration. It is *likely* to be in the range 2 to 4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values. {WGI 8.6, 9.6, Box 10.2, SPM}

Feedbacks can amplify or dampen the response to a given forcing. Direct emission of water vapour (a greenhouse gas) by human activities makes a negligible contribution to radiative forcing. However, as global average temperature increases, tropospheric water vapour concentrations increase and this represents a key positive feedback but not a forcing of climate change. Water vapour changes represent the largest feedback affecting equilibrium climate sensitivity and are now better understood than in the TAR. Cloud feedbacks remain the largest source of uncertainty. Spatial patterns of climate response are largely controlled by climate processes and feedbacks. For example, sea-ice albedo feedbacks tend to enhance the high latitude response. {WGI 2.8, 8.6, 9.2, TS 2.1.3, 2.5, SPM}

Warming tends to reduce terrestrial ecosystem and ocean uptake of atmospheric $CO_2$, increasing the fraction of anthropogenic emissions that remains in the atmosphere. This positive carbon cycle feedback leads to larger atmospheric $CO_2$ increases and greater climate change for a given emissions scenario, but the strength of this feedback effect varies markedly among models. {WGI 7.3, TS 5.4, SPM; WGII 4.4}

## 2.4 Attribution of climate change

Attribution evaluates whether observed changes are quantitatively consistent with the expected response to external forcings (e.g. changes in solar irradiance or anthropogenic GHGs) and inconsistent with alternative physically plausible explanations. {WGI TS.4, SPM}

**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.[5] This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in GHG concentrations" (Figure 2.5). {WGI 9.4, SPM}**

The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is *extremely unlikely* that global climate change of the past 50 years can be explained without external forcing, and *very likely* that it is not due to known natural causes alone. During this time, the sum of solar and volcanic forcings would *likely* have produced cooling, not warming. Warming of the climate system has been detected in changes in surface and atmospheric temperatures, and in temperatures of the upper several hundred metres of the ocean. The observed pattern of tropospheric warming and stratospheric cooling is *very likely* due to the combined influences of GHG increases and stratospheric

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

ozone depletion. It is *likely* that increases in GHG concentrations alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place. {WGI 2.9, 3.2, 3.4, 4.8, 5.2, 7.5, 9.4, 9.5, 9.7, TS 4.1, SPM}

**Global and continental temperature change**

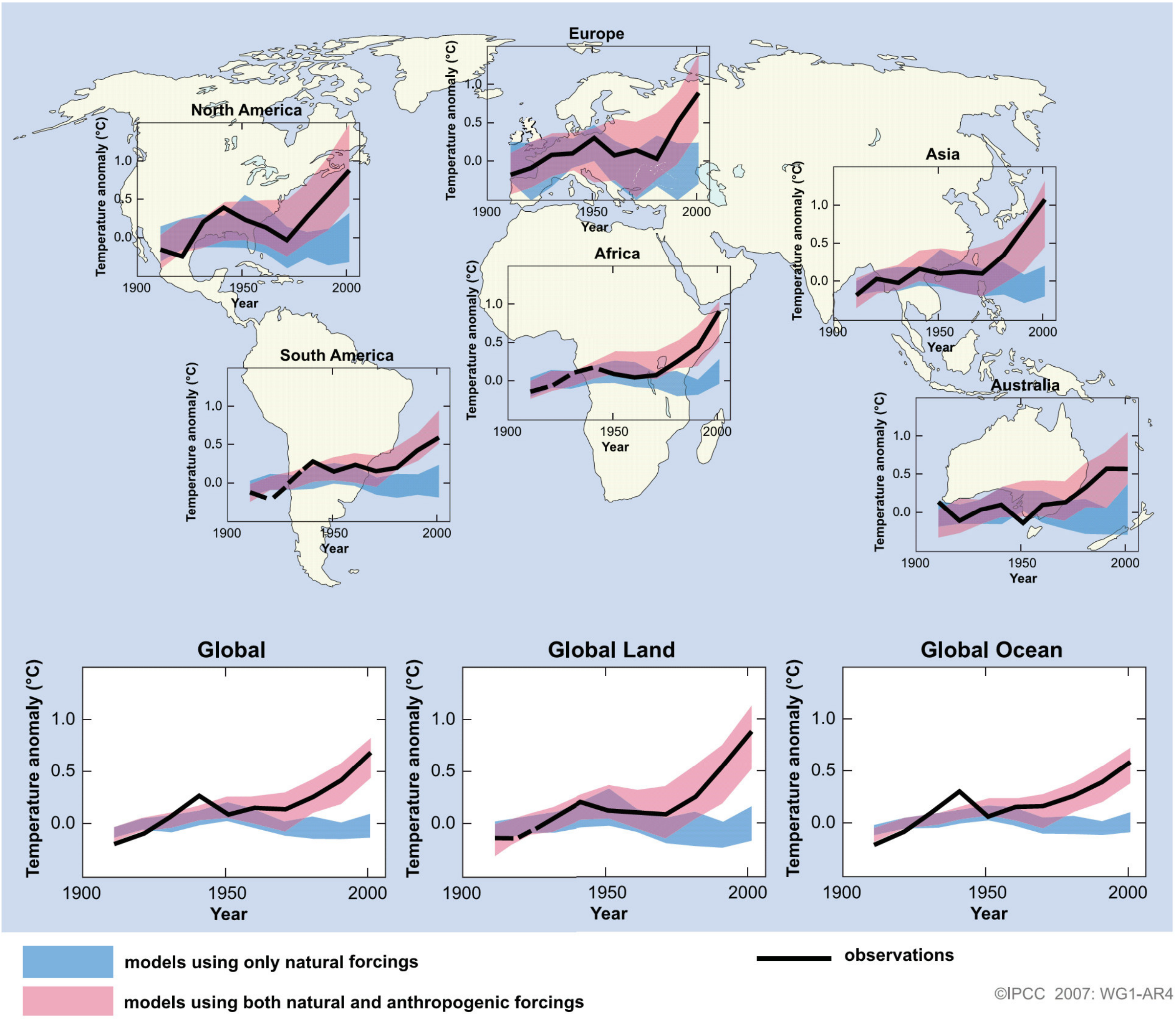



**Figure 2.5.** Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the 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. {WGI Figure SPM.4}

**It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica[6] (Figure 2.5). {WGI 3.2, 9.4, SPM}**

The observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are only simulated by models that include anthropogenic forcing.

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

No coupled global climate model that has used natural forcing only, has reproduced the continental mean warming trends in individual continents (except Antarctica[6]) over the second half of the 20th century. {WGI 3.2, 9.4, TS 4.2, SPM}

Difficulties remain in reliably simulating and attributing observed temperature changes at smaller scales. On these scales, natural climate variability is relatively larger making it harder to distinguish changes expected due to external forcings. Uncertainties in local forcings, such as due to aerosols and land-use change, and feedbacks also make it difficult to estimate the contribution of GHG increases to observed small-scale temperature changes. {WGI 8.3, 9.4, SPM}

**Discernible human influences extend to other aspects of climate, including temperature extremes and wind patterns. {WGI 9.4, 9.5, SPM}**

Temperatures of the most extreme hot nights, cold nights and cold days are *likely* to have increased due to anthropogenic forcing. It is *more likely than not* that anthropogenic forcing has increased the risk of heat waves. Anthropogenic forcing is *likely* to have contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns in both hemispheres. However, the observed changes in the Northern Hemisphere circulation are larger than simulated in response to 20th century forcing change. {WGI 3.5, 3.6, 9.4, 9.5, 10.3, SPM}

It is *very likely* that the response to anthropogenic forcing contributed to sea level rise during the latter half of the 20th century. There is also some evidence of the impact of human climatic influence on the hydrological cycle, including the observed large-scale patterns of changes in land precipitation over the 20th century. It is *more likely than not* that human influence has contributed to a global trend towards increases in drought in the second half of the 20th century. {WGI 3.3, 5.5, 9.5, TS 4.1, TS.4.3}

**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. {WGII 1.4}**

A synthesis of studies strongly demonstrates that the spatial agreement between regions of significant warming across the globe and the locations of significant observed changes in many natural systems consistent with warming is *very unlikely* to be due solely to natural variability of temperatures or natural variability of the systems. Modelling studies have linked some specific responses in physical and biological systems to anthropogenic warming, but only a few such studies have been performed. Taken together with evidence of significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica[6], it is *likely* that anthropogenic warming over the last three decades has had a discernible influence on many natural systems. {WGI 3.2, 9.4, SPM; WGII 1.4, SPM}

Limitations and gaps prevent more complete attribution of the causes of observed natural system responses to anthropogenic warming. The available analyses are limited in the number of systems, length of records and locations considered. Natural temperature variability is larger at the regional than the global scale, thus affecting identification of changes to external forcing. At the regional scale, other factors (such as land-use change, pollution and invasive species) are influential. {WGII 1.2, 1.3, 1.4, SPM}

# Topic 3 – Climate change and its impacts in the near and long term under different scenarios
**(31 August 2007)**

## 3.1 Emission scenarios

**There is *high agreement* and *much evidence*[7] that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. Baseline emissions scenarios published since the IPCC Special Report on Emissions Scenarios (SRES) are comparable in range to those presented in SRES (Figure 3.1).[8] {WGIII 1.3, 3.2, SPM}**

**SRES scenarios**

SRES refers to the scenarios described in the IPCC Special Report on Emission Scenarios (IPCC, 2000). The SRES scenarios are grouped into four scenario families (A1, A2, B1, and B2) that explore alternative development pathways in the absence of climate policies, covering a wide range of demographic, economic, and technological driving forces and resulting GHG emissions. The emission projections are widely used in the assessments of future climate change, and their underlying assumptions with respect to socio-economic, demographic and technological change serve as inputs to many recent climate change vulnerability and impact assessments. {WGI 10.1; WGII 2.4; WGIII SPM, TS.1}

The A1 storyline describes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T), and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change. No likelihood has been attached to any of the SRES scenarios. {WGIII SPM, TS.1}

The SRES (non-mitigation) scenarios project an increase of baseline global GHG emissions by a range of 9.7 $GtCO_2$-eq to 36.7 $GtCO_2$-eq (25-90%) between 2000 and 2030. In these scenarios, fossil fuels are projected to maintain their dominant position in the global energy mix to 2030 and beyond. Hence $CO_2$ emissions between 2000 and 2030 from energy use are projected to grow 40 to 110% over that period. {WGIII 1.3, SPM}

Studies since SRES have used lower values for some drivers for emissions, notably population projections. However, for those studies incorporating these new population

[7] Agreement/evidence statements in italics represent calibrated expressions of uncertainty and confidence. See Box 'Treatment of uncertainty' in the Introduction for an explanation of these terms.

[8] Baseline scenarios do not include additional climate policy above current ones; more recent studies differ with respect to UNFCCC and Kyoto inclusion.

projections, changes in other drivers, such as economic growth, result in little change in overall emission levels. Economic growth projections for Africa, Latin America and the Middle East to 2030 in post-SRES baseline scenarios are lower than in SRES, but this has only minor effects on global economic growth and overall emissions. Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulphur dioxide, black carbon, and organic carbon has improved. Generally, they are projected to be lower than reported in SRES. Available studies indicate that the choice of exchange rate for GDP (MER or PPP) does not appreciably affect the projected emissions, when used consistently. The differences, if any, are small compared to the uncertainties caused by assumptions on other parameters in the scenarios, e.g. technological change. {WGIII 3.2, TS.3, SPM}

While these post-SRES emissions scenarios have not been widely used for projections by either the climate modelling or impacts communities, they are largely consistent with the possible future development pathways and corresponding GHG emission ranges in the absence of climate policies presented in SRES. {WGIII 3.2}

**Scenarios for GHG emissions from 2000 to 2100 in the absence of climate policies**

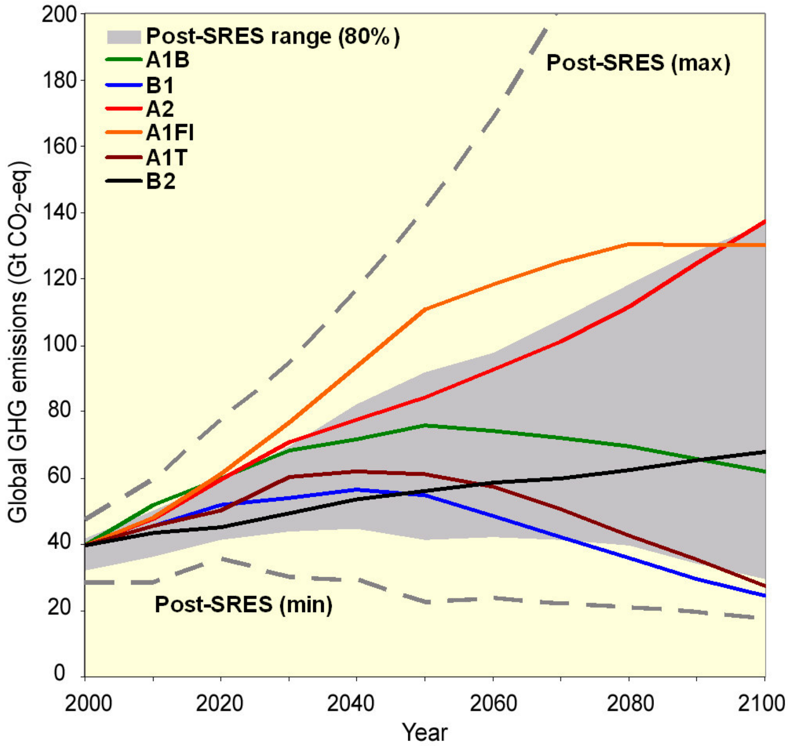



**Figure 3.1**. Global GHG emissions (in $CO_2$-eq) in the absence of climate policies: six illustrative SRES marker scenarios (coloured lines) and 80[th] percentile range of recent post-SRES baseline scenarios (grey shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include $CO_2$, $CH_4$, $N_2O$, and F-gases. {WGIII 1.3, 3.2, Figure SPM 4}

## 3.2 Projections of future changes in climate

**Since the IPCC's first report in 1990, assessed projections have suggested global averaged temperature increases between about 0.15 and 0.3°C per decade from 1990 to 2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections. For the next two decades a warming**

**of about 0.2°C per decade is projected for a range of SRES emission scenarios. Beyond the next few decades, climate projections increasingly depend on future GHG emission scenarios (Figure 3.2). {WGI 1.2, 3.2, 9.4, 10.3, 10.7; WGIII 3.2}**

### *3.2.1 21st century global changes*

**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. {WGI 10.3}**

Advances in climate change modelling now enable best estimates and *likely* assessed uncertainty ranges to be given for projected warming for different emission scenarios. Table 3.1 shows best estimates and *likely* ranges for global average surface air warming for the six SRES emissions marker scenarios (including climate-carbon cycle feedbacks). {WGI 10.5}

Although these projections are broadly consistent with the span quoted in the TAR (1.4 to 5.8°C), they are not directly comparable[9]. Assessed upper ranges for temperature projections are larger than in the TAR mainly because the broader range of models now available suggests stronger climate-carbon cycle feedbacks. A range of climate models project that by 2100, carbon cycle feedbacks could add between 20 and 220 ppm to atmospheric $CO_2$ concentration and between 0.1 and 1.5°C to temperature rise. Carbon feedbacks are discussed in topic 2.3. {WGI 7.3, 10.5, SPM}

**Table 3.1.** Projected global average surface warming and sea level rise at the end of the 21st century. {WGI 10.5, 10.6, Table 10.7, Table SPM.3}

| | 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) These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity, and a large number of Atmosphere-Ocean General Circulation Models (AOGCMs).
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.

9 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 3.1 if it had treated uncertainties in the same way.

Because understanding of some important effects that 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, model-based projections of global average sea level rise at the end of the 21st century (2090-2099) are shown in Table 3.1. For each scenario, the midpoint of the range in Table 3.1 is within 10% of the TAR model average for 2090-2099. The ranges are narrower than in the TAR mainly because of improved information about some uncertainties in the projected contributions. The sea level projections do not include uncertainties in climate-carbon cycle feedbacks nor do they include the full effects of changes in ice sheet flow, because a basis in published literature is lacking. The projections 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. If this contribution were to grow linearly with global average temperature change, the upper ranges of sea level rise for SRES scenarios shown in Table 3.1 would increase by 0.1 m to 0.2 m. Larger values for sea level rise cannot be excluded. {WGI 10.6, SPM}

### *3.2.2 21st century regional changes*

**The projected patterns of climate change are not uniform across the globe. 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. {WGI 8.2, 8.3, 8.4, 8.5, 9.4, 9.5, 10.3, 11.1}**

Projected warming in the 21st century shows scenario-independent geographical patterns similar to those observed over the past several decades. Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean (near Antarctica) and northern North Atlantic (Figure 3.2 right panels). {WGI 10.3, SPM}

**Atmosphere-Ocean General Circulation Model projections of surface warming**

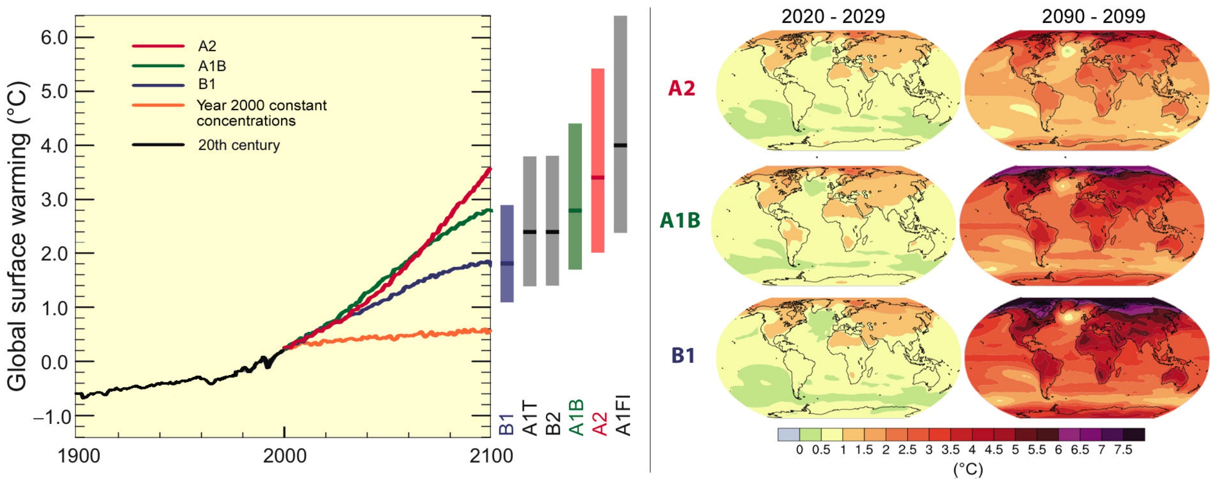



**Figure 3.2. Left panel:** Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for the experiment where concentrations were held constant at year 2000 values. The bars in the middle of the figure indicate the best estimate (solid line within each bar) and the *likely* range assessed for the six SRES marker scenarios at 2090-2999 relative to 1980-1999. The assessment of the best estimate and *likely* ranges in the bars includes the Atmosphere-Ocean General Circulation Models (AOGCMs) in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. **Right panels:** Projected surface temperature changes for the early and late 21st century relative to the period 1980-1999. The panels show the multi-AOGCM average projections for the A2 (top), A1B (middle) and B1 (bottom) SRES scenarios averaged over decades 2020-2029 (left) and 2090-2099 (right). {WGI 10.4, 10.8; Figures 10.28, 10.29, SPM}

Snow cover area is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. Sea ice is projected to shrink in both the Arctic and Antarctic under all SRES scenarios. In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century. {WGI 10.3, 10.6, SPM; WGII 15.3.4}

It is *very likely* that hot extremes, heat waves, and heavy precipitation events will become more frequent. {SYR Table 3.2; WGI 10.3, SPM}

Based on a range of models, it is *likely* that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea-surface temperatures. There is less confidence in projections of a global decrease in numbers of tropical cyclones. The apparent increase in the proportion of very intense storms since 1970 in some regions is much larger than simulated by current models for that period. {WGI 3.8, 9.5, 10.3, SPM}

Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation, and temperature patterns, continuing the broad pattern of observed trends over the last half-century. {WGI 3.6, 10.3, SPM}

Since the TAR there is an improving understanding of projected patterns of precipitation. Increases in the amount of precipitation are *very likely* in high-latitudes, while decreases are *likely* in most subtropical land regions (by as much as about 20% in the A1B scenario in 2100, Figure 3.3), continuing observed patterns in recent trends. {WGI 3.3, 8.3, 9.5, 10.3, 11.2-11.9, SPM}

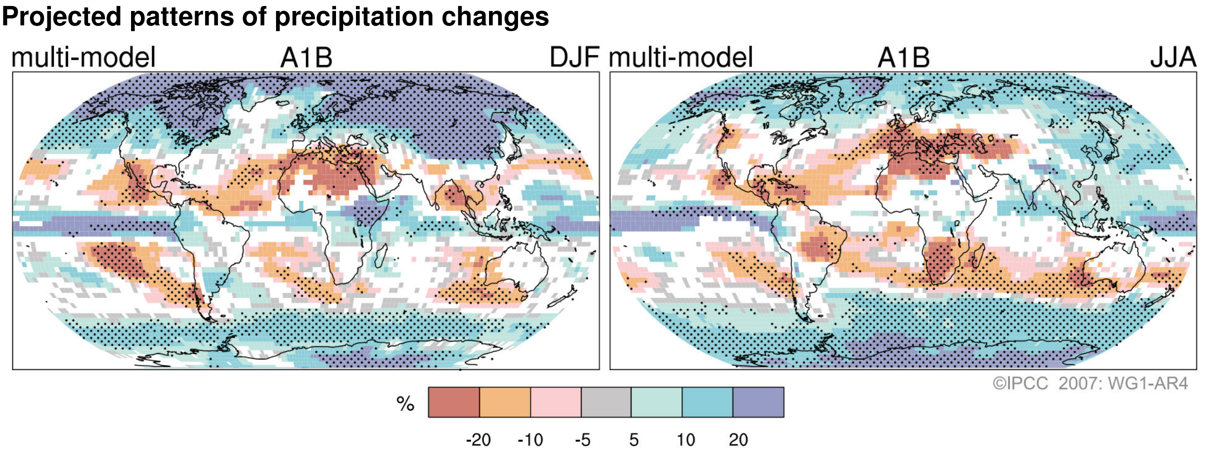



**Figure 3.3.** Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {WGI Figure 10.9, SPM}

### *3.2.3 Beyond 21st century changes*

**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. {WGI 10.4, 10.5, 10.7, SPM}**

If radiative forcing were to be stabilised, keeping all the radiative forcing agents constant at B1 or A1B levels in 2100, model experiments show that a further increase in global average temperature of about 0.5°C would still be expected by 2200. In addition, thermal expansion alone would lead to 0.3 to 0.8 m of sea level rise by 2300 (relative to 1980-1999). Thermal expansion would continue for many centuries, due to the time required to transport heat into the deep ocean. {WGI 10.7, SPM}

Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest ice mass losses increase with temperature more rapidly than gains due to increased precipitation and that the surface mass balance becomes negative (net ice loss) at a global average warming (relative to pre-industrial values) in excess of 1.9 to 4.6°C. If a negative surface mass balance were sustained for millennia, that would lead to virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7 m. The corresponding future temperatures in Greenland (1.9 to 4.6°C global) 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. {WGI 6.4, 10.7, SPM}

Dynamical processes related to ice flow – which are not included in current models but suggested by recent observations – could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude. {WGI 4.6, 10.7, SPM}

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. {WGI 10.7, SPM}

Both past and future anthropogenic $CO_2$ emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the time scales required for the removal of this gas from the atmosphere. {WGI 7.3, 10.3, Figure 7.12, Figure 10.35, SPM}

## 3.3 Impacts of future climate changes

The following is a selection of key findings[10] regarding the impacts of climate change on systems, sectors and regions, as well as some findings on vulnerability[11], for the range of climate changes projected over the 21st century. {WGII SPM}

The magnitude and timing of projected impacts depend on the amount and timing of climate change, the development pathway, i.e., projected social and economic changes, and in some cases, the capacity to adapt. {WGII 2.4, 19.4.1, SPM}

[10] Criteria of choice: magnitude and timing of impact, confidence in the assessment, representative coverage of the system, sector and region.

[11] Vulnerability to climate change is the degree to which systems are susceptible to, and unable to cope with, adverse impacts.

In the selected examples below, quantitative information is available and impacts are judged to be relevant for people and the environment, in the absence of adaptation. Unless otherwise stated, the confidence level in the projections is *high*. Global average temperature increases are given relative to 1980-1999. Additional information on impacts can be found in the WG II report. {WGII SPM}

### *3.3.1 Impacts on systems and sectors*

**Ecosystems:**

- The resilience of many ecosystems is *likely* to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g. flooding, drought, wildfire, insects, ocean acidification), and other global change drivers (e.g. land-use change, pollution, fragmentation of natural systems, over-exploitation of resources). {WGII 4.1-4.6, SPM}
- Over the course of this century, net carbon uptake by terrestrial ecosystems is likely to peak before mid-century and then weaken or even reverse[12], thus amplifying climate change. {WGII 4.ES, Figure 4.2, SPM}
- For increases in global average temperature exceeding 1.5-2.5°C and in concomitant atmospheric $CO_2$ concentrations, there are projected to be major changes in ecosystem structure and function, species' ecological interactions, and shifts in species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services, e.g. water and food supply. {WGII Box TS.6, 4.4, SPM}
- The progressive acidification of oceans due to increasing atmospheric $CO_2$ is expected to have negative impacts on marine shell-forming organisms (e.g. corals) and their dependent species (*medium confidence*). {WGI 5.4, Box 7.3, 10.4, SPM; WGII Box 4.4, 6.4, TS.4.1, SPM}

**Food:**

- Crop productivity is projected to increase slightly at mid- to high latitudes for local mean temperature increases of up to 1-3°C depending on the crop, and then decrease beyond that in some regions (*medium confidence*). {WGII 5.4, SPM}
- At lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1-2°C), which would increase the risk of hunger (*medium confidence*). {WGII 5.4, SPM}
- Globally, the potential for food production is projected to increase with increases in local average temperature over a range of 1-3°C, but above this it is projected to decrease (*medium confidence*). {WGII 5.4, 5.5, SPM}

**Coasts:**

- Coasts are projected to be exposed to increasing risks, including coastal erosion, due to climate change and sea level rise. The effect will be exacerbated by increasing human-induced pressures on coastal areas (*very high confidence*). {WGII 6.3, 6.4, SPM}
- By the 2080s, many millions more people than today are projected to experience floods every year due to sea level rise. The numbers affected will be largest in the

[12] Assuming continued GHG emissions at or above current rates and other global changes including land-use changes.

densely-populated and low-lying areas megadeltas of Asia and Africa while small islands are especially vulnerable. (*very high confidence*) {WGII 6.4, 6.5, Table 6.11, SPM}

**Industry, settlements and society:**

- The most vulnerable industries, settlements and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources, and those in areas prone to extreme weather events, especially where rapid urbanisation is occurring. {WGII 7.1, 7.3, 7.4, 7.5, SPM}
- Poor communities can be especially vulnerable, in particular those concentrated in high-risk areas. {WGII 7.2, 7.4, 5.4, SPM}

**Health:**

- The health status of millions of people is projected to be affected through, for example, increases in malnutrition; increased deaths, diseases and injury due to extremes; increased burden of diarrhoeal diseases; increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone in urban areas related to climate change; and the altered spatial distribution of some infectious diseases. {WGI 7.4, Box 7.4; WGII 8.4, 8.ES, 8.2, SPM}
- Climate change is projected to bring some benefits in temperate areas, such as fewer deaths from cold exposure, and some mixed effects such as changes in range and transmission potential of malaria in Africa. Overall it is expected that benefits will be outweighed by the negative health effects of rising temperatures, especially in developing countries. {WGII 8.4, SPM}
- Critically important will be factors that directly shape the health of populations such as education, health care, public health initiatives, and infrastructure and economic development. {WGII 8.3, SPM}

**Water:**

- Water impacts are key for all sectors and regions. These are discussed below in the Box 'Climate change and water'.

**Climate change and water**

Climate change is expected to exacerbate current stresses on water resources from population growth and economic and land-use change, including urbanisation. On a regional scale, mountain snow pack, glaciers and small ice caps play a crucial role in fresh water availability. Widespread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21$^{st}$ century, reducing water availability, hydropower potential, and changing seasonality of flows in regions supplied by meltwater from major mountain ranges (e.g. Hindu-Kush, Himalaya, Andes), where more than one-sixth of the world population currently lives. {WGI 4.1, 4.5; WGII 3.3, 3.4, 3.5}

Changes in precipitation (Figure 3.3) and temperature (Figure 3.2) lead to changes in runoff (Figure 3.4) and water availability. Runoff is projected to increase by 10-40% by mid-century at higher latitudes and in some wet tropical areas, including populous areas in East and South-East Asia, and decrease by 10-30% over some dry regions at mid-latitudes and dry tropics (Figure 3.3), due to decreases in rainfall and higher rates of evapotranspiration. Drought-affected areas are projected to increase in extent, with the potential for adverse impacts on multiple sectors, e.g. agriculture, water supply, energy production, and health. Regionally, large increases in irrigation water demand as a result of climate changes are projected. {WGI 10.3, 11.2-11.9; WGII 3.4, 3.5, SPM}

The beneficial impacts of increased annual runoff in some areas are likely to be tempered by negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality and flood risk. {WGII TS.4.1}

Available research suggests a significant future increase in heavy rainfall events in many regions, including some in which the mean rainfall is projected to decrease. The resulting increased flood risk poses challenges to society, physical infrastructure and water quality. It is *likely* that up to 20% of the world population will live in areas where river flood potential could increase by the 2080s. Increases in the frequency and severity of floods and droughts are projected to adversely affect sustainable development. {WGI 11.2-11.9; WGII 3.2, 3.3, 3.4}

**Projected relative changes in runoff by the end of the 21st century**

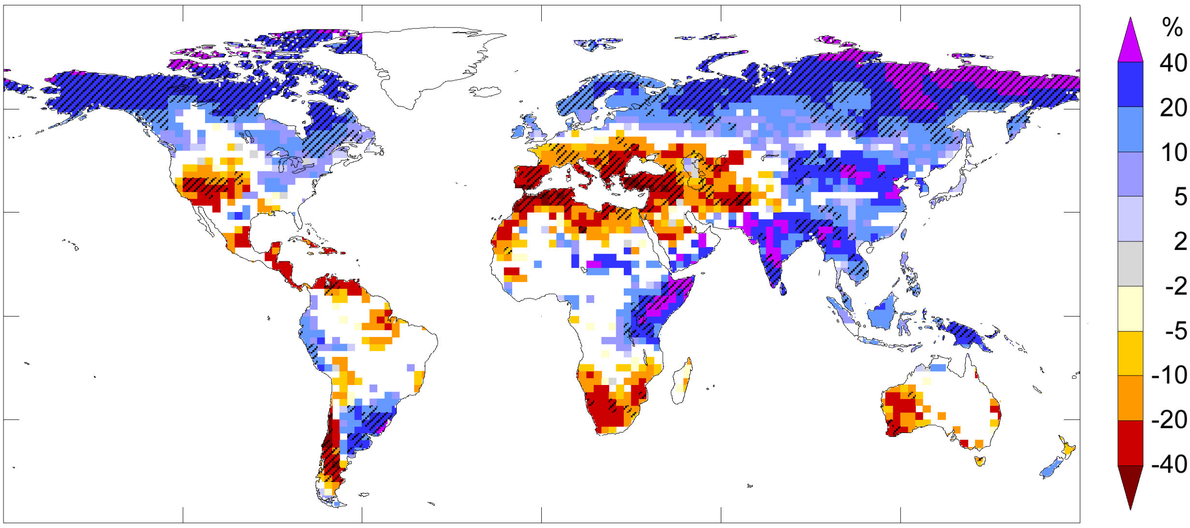
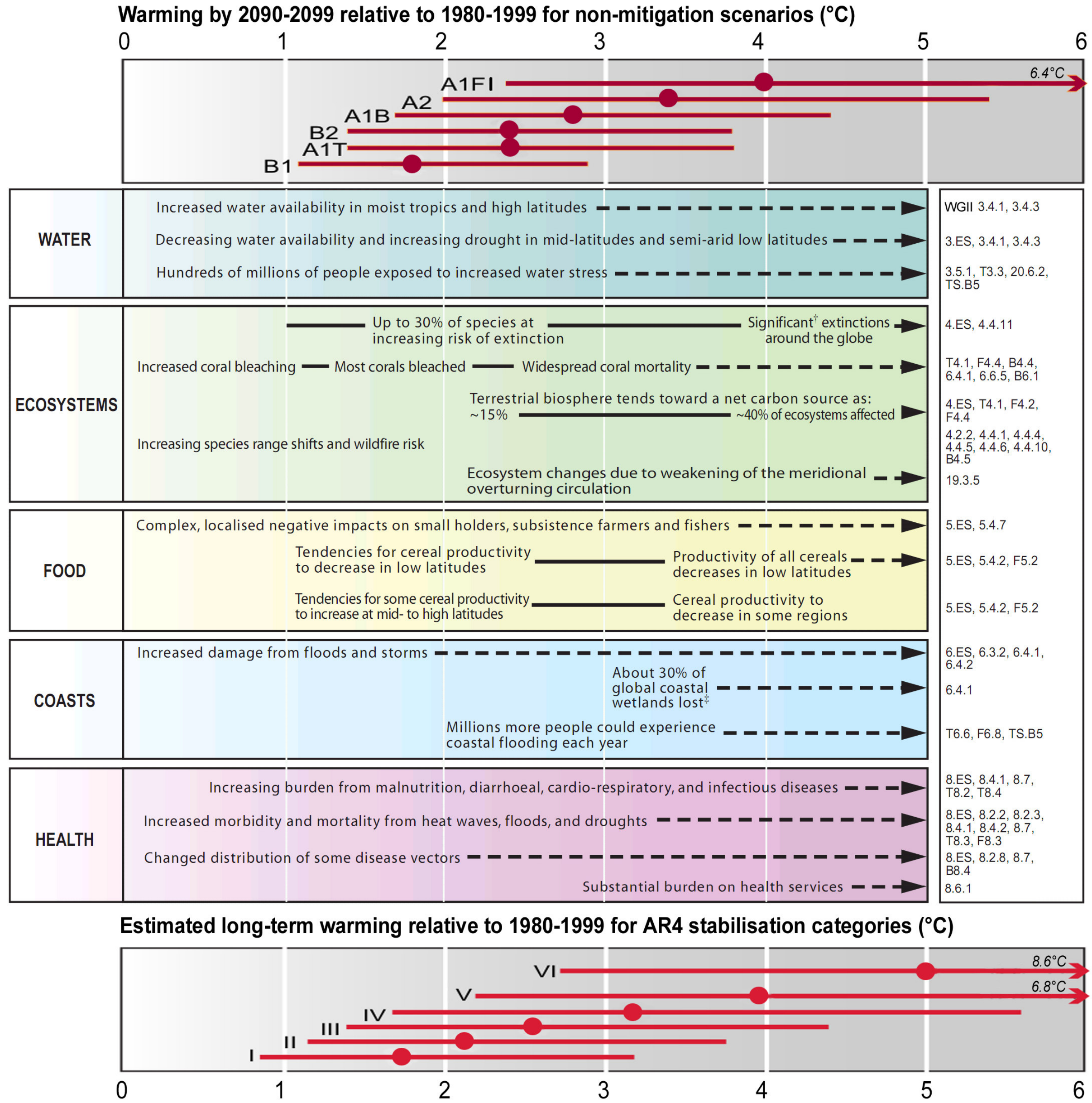



**Figure 3.4.** Relative changes in annual runoff (in %) for the period 2090-2099, relative to 1980-1999. Values are derived from a multi-model ensemble and are based on the SRES A1B scenario. White areas are where less than 66% of the 12 considered models agree on the sign of change and stippled areas are where more than 90% models agree on the sign of change. The global map of annual runoff illustrates a broad future but it is not intended to refer to smaller temporal and spatial scales. In some areas with projected increases in annual runoff, different seasonal effects are expected, such as increased wet season runoff and decreased dry season runoff. Hence dry season problems would increase in severity if the extra water in the wet season is not stored. Many national studies have been based on results of one or two climate models, which can be considerably different from the median of a multi-model ensemble. {WGII Figure 3.4, adjusted to match the assumptions of Figure SYR 3.3; WGII 3.3.1, 3.4.1, 3.5.1}

**Magnitudes of impact can now be estimated more systematically for a range of possible increases in global average temperature. {WGII SPM}**

Examples of this new information are presented in Figure 3.5. Depending on circumstances, some of the impacts shown in Figure 3.5 could be associated with ‘key vulnerabilities’, based on a number of criteria in the literature (magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and ‘importance’ of the impacts) (see topic 5.2). {WGII SPM}

**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 3.5.** 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. **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 21$^{st}$ 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*. The middle right panel gives the WG II references for the statements made in the middle left panel[13]. **Lower panel:** Estimated long term (multi-century) warming corresponding to the six AR4 WG III stabilisation categories

[13] Where ES = Executive Summary, T = Table, B = Box and F = Figure. Thus B4.5 indicates Box 4.5 in Chapter 4 and 3.5.1 indicates Section 3.5.1 in Chapter 3.

(Table 5.1). Warming is reduced by half a degree C compared to Table 5.1 to account approximately for the warming between pre-industrial and 1980-1999. {WGI Figure SPM.5, 10.7; WGII Figure SPM.2; WGIII Table TS.2, Table 3.10}

**Some future impacts already appear unavoidable owing to the inertia of the climate system. {WGI 10.3, 10.7, SPM; WGII Figure SPM.2}**

Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.6°C relative to 1980-1999 levels would be expected over the 21st century. Even the most stringent stabilisation scenarios assessed in the AR4 (see topic 5.4) project further increases in GHG concentrations, leading to even higher temperature increases and associated climate changes. {WGI 10.3, 10.7, SPM; WGIII 3.2, 3.3}

This suggests that some future impacts projected to occur at low levels of additional warming over the 21st century (see Figure 3.5) are already unavoidable, even with adaptation, for example increases in:

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

### *3.3.2 Impacts on regions*

**Africa:**

- Between 75 and 250 million people are projected to be exposed to increased water stress due to climate change by 2020 (a warming of less than 1°C). {WGII 3.4, 8.2, 8.4, 9.4, SPM}
- The area suitable for agriculture, the length of the growing seasons and yield potential, particularly along the margins of semi-arid and arid areas, are expected to decrease. This would further adversely affect food security and exacerbate malnutrition in the continent. {WGII 9.2, 9.4, 9.6, SPM}
- Ecosystems in Africa are projected to experience major shifts in species range and possible extinctions (*medium confidence*). {WGII Box TS.6, Table TS.4, 9.4.5, SPM}

**Asia:**

- Freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease during the dry season. Along with population growth and increasing demand arising from higher standards of living, this could adversely affect more than a billion people by the 2050s.{WGI 11.4; WGII 10.4, SPM}
- 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 rivers. {WGII 10.2, 10.4, 10.5, SPM}
- It is projected that crop yields could increase up to 20% in East and Southeast Asia, while they could decrease up to 30% in Central and South Asia by the mid-21st century (*medium confidence*). {WGII Box TS.6, Table TS.4, 10.4.1, SPM}

**Australia and New Zealand:**

- Water security problems are projected to intensify by 2030 in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions. {WGII Box TS.6, 11.4.1, SPM}
- Significant loss of biodiversity is projected to occur by 2020 in some ecologically rich sites including the Great Barrier Reef and Queensland Wet Tropics; other sites are also at risk (*very high confidence*). {WGII Table TS.4, Box TS.6, Box 11.3, SPM}
- Production from agriculture and forestry by 2030 is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire, but initial benefits are projected in some regions of New Zealand. {WGII Box TS.6, 11.4, SPM}

**Europe:**

- Climate change is expected to magnify regional differences in Europe's natural resources and assets (*very high confidence*). {WGII Box TS.6, Table TS.4, SPM}
- By the 2070s, hydropower potential for the whole of Europe is expected to decline by 6%, varying regionally from a 15 to 30% increase in northern and eastern Europe to a 20 to 50% decrease in the Mediterranean region. {WGII Box TS.6, 12.4.8}
- Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extensive species losses (in some areas up to 60% under high-emission scenarios by 2080) (*very high confidence*). {WGII SPM}

**Latin America:**

- Productivity of some important crops and livestock is projected to decrease, while in temperate zones soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase. {WGII Box TS.6, 13.4, SPM}
- Changes in precipitation patterns and the disappearance of small glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation. {WGII 13.4, SPM}
- By mid-century, climate change is 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. {WGII 13.4.1, SPM}

**North America:**

- Warming in the western mountains by the mid-21st century is projected to cause large decreases in the snowpack, more winter flooding and reduced summer flows, thus exacerbating competition for over-allocated water resources (*very high confidence*). {WGII Box TS.6, 14.4, SPM}
- Moderate climate change in the early decades of the century is projected to increase aggregate yields of rain-fed agriculture by 5-20%, but with important variability among regions. {WGII 14.4, SPM}
- Cities that currently experience heatwaves are expected to be further challenged by an increased number, intensity and duration of heatwaves during the 21st century, with potential for adverse health impacts (*very high confidence*). {WGII SPM}

**Polar regions:**

- Changes in snow and ice cover in polar regions are projected to affect many natural ecosystems, with detrimental effects on many organisms including migratory birds, mammals and higher predators. {WGII Table TS.4, 15.3.4, 15.6, SPM}
- Projected effects on Arctic communities are mixed. Detrimental impacts would include those on infrastructure and traditional indigenous ways of life (*high confidence*); beneficial impacts would include reduced heating costs and more navigable northern sea routes (*medium confidence*). {WGII 15.ES, 15.4, 15.5, 15.7, SPM}
- By the end of the century, for a warming greater than 4°C, 10-50% of Arctic tundra is projected to be replaced by forest, and around 15-25% of polar desert is projected to be replaced by tundra (*medium confidence*). {WGII Table TS.4, 15.4.2}

**Small islands:**

- 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 (*very high confidence)*. {WGII 16.4, SPM}
- Increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands. {WGII 16.4, SPM}
- By mid-century (a warming of 1-3°C), water resources in many small islands, e.g. in the Caribbean and Pacific, are projected to become insufficient to meet demand during low rainfall periods (*very high confidence*). {WGII TS.4.2, 16.4.1, SPM}

### *3.3.3 Extreme events*

**Since the TAR, confidence has increased that some weather events and extremes will become more frequent, more widespread and/or more intense during the 21$^{st}$ century, and more is known about the potential effects of such changes (Table 3.2). {WGII SPM}**

**Table 3.2.** Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid- to late $21^{st}$ 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[a] and direction of trend | Likelihood of future trends based on projections for $21^{st}$ 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 | Virtually certain[b] | 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 | Very likely | 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 | Very likely | 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 | Likely | 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 | Likely | 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)[c] | Likely[d] | 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.

### *3.3.4 Especially affected systems, sectors, and regions*

**Some systems, sectors and regions are *likely* to be especially affected by climate change. {WGII TS 4.5}**

Regarding systems and sectors, these are: {WGII TS 4.5}

- 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 due to the threat of sea level rise and increased risk from extreme weather events
- water resources in dry tropics and subtropics due to decreases in rainfall and higher rates of evapotranspiration
- agriculture in low-latitude regions due to reduced water availability
- human health in areas with low adaptive capacity.

Regarding regions, these are: {WGII TS 4.5}

- 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. {WGII TS.4.5, 7.1, 7.2, 7.4}

## 3.4 Risk of abrupt or irreversible changes

**Human activities could lead to abrupt or irreversible climate changes and impacts. The risks are related to the rate and magnitude of climate change. {WGII 19.4, 19.5, SPM}**

Abrupt climate change on decadal time scales is normally thought of as involving ocean circulation changes. In addition on longer time scales, ice sheet and ecosystem changes may also play a role. If a large scale abrupt climate change were to occur, its impact could be quite high (see topic 5.2). {WGI 8.7, 10.3, 10.7; WGII 4.4, 19.3}

Based on current model simulations, it is *very likely* that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21$^{st}$ century. It is *very unlikely* that the MOC will undergo a large abrupt transition during the 21$^{st}$century. Longer-term changes in the MOC cannot be assessed with confidence. {WGI 10.3, 10.7; WGII Figure SPM.3, Table TS.5}

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. {WGII 12.6, 19.3, Figure SPM.2}

Partial deglaciation of polar ice sheets and/or the thermal expansion of seawater over very long time scales 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 very long time scales (millennial) if a global temperature increase of 1-4°C (relative to 1990-2000) were to be sustained. Rapid sea level rise on century time scales cannot be excluded. {SYR 3.2.3; WGI 6.4, 10.7; WGII 19.3, SPM}

Climate changes are *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 there is *high confidence* of significant (>40%) extinctions around the globe for warming above 4°C. {WGII 4.4, Figure SPM.2}

# Topic 4 – Adaptation and mitigation options and responses, and the inter-relationship with sustainable development, at global and regional levels (31 August 2007)

## 4.1 Responding to climate change

Societies can respond to climate change by adapting to its impacts and reducing the rate and magnitude of climate change by reducing GHG emissions (mitigation). This topic focuses on adaptation and mitigation options that can be implemented by 2030, and their inter-relationship with sustainable development; topic 5 addresses the complementary roles of adaptation and mitigation on a more conceptual basis and extends the timeframe.

The capacity to adapt and mitigate is dependent on socio-economic and environmental circumstances and the availability of information and technology[14]. However, much less information is available about the costs and effectiveness of adaptation measures than about mitigation measures. {WGII 17.1, 17.3; WGIII 1.2}

## 4.2 Adaptation options

**Adaptation reduces vulnerability, especially in the short-term. {WGII 17.2, 18.1, 18.5, 20.3, 20.8}**

Vulnerability to climate change can be exacerbated by non-climate stresses and factors. Non-climate factors, for example, poverty, unequal access to resources, food insecurity, trends in economic globalisation, conflict, and incidence of diseases such as HIV/AIDS may reduce the capacity of some communities to respond to the effects of climate change. {WGII 7.4, 8.3, 17.3, 20.3, 20.4, 20.7, SPM}

Societies across the world have a long record of adapting and reducing their vulnerability to 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 at regional and local levels to reduce the adverse impacts of projected climate change and variability. However, adaptation alone is not expected to cope with all the projected effects of climate change, especially over the long term as most impacts increase in magnitude. {WGII 17.2, SPM; WGIII 1.2}

Some planned adaptation to climate change is already occurring on a limited basis. Table 4.1 provides examples of planned adaptation options by sector. Many adaptation actions have multiple drivers, such as economic development and poverty alleviation, and are embedded within broader development, sectoral, regional and local planning initiatives such as water resources planning, coastal defence and disaster risk reduction strategies. Examples of this approach are the Bangladesh National Water Management Plan, and the coastal defence plans of The Netherlands and Norway which incorporate specific climate change scenarios. {WGII 1.3, 11.6, 15, 5.2, 17.2}

[14] Technology is defined as the practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information ("software", know-how for production and use of artefacts).

Comprehensive estimates of the costs and benefits of adaptation at the global level are limited in number. However, the number of adaptation cost and benefit estimates at the regional and project levels for impacts on specific sectors such as, agriculture, energy demand for heating and cooling, water resources management and infrastructure, is growing. Based on these studies there is *high confidence* that there are viable adaptation options that can be implemented in some of these sectors at low cost, and/or with high benefit-cost ratios. Empirical research also suggests that higher benefit/cost ratios can be achieved by implementing some adaptation measures now compared to retrofitting long-lived infrastructure at a later date. {WGII 17.2}

**Adaptive capacity is intimately connected to social and economic development, but it is not evenly distributed across and within societies. The poor, elderly, women, children, and indigenous populations typically have less capacity. {WGII 7.1, 7.2, 7.4, 17.3}**

The capacity to adapt is a dynamic process influenced by a society's productive base including: natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance structures, national income, and technology. It is also affected by multiple climate and non-climate stresses, as well as development policy. {WGII 17.3}

Recent studies reaffirm the TAR finding that adaptation will be vital and beneficial. However, financial, technological, cognitive, behavioural, political, social, and cultural constraints limit both the implementation and effectiveness of adaptation measures. Many societies have high adaptive capacity and the necessary financial resources, but remain vulnerable to climate change, variability and extremes. For example, a heat wave in 2003 caused high levels of mortality in European cities (especially among the elderly), and in 2005 Hurricane Katrina caused large human and financial costs in the United States. {WGII 7.4, 8.2, 17.4}

1 **Table 4.1.** Selected examples of planned adaptation by sector.

| Sector | Adaptation option/strategy<br>* indicates potential synergy with mitigation.<br># indicates potential trade-off with mitigation | Underlying policy framework | Key constraints and opportunities to implementation (Normal font = constraints; *italics = opportunities*) |
|---|---|---|---|
| Water {WGII, 5.5, 16.4; Tables 3.5, 11.6,17.1} | 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; *integrated water resources management; synergies with other sectors* |
| Agriculture {WGII 10.5, 13.5; Table 10.8} | 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; *longer growing season in higher latitudes; revenues from 'new' products* |
| Infrastructure/settlement (including coastal zones) {WGII 3.6, 11.4; Tables 6.11, 17.1} | 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; *integrated policies and managements; synergies with sustainable development goals* |
| Human health {WGII 14.5, Table 10.8} | Heat-health action plans; access to public 'cooling centres'; emergency medical services; improved climate-sensitive disease surveillance and control; safe water and improved sanitation | Public health policies that recognise climate risk; strengthen health services; regional and international cooperation | Limits to human tolerance (vulnerable groups); knowledge limitations; financial capacity; *upgraded health services; improved quality of life* |
| Tourism {WGII 12.5, 15.5, 17.5; Table 17.1} | 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); *revenues from 'new' attractions; involvement of wider group of stakeholders* |
| Transport {WGII 7.6, 17.2} | Realignment/relocation; design standards and planning for roads, rail, etc. 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; *improved technologies and integration with key sectors (e.g. energy)* |
| Energy {WGII 7.4, 16.2} | Strengthening of overhead transmission and distribution infrastructure; underground cabling for utilities; energy efficiency; use of renewable sources*#; reduced dependence on single sources of energy, e.g. large hydropower dams | 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; *stimulation of new technologies; use of local resources* |

## 4.3 Mitigation options

**There is *high agreement* and *much evidence* from both bottom-up and top-down studies[15] indicating that there is a substantial economic potential[15] 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[16]. {WGIII 11.3, SPM}**

Table 4.2 provides information on the global economic mitigation potential in 2030. Bottom-up studies suggest that mitigation opportunities with net negative costs[17] have the potential to reduce emissions by about 6 $GtCO_2$-eq/yr in 2030. The economic potential is generally greater than the market potential[15]. {WGIII 11.3, SPM}

**Table 4.2.** Global economic mitigation potential in 2030 estimated from bottom-up and top-down studies. {WGIII 11.3, 3.6, SPM}

| 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.

Sectoral estimates of economic mitigation potential and marginal costs derived from bottom-up studies corrected for double counting of mitigation potential are shown in Figure 4.1. While top-down and bottom-up studies agree at the global level, there are considerable differences at the sectoral level. {WGIII 11.3, SPM}

[15] For a definition and explanation, see glossary.

[16] Emissions in 2000 were equal to 43 $GtCO_2$-eq.

[17] Net negative costs (no regrets opportunities) are defined as those options whose benefits such as reduced energy costs and reduced emissions of local/regional pollutants equal or exceed their costs to society, excluding the benefits of avoided climate change.

**Economic mitigation potentials for different sectors in 2030 derived from bottom-up studies**

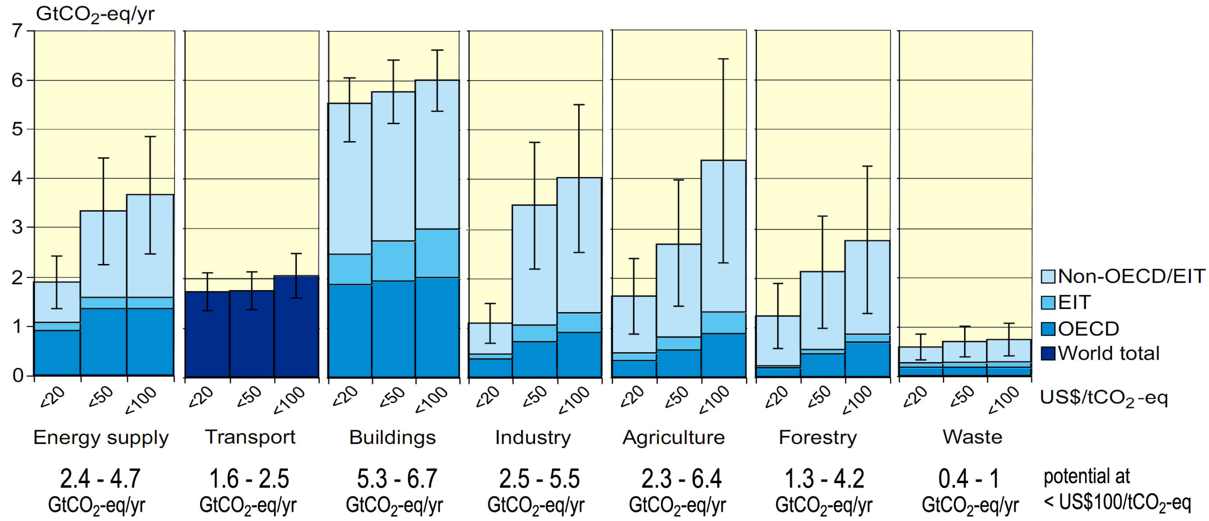



**Figure 4.1.** Estimated economic mitigation potential by sector and region using technologies and practices expected to be available in 2030. Notes: {WGIII Figure SPM.6}

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-$CO_2$ 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%.

No one technology can provide all of the mitigation potential in any sector, and the potential can only be achieved when adequate government policies are in place. Table 4.3 lists selected examples of key technologies, policies, constraints and opportunities by sector. {WGIII SPM}

Future energy infrastructure investment decisions, expected to total over 20 trillion US$[18] between now 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 $CO_2$ emissions to 2005 levels by 2030 would require a large shift in the pattern of investment, although the net additional investment required ranges from negligible to 5-10%. {WGIII 4.1, 4.4, 11.6, SPM}

[18] 20 trillion = 20,000 billion = $20\times10^{12}$.

**Table 4.3** 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.* * indicates potential synergy with adaptation. # indicates potential trade-off with adaptation. | Policies, measures and instruments shown to be environmentally effective | Key constraints or opportunities (Normal font = constraints; *italics = opportunities*) |
|---|---|---|---|
| Energy Supply {WGIII 4.3, 4.4} | 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 CCS (e.g. storage of removed $CO_2$ from natural gas); *Carbon Dioxide Capture and Storage (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* | 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 | *May be appropriate to create markets for low emissions technologies* |
| Transport {WGIII 5.4} | 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*; *Second generation biofuels*#; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries* | Mandatory fuel economy, biofuel blending and $CO_2$ 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 | *Particularly appropriate for countries that are building up their transportation systems* |
| Buildings {WGIII 6.5} | 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; *Integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar photovoltaics integrated in buildings* | Appliance standards and labelling | Periodic revision of standards needed |
| | | Building codes and certification | *Attractive for new buildings.* Enforcement can be difficult |
| | | Demand-side management programmes | Need for regulations so that utilities may profit |
| | | Public sector leadership programmes, including procurement | *Government purchasing can expand demand for energy-efficient products* |
| | | Incentives for energy service companies (ESCOs) | *Success factor: Access to third party financing* |
| Industry {WGIII 7.5} | More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-$CO_2$ gas emissions; and a wide array of process-specific technologies; *Advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture* | Provision of benchmark information; Performance standards; Subsidies, tax credits | *May be appropriate to stimulate technology uptake.* 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 {WGIII 8.4} | 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 $CH_4$ emissions; improved nitrogen fertiliser application techniques to reduce $N_2O$ emissions; dedicated energy crops to replace fossil fuel use*#; improved energy efficiency; *Improvements of crop yields* | Financial incentives and regulations for improved land management, maintaining soil carbon content, efficient use of fertilisers and irrigation | *May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation* |
| Forestry/ forests {WGIII 9.4} | Afforestation*; reforestation*; forest management*; reduced deforestation*; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use; *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* | 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. *Can help poverty alleviation.* |
| Waste {WGIII 10.4} | Landfill CH4 recovery; waste incineration with energy recovery; composting of organic waste; controlled waste water treatment; recycling and waste minimisation; *biocovers and biofilters to optimise $CH_4$ oxidation* | Financial incentives for improved waste and wastewater management | *May stimulate technology diffusion* |
| | | Renewable energy incentives or obligations | Local availability of low-cost fuel |
| | | Waste management regulations | Most effectively applied at national level with enforcement strategies |

**While studies use different methodologies, there is *high agreement* and *much evidence* that in all analysed world regions near-term health co-benefits from reduced air pollution, as a result of actions to reduce GHG emissions, can be substantial, and may offset a substantial fraction of mitigation costs. {WGIII 11.8, SPM}**

Energy efficiency and utilisation of renewable energy offer synergies with sustainable development. In least developed countries energy substitution can lower mortality and morbidity by reducing indoor air pollution, reduce the workload for women and children, and decrease the unsustainable use of fuelwood and related deforestation. {WGIII 11.8, 11.9,12.4}

**Literature since the TAR confirms with *high agreement* and *medium evidence* that there may be effects from Annex I countries action on the global economy and global emissions, although the scale of carbon leakage remains uncertain. {WGIII 11.7, SPM}**

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. {WGIII 11.7, SPM}

Critical uncertainties remain in the assessment of carbon leakage. Most equilibrium modelling supports the conclusion in the TAR of economy-wide leakage from Kyoto action in the order of 5-20%, which would be less if competitive low-emissions technologies were effectively diffused. {WGIII 11.7, SPM}

**There is also *high agreement* and *medium evidence* that changes in life style and behaviour patterns can contribute to climate change mitigation across all sectors. Management practices can also have a positive role. {WGIII SPM}**

Examples that can have positive impacts on mitigation include: changes in consumption patterns, education and training, changes in building occupant behaviour, transport demand management, and management tools in industry. {WGIII 4.1, 5.1, 6.7, 7.3, SPM}

**Policies that provide a real or implicit price of carbon could create incentives for producers and consumers to significantly invest in low-GHG products, technologies and processes. {WGIII SPM}**

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 since TAR that take into account induced technological change lower these price ranges to 5-65 US$/t$CO_2$-eq in 2030. {WGIII 3.3, 11.4, 11.5, SPM}

**There is *high agreement* and *much evidence* that a wide variety of national policies and instruments are available to governments to create the incentives for mitigation action. Their applicability depends on national circumstances and an understanding of their interactions, but experience from implementation in various countries and sectors shows there are advantages and disadvantages for any given instrument. {WGIII 13.2, SPM}**

Four main criteria are used to evaluate policies and instruments: environmental effectiveness, cost effectiveness, distributional effects, including equity, and institutional feasibility. {WGIII 13.2, SPM}

General findings about the performance of policies are: {WGIII 13.2, SPM}

- *Integrating climate policies in broader development policies* makes implementation and overcoming barriers easier.
- *Regulations and standards* generally provide some certainty about emission levels. They may be preferable to other instruments when information or other barriers prevent producers and consumers from responding to price signals. However, they may not induce innovations and more advanced technologies.
- *Taxes and charges* can set a price for carbon, but cannot guarantee a particular level of emissions. Literature identifies taxes as an efficient way of internalising costs of GHG emissions.
- *Tradable permits* will establish a carbon price. The volume of allowed emissions determines their environmental effectiveness, while the allocation of permits has distributional consequences. Fluctuation in the price of carbon makes it difficult to estimate the total cost of complying with emission permits.
- *Financial incentives* (subsidies and tax credits) are frequently used by governments to stimulate the development and diffusion of new technologies. While economic costs are generally higher than for the instruments listed above, they are often critical to overcome barriers.
- *Voluntary agreements* between industry and governments are politically attractive, raise awareness among stakeholders, and have played a role in the evolution of many national policies. The majority of agreements have not achieved significant emissions reductions beyond business as usual. However, some recent agreements, in a few countries, have accelerated the application of best available technology and led to measurable emission reductions.
- *Information instruments* (e.g. awareness campaigns) may positively affect environmental quality by promoting informed choices and possibly contributing to behavioural change, however, their impact on emissions has not been measured yet.
- *Research, Development and Demonstration (RD&D)* can stimulate technological advances, reduce costs, and enable progress toward stabilisation.

Some corporations, local and regional authorities, NGOs and civil groups are adopting a wide variety of voluntary actions. These voluntary actions may limit GHG emissions, stimulate innovative policies, and encourage the deployment of new technologies. On their own, they generally have limited impact on national or regional level emissions. {WGIII 13.4, SPM}

## 4.4 Relationship between adaptation and mitigation options and relationship with sustainable development

**There is growing understanding of the possibilities to choose and implement climate response options in several sectors to realise synergies and avoid conflicts with other dimensions of sustainable development. {WGIII SPM}**

Climate change policies related to renewable energy are often economically beneficial, improve energy security and reduce local pollutant emissions. Reducing both loss of natural habitat and deforestation can have significant biodiversity, soil and water conservation benefits, and can be implemented in a socially and economically sustainable manner.

Forestation and bioenergy plantations can restore degraded land, manage water runoff, retain soil carbon and benefit rural economies, but could compete with food production and may be negative for biodiversity, if not properly designed. {WGII 20.3, 20.8; WGIII 4.5, 9.7, 12.3, SPM}

There is growing evidence that decisions about macro-economic policy, agricultural policy, multilateral development bank lending, insurance practices, electricity market reform, energy security and forest conservation, for example, which are often treated as being apart from climate policy, can significantly reduce emissions (Table 4.4). Similarly, non-climate policies can affect adaptive capacity and vulnerability. {WGII 20.3; WGIII SPM, 12.3}

**Both synergies and trade-offs exist between adaptation and mitigation options. {WG II 18.4.3; WG III 11.9)**

Examples of synergies include properly designed biomass production, formation of protected areas, land management, energy use in buildings, and forestry, but options are rather limited in other sectors (see Tables 4.1 and 4.3). Potential trade-offs include increased GHG emissions due to increased consumption of energy related to adaptive responses. {WGII 18.4.3, 18.5, 18.7, TS.5.2; WGIII 4.5, 6.9, 8.5, 9.5, SPM}

**Table 4.4.** Integrating climate change considerations into development policies – selected examples in the area of mitigation. {WGIII 12.2.4.6}

| Selected sectors | Non-climate change policy instruments and actions | Potential impact on GHG emissions |
|---|---|---|
| Macro-economy | Implement non-climate taxes/subsidies and/or other fiscal and regulatory policies that promote sustainable development | Total global GHG emissions |
| Forestry | Adoption of forest conservation and sustainable management practices | GHG emissions from deforestation |
| Electricity | Adoption of cost-effective renewables, demand-side management programs, and transmission and distribution loss reduction | Electricity sector $CO_2$ emissions |
| Petroleum imports | Diversifying imported and domestic fuel mix and reducing economy's energy intensity to improve energy security | Emissions from crude oil and product imports |
| Insurance for building, transport sectors | Differentiated premiums, liability insurance exclusions, improved terms for green products | Transport and building sector GHG emissions |
| International finance | Country and sector strategies and project lending that reduces emissions | Emissions from developing countries |

## 4.5 International and Regional 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 the climate change problem, stimulation of an array of national policies, the creation of an international carbon market and the establishment of new institutional mechanisms that may provide the foundation for future mitigation and adaptation efforts. {WGII 18.7; WGIII 13.3, SPM}**

The impact of the protocol's first commitment period relative to global emissions is projected to be limited. Its economic impacts on participating Annex-B countries are projected to be smaller than presented in the TAR, that showed 0.2-2% lower GDP in 2012 without emissions trading, and 0.1-1.1% lower GDP with emissions trading among Annex-B countries. To be more environmentally effective, future mitigation efforts would need to achieve deeper reductions covering a higher share of global emissions (see topic 5). {WGIII 1.4, 11.4, 13.3, SPM}

**The literature provides *high agreement* and *much evidence* of many options for achieving reductions of global GHG emissions at the international level through cooperation. It also suggests that successful agreements are environmentally effective, cost-effective, incorporate distributional considerations and equity, and are institutionally feasible. {WGIII 13.3, SPM}**

Greater cooperative efforts to reduce emissions will help to reduce global costs for achieving a given level of mitigation, or will improve environmental effectiveness. Improving and expanding the scope of market mechanisms (such as emission trading, Joint Implementation and Clean Development Mechanism) could reduce overall mitigation costs. {WGIII 13.3, SPM}

Efforts to address climate change 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. These elements can be implemented in an integrated fashion, but comparing the efforts made by different countries quantitatively would be complex and resource intensive. {WGIII 13.3, SPM}

Actions that could be taken by participating countries can be differentiated both in terms of when such action is undertaken, who participates and what the action will be. Actions can be binding or non-binding, include fixed or dynamic targets, and participation can be static or vary over time. {WGIII 13.3, SPM}

# Topic 5 – The long-term perspective: scientific and socio-economic aspects relevant to adaptation and mitigation, consistent with the objectives and provisions of the Convention, and in the context of sustainable development
**(31 August 2007)**

## 5.1 Risk management perspective

**Decision-making about responding to climate change involves an iterative risk management process that includes both mitigation and adaptation, taking into account actual and avoided climate change impacts, co-benefits, sustainability, equity, and attitudes to risk. {WGII 20. 9, SPM; WGIII SPM}**

Risk management techniques can explicitly accommodate sectoral, regional, and temporal diversity, but their application requires information about not only impacts resulting from the most likely climate scenarios, but also impacts arising from lower-probability but higher-consequence events and the consequences of proposed policies and measures. Risk is defined here as the product of likelihood and consequence. Climate change impacts depend on the characteristics of natural and human systems, their development pathways, and their specific locations. {SYR 3.3, Figure 3.5; WGII 20.2, 20.9, SPM; WGIII 3.5, 3.6, SPM}

**Key Vulnerabilities and Article 2 of the UNFCCC**

Article 2 of the UNFCCC states:

"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Determining what constitutes "dangerous anthropogenic interference" involves value judgements, and its interpretation varies across the globe and evolves with changes in scientific knowledge, social values, development status, political priorities and the potential to adapt. Science can facilitate informed decisions by offering explicit criteria for judging which vulnerabilities might be labeled "key" in this context. {SYR 3.3, WGII 19.ES}

More specific information is now available across the regions of the world concerning the nature of future impacts, including for some places not covered in previous assessments. Sharp differences across regions are evident from this assessment of key vulnerabilities. They show that those in the weakest economic and/or political position are frequently the most susceptible to climate-related damages, especially when they face multiple stresses. {WGII 19.ES, 20.ES, SPM}

## 5.2 Key vulnerabilities, impacts and risks – long term perspectives

**The "reasons for concern" identified in the TAR are now stronger due to: (1) better understanding of the magnitude of impacts and risks associated with increases in global average temperature and GHG concentrations, including vulnerability to present-day climate variability, (2) more precise identification of especially vulnerable systems, sectors, groups and regions, and (3) growing evidence that the risk of very large impacts on multiple century time scales would continue to increase as long as GHG concentrations and temperature continue to increase. {WGII 4.4, 5.4, 19.ES, 19.3.7, TS.4.6; WGIII 3.5, SPM}**

The TAR found that vulnerability is a function of exposure and sensitivity. Adaptation can influence sensitivity to climate change while mitigation can influence the rate and extent of climate change and hence exposure. Both conclusions are confirmed in this assessment. {WGII 20.2, 20.7.3}

No single metric can adequately describe the diversity of key vulnerabilities or support their ranking. A sample of relevant impacts is provided in Figure 3.5. The estimation of key vulnerabilities in any system, and damage implied, will depend on the rate and magnitude of climate change and development status, which also determines adaptive capacity.[19] 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. {WGII 19.ES, 19.1}

The five "reasons for concern" that were identified in the TAR were intended to synthesise information on climate risks and key vulnerabilities and to "aid readers in making their own determination" about risk. These remain a viable framework to consider key vulnerabilities, and they have been updated in the AR4. {TAR WGII Chapter 19; WGII SPM}

**Risks to unique and threatened systems.** There is new and much stronger evidence of the adverse impacts of observed climate change to date on several unique and threatened systems, consistent with the expected effects of warming. Confidence has increased that a 1-2°C increase in global average temperature above 1980-1999 levels (about 1.5-2.5°C above pre-industrial) poses significant risks to many unique and threatened systems, including many biodiversity hotspots. For global average temperature increases above 1.5-2.5°C above 1980-1999 levels, predominantly negative effects on biodiversity are projected, with significant extinctions for warming over 4°C and widespread coral reefs mortality over 2.5-3.0°C. {SYR 3.3, 3.4, Figure 3.5, Table 3.2; WGII 4.4, 6.4, Figure TS.12, Figure TS.14, 19.3.7}

**Risks of extreme weather events.** Recent extreme climate events have exposed a higher vulnerability in both developing and developed countries than was assessed in the TAR. As summarised in Table 3.2, changes in extreme events (such as drought, heat-waves and tropical cyclones) are projected in many regions and would have mostly adverse impacts, including increased water stress and wild fire frequency, adverse effects on food production, adverse health effects, increased flood risk and extreme high sea level, and damage to infrastructure. {SYR 3.2, 3.3, Table 3.2; WGI 10.3, Table SPM.2; WGII 1.3, 5.4, 7.1, 7.5, 8.2, 12.6, 19.3, Table 19.1, Table SPM.1}

[19] WGII identifies seven criteria from the literature that are often used to identify key vulnerabilities; they are listed in topic 3.3.1. {WGII 19.2}

**Distribution of impacts and vulnerabilities.** Substantial improvements have occurred in the prediction of regional patterns of climate change (see topic 3.2) and in the projections of regional impacts, enabling better identification of particularly vulnerable systems, sectors and regions (see topic 3.3). For example, observed adverse impacts of climate change on Arctic indigenous communities and natural ecosystems are projected to increase with warming. New studies confirm that Africa is one of the most vulnerable continents because of the range of projected impacts, multiple stresses and low adaptive capacity. Substantial risks due to sea level rise are projected particularly for Asian megadeltas and for small-island communities. {SYR 3.2, 3.3, 5.4; WGI 11.2-11.7, SPM; WGII 3.4.3, 5.3, 5.4, 9.ES, Table 10.9, 10.6, 16.3, 19.3, Table 19.1, TS.5.4, Tables TS.3 and TS.4}

**Net aggregate impacts.** There is some evidence that initial market benefits from climate change will peak at a lower magnitude and sooner than was assessed in the TAR. Aggregate impacts have also been quantified in other metrics (see topic 3.3): for example, climate change over the next century could adversely affect hundreds of millions of people through increased likelihood of coastal flooding, reductions in water supplies, increased likelihood of malnutrition and increased exposure to health impacts. {SYR 3.3, Figure 3.5; WGII 19.3.7, 20.7.3, TS.5.3}

**Risks of large scale singularities: abrupt or irreversible changes.**[20] As discussed in topic 3.4, during the current century, a large-scale abrupt change in the MOC is *very unlikely*. Ice sheet models project a gradual widespread loss of ice from the Greenland ice sheet if warming were to be sustained for millennia. There is, nonetheless, a risk that larger sea level contributions from both the Greenland and Antarctic ice sheets could occur on century time scales, because ice dynamical processes not included in current ice sheet models, but seen in recent observations, could increase the rate of ice loss. Complete deglaciation of the Greenland ice sheet would raise sea level by 7 m over millennia and could be irreversible. {SYR 3.4; WGI 10.3, Box 10.1; WGII 4.ES, 4.4, Box 4.3, 19.3.7, SPM}

## 5.3 Adaptation and mitigation

**There is *high confidence* that neither adaptation nor mitigation alone can avoid significant climate change impacts. Adaptation is necessary both in the short term and in the longer term, even for the lowest stabilisation scenarios assessed, but there are significant barriers, limits and costs. However, adaptation and mitigation can complement each other and together can significantly reduce the risks of climate change. {WGII 4.ES, TS 5.1, 18.4, 18.6, 20.7, SPM; WGIII 1.2, 2.5, 3.5, 3.6}**

Adaptation will be ineffective in some cases (such as for biodiversity and natural ecosystems e.g. loss of Arctic sea ice and polar bear ecosystem viability, disappearance of mountain glaciers that play vital roles in water storage and supply, or adaptation to sea level rise of several metres[21]) and less feasible or very costly in many cases for the projected climate change beyond the next several decades (such as deltaic regions and estuaries). The adaptive capacity

[20] Singularities are defined in the AR4 as the property of something which may behave irregularly, abruptly, non-linearly or in a discontinuous manner in response to smoothly changing driving forces, which is broadly consistent with the TAR. For further discussion refer to TAR WGII 19.6.

[21] While it is technically possible to adapt to several metres of sea level rise, the resources required are so unevenly distributed that in reality this risk is outside the scope of adaptation. {WGII 17.4.2, 19.4.1}

of natural ecosystems is limited and there is *high confidence* that the ability of many ecosystems to adapt naturally is *likely* to be exceeded this century. In addition, multiple barriers and constraints to effective adaptation exist in human systems (see topic 4.2). {SYR 4.2; WGII 17.4.2, 19.2, 19.4.1}

Reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is not possible, or will only be available at very high social, environmental and economic costs. {WGII 18.1}

**Efforts to mitigate GHG emissions to reduce the rate and magnitude of climate change need to account for inertia in the climate and socio-economic systems. {SYR 3.2; WGI 10.3, 10.4, 10.7, SPM; WGIII 2.3.4}**

After GHG concentrations are stabilised, the rate at which the global average temperature increases is expected to slow within a few decades, assuming the absence of substantial carbon cycle and methane feedbacks. Small increases in global average temperature could still be expected for several centuries. Sea level rise from thermal expansion would continue for many centuries at a rate that eventually decreases from that reached before stabilisation due to ongoing heat uptake by oceans. The eventual contribution from Greenland ice sheet loss, should global temperature increases in excess of 1.9-4.6$^{o}$C above pre-industrial be sustained over many centuries, could be much larger than from thermal expansion. {SYR 3.2, WGI 10.3, 10.4, 10.7, SPM}

The extent to which risks of major impacts on vulnerable systems can be reduced, avoided or delayed in the long term depends on the scale of mitigation effort and investments over the next two to three decades. Even though benefits of mitigation measures in terms of avoided climate change would take several decades to materialise, mitigation actions begun in the short term would avoid locking in both long-lived carbon intensive infrastructure and development pathways, reduce the rate of climate change and reduce the adaptation needs associated with higher levels of warming. {WGII 18.4, 20.6, 20.7, SPM; WGIII 2.3.4, 3.4, 3.5, 3.6, SPM}

## 5.4 Emission trajectories for stabilisation

**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 (Figure 5.1). {WGIII 3.3, 3.5, SPM}**

Advances in modelling since the TAR permit the assessment of multi-gas mitigation strategies for exploring the attainability and costs for achieving stabilisation of GHG concentrations. These scenarios explore a wider range of future scenarios, including lower levels of stabilisation, than reported in the TAR. {WGIII 3.3, 3.5, SPM}

**Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels (Table 5.1 and Figure 5.1). {WGIII 3.5, SPM}**

Table 5.1 summarises the required emission levels for different groups of stabilisation concentrations and the associated equilibrium global average temperature increase, using the 'best estimate' of climate sensitivity (see Figure 5.1 for the *likely* range of uncertainty).

Stabilisation at lower concentration and related equilibrium temperature levels advances the date when emissions need to peak, and requires greater emissions reductions by 2050.[22] Climate sensitivity is a key uncertainty for risk management and, in particular, for mitigation scenarios that aim to meet specific temperature levels. If climate sensitivity is high, then the timing and level of mitigation is earlier and more stringent than if it is low. {WGIII 3.3, 3.4, 3.5, 3.6, SPM}

**Table 5.1.** Characteristics of post-TAR stabilisation scenarios. {WGI 10.7; WGIII Table TS.2, Table 3.10, Table SPM.5}

| 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 | °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) 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. {WGI 2.3.1, Table 2.12}

b) Ranges correspond to the 15$^{th}$ to 85$^{th}$ 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°C. {WGI SPM}

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°C 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.

Thermal expansion of the ocean will cause, for any of the assessed GHG concentration levels, a continuing sea level rise that is much larger than that projected for the 21$^{st}$ century (Table 5.1). If GHG and aerosol concentrations had been stabilised at year 2000 levels, thermal expansion alone would be expected to lead to further sea level rise of 0.3-0.8 m. These long-term

[22] 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 5.1), the equilibrium temperature may be reached earlier.

consequences could have major implications for world coastlines, and they do not include contributions from ice sheets, glaciers, or ice caps. The long time scale response of thermal expansion and ice sheets implies that mitigation strategies that seek to stabilise GHG concentrations (or radiative forcing) at or above present levels do not stabilise sea level for more than a millennium. {WG1 10.7}

**Gobal $CO_2$ emission pathways and equilibrium temperatures for a range of stabilisation scenarios**

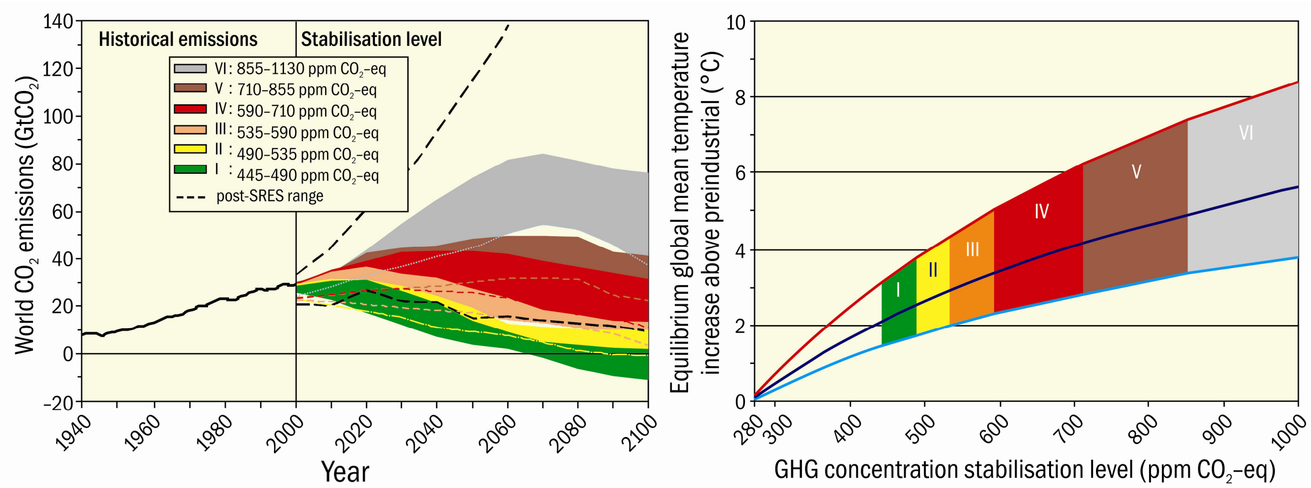



**Figure 5.1.** Global $CO_2$ emissions for 1940 to 2000 and emissions ranges for groups of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the likely equilibrium global average temperature increase above pre-industrial (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. {Figures SPM.7 and SPM.8}

Feedbacks between the carbon cycle and climate change affect the required mitigation and adaptation response to climate change.  Climate-carbon cycle coupling is expected to increase the fraction of anthropogenic emissions that remains in the atmosphere as the climate system warms (see topic 2.3 and 3.2.1), but mitigation studies have not yet incorporated the full range of these feedbacks. As a consequence, the emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed in Table 5.1 might be underestimated. Based on current understanding of climate-carbon cycle feedbacks, model studies suggest that stabilising $CO_2$ concentrations at, for example, 450 ppm[23], could require that cumulative emissions over the $21^{st}$ century be reduced from approximately 2460 [2310 to 2600] $GtCO_2$ to approximately 1800 [1370 to 2200] $GtCO_2$. {SYR 2.3, 3.2.1; WGI 7.3, 10.4, SPM}

[23] Based on the range of multigas scenarios reviewed such a $CO_2$ concentration scenario would involve substantial emissions of other GHGs raising the overall radiative forcing to about 550 ppm $CO_2$-eq. To stabilise at 1000 ppm $CO_2$ (which with other GHGs emissions in multigas scenarios would correspond to about 1800 ppm $CO_2$-eq.) this feedback could require that cumulative emissions be reduced from a model average of approximately 5190 [4910 to 5460] $GtCO_2$ to approximately 4030 [3590 to 4580] $GtCO_2$.  {WGI 7.3, 10.4, SPM}

## 5.5 Technology flows and development

**There is *high agreement* and *much evidence* that the range of stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are currently available and those that are expected to be commercialised in coming decades. This assumes that appropriate and effective incentives are in place for development, acquisition, deployment and diffusion of technologies and for addressing related barriers. {WGIII SPM}**

The lower the stabilisation levels, especially those of 550 ppm $CO_2$-eq or lower, the greater the need for more investment in new technologies during the next few decades. {WGIII SPM}

World-wide deployment of low-GHG emission technologies as well as technology improvements through public and private RD&D would be required for achieving stabilisation targets as well as cost reduction.[24] Figure 5.2 gives illustrative examples of the contribution of the portfolio of mitigation options. The contribution of different technologies varies over time and region and depends on the baseline development path, available technologies and relative costs, and the analysed stabilisation levels. Stabilisation at low levels (490-540 ppm $CO_2$-eq) requires early investments and substantially more rapid commercialisation of advanced low-emissions technologies over the next decades (2000-2030) and higher contributions across abatement options in the long term (2000-2100). This requires that barriers to development, acquisition, deployment and diffusion of technologies are effectively addressed with appropriate incentives. {WGIII 2.7, 3.3, 3.4, 3.6, 4.3, 4.4, 4.6, SPM}

There are large uncertainties concerning the future contribution of different technologies. However, all assessed stabilisation scenarios concur that 60-80% of the reductions over the course of the century would come from energy supply and use and industrial processes. Including non-$CO_2$ and $CO_2$ land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Energy efficiency plays a key role across many scenarios for most regions and timescales. For lower stabilisation levels, scenarios put more emphasis on the use of low carbon energy sources, such as renewable energy and nuclear power, and the use of $CO_2$ capture and storage (CCS). In these scenarios improvements of carbon intensity of energy supply and the whole economy needs to be much faster than in the past (Figure 5.2). {WGIII 3.3, 3.4, TS.3, SPM}

[24] By comparison, government funding in real absolute terms for most energy research programmes has been flat or declining for nearly two decades (even after the UNFCCC came into force) and is now about half of the 1980 level. {WGIII 2.7, 3.4, 4.5, 11.5, 13.2}

**Illustrative mitigation portfolios for achieving stabilisation of GHG concentrations**

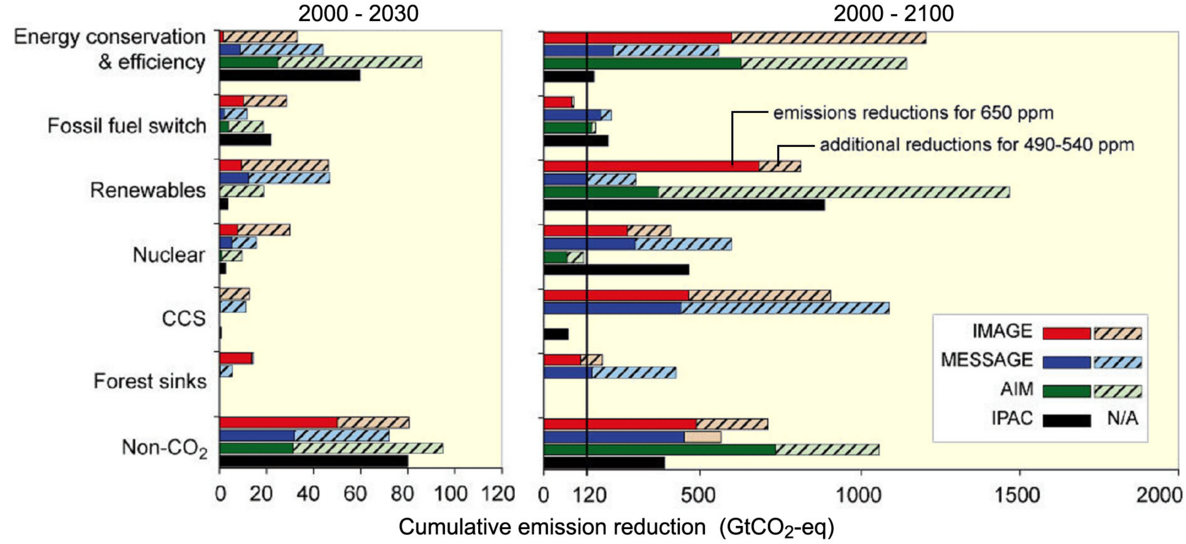



**Figure 5.2.** Cumulative emissions reductions for alternative mitigation measures for 2000-2030 (left-hand panel) and for 2000-2100 (right-hand panel). The figure shows illustrative scenarios from four models (AIM, IMAGE, IPAC and MESSAGE) aiming at the stabilisation at low (490-540 ppm $CO_2$-eq) and intermediate levels (650 ppm $CO_2$-eq) respectively. Dark bars denote reductions for a target of 650 ppm $CO_2$-eq and light bars the additional reductions to achieve 490-540 ppm $CO_2$-eq. Note that some models do not consider mitigation through forest sink enhancement (AIM and IPAC) or $CO_2$ capture and storage (CCS) (AIM) and that the share of low-carbon energy options in total energy supply is also determined by inclusion of these options in the baseline. CCS includes $CO_2$ capture and storage from biomass. Forest sinks include reducing emissions from deforestation. The figure shows emissions reductions from baseline scenarios with cumulative emissions between 6000 to 7000 $GtCO_2$-eq (2000-2100). {WGIII Figure SPM.9}

## 5.6 Costs of mitigation and long-term stabilisation targets

**The macro-economic cost of mitigation generally rises as the stringency of the stabilisation target is increased, and it is relatively higher when derived from baseline scenarios characterised by high emission levels. {WGIII SPM}**

There is *high agreement* and *medium evidence* that in 2050 global average macro-economic costs for multi-gas mitigation towards stabilisation between 710 and 445 ppm $CO_2$-eq are between a 1% gain to a 5.5% decrease of global GDP (Table 5.2). Estimated GDP losses by 2030 are on average lower and show a smaller spread compared to 2050 (Table 5.2). For specific countries and sectors, costs vary considerably from the global average.[25] {WGIII 3.3, 13.3, SPM}

[25] 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. {WGIII SPM}

**Table 5.2.** 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. {WGIII 3.3, 13.3, Tables SPM.4 and SPM.6}

| 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.
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.

## 5.7 Costs, benefits and avoided climate impacts at global and regional levels

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

For increases in global average temperature of less than 1-3°C above 1980-1999 levels, some impacts are projected to produce market benefits in some places and some sectors, and produce costs in other places and other sectors. Global mean losses could be 1-5% of GDP for 4°C of warming. {WGII 9.ES, 10.6, 15.ES, SPM}

Peer-reviewed estimates of the social cost of carbon (net economic costs of damages from climate change across the globe discounted to the present) for 2005 have an average value of 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). They indicate that the net damages of climate change are likely to be significant and to increase over time. {WGII 20.6, SPM}

It is *very likely* that globally-aggregated figures underestimate the damage costs because they do not include many non-monetised impacts. It is *virtually certain* that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries, and populations. In some locations and amongst some groups of people with high exposure, high sensitivity, and/or low adaptive capacity, net costs will be significantly larger than the global aggregate. {WGII 7.4, 20.ES, 20.6, 20.ES, SPM}

**Many impacts can be avoided, reduced or delayed by mitigation. {WGII SPM}**

Although the small number of impact assessments that evaluate stabilisation scenarios do not take full account of uncertainties in projected climate under stabilisation, they nevertheless provide indications of damages avoided or vulnerabilities and risks reduced for different amounts of emissions reduction. The rate and magnitude of future human induced climate change and its associated impacts are determined by human choices defining alternative socio-economic futures and mitigation actions that influence emission pathways. Figure 3.2 demonstrates that alternative SRES emission pathways could lead to substantial differences in climate change throughout the 21st century. Some of the impacts at the high temperature end of Figure 3.5 could be avoided by socio-economic development pathways that limit emissions and associated climate change towards the lower end of the ranges illustrated in Figure 3.5. {SYR 3.2, 3.3; WGIII 3.5, 3.6, SPM}

Stabilisation alternatives, with associated temperature ranges and sea level rise estimates, illustrated in Table 5.1 and Figure 3.5, show how choices between different stabilisation targets could reduce the risk of specific impacts. Figure 3.5 illustrates that limiting global average warming to below about 3°C relative to 1980-1999 average temperatures could, for example, reduce the likelihood of affecting a significant (>40%) number of ecosystems and reduce the risk of extinctions, and reduce the likelihood that cereal productivity in some regions would tend to fall. Limiting warming to below about 1.5°C relative to 1980-1999 average temperatures could reduce significantly the number of people directly affected by coastal flooding, further reduce the risk of extinctions and damage to coral reefs, and reduce the risk of damage to infrastructure and loss of agricultural production in small island states. However, some impacts appear already unavoidable even if warming were limited to 1.5°C relative to 1980-1999 average temperatures (see topic 3.3). {SYR 3.3, Figure 3.5; WGII 4.4, 5.4, Table 20.6}

**Limited and early analytical results from integrated analyses of the costs and benefits of mitigation indicate that these 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. {WGIII SPM}**

Comparing the costs of mitigation with avoided damages would require the reconciliation of welfare impacts on people living in different places and at different points in time into a global aggregate measure of well-being. {WGII 18.ES}

## 5.8 Broader environmental and sustainability issues

**Unabated climate change, with *very high confidence*, threatens sustainable development and would impede achievement of the mid-century Millennium Development Goals. {WGII 20.6, 20.7, SPM}**

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. Their combined impacts may be compounded in the future in the absence of integrated mitigation and adaptation measures. {WGII 20.3, 20.7, 20.8, SPM}

**Making development more sustainable can enhance mitigative and adaptive capacities, reduce emissions, and reduce vulnerability, but there may be barriers to implementation. {WGII 20.8; WGIII 12.2, SPM}**

Both adaptive and mitigative capacities can be enhanced through sustainable development. Sustainable development can, thereby, reduce vulnerability to climate change by reducing sensitivities (through adaptation) and/or exposure (through reduced emissions). At present, however, few plans for promoting sustainability have explicitly included either adapting to climate change impacts, or promoting adaptive capacity. Similarly, changing development paths can make a major contribution to mitigation but may require resources to overcome multiple barriers. {WGII 20.3, 20.5, SPM; WGIII 2.1, 2.5, 12.1, SPM}

# Topic 6 – Robust findings, key uncertainties
# (31 August 2007)

As in the TAR, a robust finding for climate change is defined as one that holds under a variety of approaches, methods, models and assumptions, and is expected to be relatively unaffected by uncertainties. Key uncertainties are those that, if reduced, could lead to new robust findings. {TAR SYR Q.9}

Robust findings do not encompass all key findings of the AR4. Some key findings may be policy-relevant even though, or in some cases because, they are associated with large uncertainties or depend on assumptions and possible futures. {WGII 20.9}

The robust findings and key uncertainties listed below do not represent an exhaustive list.

## 6.1 Observed changes in climate and their effects, and their causes

### Robust findings

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. {WGI 3.9, SPM}

Many natural systems, on all continents and in some oceans, are being affected by regional climate changes. Observed changes in many physical and biological systems are consistent with warming. {WGII 1.3}

Global total annual anthropogenic GHG emissions, weighted by their 100-year GWPs, have grown by 70% between 1970 and 2004. As a result of anthropogenic emissions, atmospheric concentrations of $CH_4$ and $N_2O$ now far exceed pre-industrial values spanning many thousands of years, and $CO_2$ now far exceeds the natural range over the last 650,000 years. {WGI SPM; WGIII 1.3}

Most of the global average warming over the past 50 years is *very likely* due to anthropogenic GHG increases and it is *likely* that there is a discernible human induced warming averaged over every continent except Antarctica[26]. {WGI 9.4, SPM}

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. {WGII 1.4, SPM}

### Key uncertainties

Climate data coverage remains limited in some regions and there is a notable lack of geographic balance in data and literature on observed changes in natural and managed systems, with marked scarcity in developing countries. {WGI SPM; WGII 1.3, SPM}

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

Analysing and monitoring extremes including drought, tropical cyclones, extreme temperatures, and the frequency and intensity of precipitation is more difficult than for climatic averages as it requires longer data time-series of higher spatial and temporal resolution. {WGI 3.8, SPM}

Effects of climate changes on human and some natural systems are difficult to detect due to adaptation and non-climatic drivers. {WGII 1.3}

Difficulties remain in reliably simulating and attributing observed temperature changes to natural or human causes at smaller than continental scales. At these smaller scales, factors such as land-use change and pollution also complicate the detection of anthropogenic warming influence on physical and biological systems. {WGI 8.3, 9.4, SPM; WGII 1.4, SPM}

The magnitude of $CO_2$ emissions from land-use change and from individual methane sources remain as key uncertainties. {WGI 2.3, 7.3, 7.4; WGIII 1.3, TS.14}

## 6.2 Drivers and projections of future climate changes and their impacts

### Robust findings

With current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. {WGIII 3.2, SPM}

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. {WGI 10.3, 10.7, SPM}

Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21$^{st}$ century that would *very likely* be larger than those observed during the 20$^{th}$ century. {WGI 10.3, 11.1, SPM}

The pattern of future warming where land warms more than the adjacent oceans and more in northern high latitudes is seen in all future scenarios. {WGI 10.3, 11.1, SPM}

Warming tends to reduce terrestrial ecosystem and ocean uptake of atmospheric $CO_2$, increasing the fraction of anthropogenic emissions that remains in the atmosphere. {WGI 7.3, 10.4, 10.5, SPM}

Anthropogenic warming and sea level rise would continue for centuries even if GHG emissions were to be reduced sufficiently for GHG concentrations to stabilise, due to the timescales associated with climate processes and feedbacks. {WGI 10.7, SPM}

Equilibrium climate sensitivity is *very unlikely* less than 1.5°C. {WGI 8.6, 9.6, Box 10.2, SPM}

Some systems, sectors and regions are more vulnerable to climate change than others. Vulnerable sectors are some ecosystems, low-lying coasts, water resources in dry tropics and subtropics, agriculture in low-latitude regions, and human health in areas with low adaptive capacity. Vulnerable regions are the Arctic, sub-Saharan Africa, small islands and Asian megadeltas. Within other regions, even those with high incomes, some people, areas and activities can be particularly at risk. {WGII TS.4.5}

Impacts are *very likely* to increase due to increased frequencies and intensities of some extreme weather events. Recent events have demonstrated the vulnerability of some sectors and regions, including developed countries, to heat waves and tropical cyclones, providing stronger reasons for concern as compared to the findings of the TAR. {WGII Table SPM.2, 19.3}

**Key uncertainties**

Uncertainty in equilibrium climate sensitivity creates uncertainty in the expected warming for a given $CO_2$-eq stabilisation scenario. Uncertainty in the carbon cycle feedback creates uncertainty in the emission trajectory required to achieve a particular stabilisation level. {WGI 7.3, 10.4, 10.5, SPM}

Models differ considerably in their estimates of the strength of different feedbacks in the climate system, particularly cloud feedbacks, oceanic heat uptake, and carbon cycle feedbacks, although progress has been made in these areas. Also, the confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. precipitation), and is higher for larger spatial scales and longer time averaging periods. {WGI 7.3, 8.1-8.7, 9.6, 10.2, 10.7, SPM; WGII 4.4}

Aerosol impacts on the magnitude of the temperature response, clouds and precipitation remain uncertain. {WGI 2.9, 7.5, 9.2, 9.4, 9.5}

Future changes in the Greenland and Antarctic ice sheet mass, particularly due to changes in ice flow, are a major source of uncertainty that could increase sea level rise projections. The uncertainty in the penetration of the heat into the oceans also contributes to the future sea level rise uncertainty. {WGI 4.6, 6.4, 10.3, 10.7, SPM}

Large scale ocean circulation changes beyond the 21$^{st}$ century cannot be reliably assessed because of uncertainties in the meltwater supply from Greenland ice sheet and model response to the warming. {WGI 6.4, 10.3, 10.7, SPM}

Projections of climate change and its impacts beyond about 2050 are strongly scenario- and model-dependent, and improved projections would require improved understanding of sources of uncertainty and enhancements in systematic observation networks. {WGII TS.6}

Impacts research is hampered by uncertainties surrounding regional projections of climate change, particularly precipitation. {WGII TS.6}

Understanding of low-probability/high-impact events, which is required for risk-based approaches to decision-making, is generally limited. {WGII 19.4, 20.2, 20.4, 20.9, TS.6}

## 6.3 Responses to climate change

### Robust findings

Some adaptation is occurring now, and more extensive adaptation is required to reduce vulnerability to higher levels and rates of warming. {WGII 17.ES, 20.5, Table 20.6, SPM}

Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural managed and human systems to adapt. {WGII 20.7, SPM}

A wide range of mitigation options are currently available or projected to be available by 2030 in all sectors, with the economic potential at costs from net negative up to 100 US$/t$CO_2$-equivalent, sufficient to offset the projected growth of global emissions or to reduce emissions to below current levels over the coming decades. {WGIII 11.3, SPM}

The range of stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are currently available and those that are expected to be commercialised in coming decades, provided that appropriate and effective incentives are in place. In addition, further RD&D would be required to improve the technical performance, reduce the costs, and achieve social acceptability of new technologies. The lower the stabilisation levels, the greater the need for investment in new technologies during the next few decades. {WGIII 3.3, 3.4}

The lowest stabilisation scenarios (445-490 ppm, with best estimate equilibrium temperature increase of 2-2.4°C above pre-industrial) could significantly reduce the risks of many major impacts on vulnerable systems over the longer term. In these scenarios, global emissions would need to peak over the next decade and to fall below 50% of current levels by 2050. {WGII Table 20.6; WGIII 3.3}

Making development more sustainable by changing development paths can make a major contribution to climate change mitigation and adaptation and to reducing vulnerability. {WGII 18.7, 20.3, SPM; WGIII 13.2, SPM}

Decisions about macro-economic and other policies that seem unrelated to climate change can significantly affect emissions. {WGIII 12.2}

### Key uncertainties

Understanding of how development planners incorporate information about climate variability and change into their decisions is limited. This is a key uncertainty in the integrated assessment of vulnerability. {WGII 18.8, 20.9}

The evolution and utilisation of adaptive and mitigative capacity depend on underlying long-term socio-economic development pathways. {WGII 17.3, 17.4, 18.6, 19.4, 20.9}

Barriers, limits and costs of adaptation are not fully understood, partly because effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political and financial constraints. {WGII SPM}

Estimates of mitigation costs and potentials depend on assumptions about future socio-economic growth, technological change and consumption patterns. Uncertainty arises in particular from assumptions regarding the drivers of technology diffusion and the potential of long-term technology performance and cost improvements. {WGIII 3.3, 3.4}

The effects of non-climate policies on emissions are poorly quantified. {WGIII 12.2}