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

Climate Change 2007: The Physical Science Basis

Summary for Policymakers

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INTRODUCTION

The Fourth Assessment Report of IPCC Working Group I builds upon past assessments and incorporates new results from the past six years of research on climate change[1]. Many hundreds of scientists from many countries have participated in its preparation and review.

This Summary for Policymakers (SPM) describes the current state of understanding of the processes that cause climate change and provides estimates of its projected future evolution for a broad range of assumptions. Further details can be found in the chapter sections of the underlying report that are specified in square brackets at the end of substantive paragraphs.

Standard terms used here to describe the likelihood of assessed outcomes are consistent with the IPCC Third Assessment Report (TAR) and are explained in the underlying chapters and Box TS.1 of the Technical Summary to this report.

CHANGES IN HUMAN AND NATURAL DRIVERS OF CLIMATE

Changes in the atmospheric abundance of greenhouse gases and aerosols affect the absorption and re-emission of radiation within the atmosphere and at the Earth's surface. The resulting changes in energy balance are defined as radiative forcing[2]. Radiative forcing can also be determined for changes in solar radiation and land surface properties, and is used to compare a range of natural and human factors that drive warming and cooling influences on global climate.

Atmospheric concentrations of the greenhouse gases carbon dioxide, methane and nitrous oxide are the highest experienced for at least 650,000 years. The sustained rate of increase in radiative forcing over the past century due to these gases is unprecedented in at least the last 20,000 years (see Figure SPM-1). [2.3, 6.4]

- Observed increases in carbon dioxide, methane and nitrous oxide, compared to pre-industrial values, and their associated positive radiative forcing (warming effect), are directly linked to fossil fuel use, agriculture, land use change, and other human activities. The concentrations of these gases also increased at the end of the last ice age about 17,000 years ago as the planet warmed, but the rates of those changes were much slower than those in the last century. [2.3, 6.4]

- Carbon dioxide concentrations increased by more than 1.8 ppm yr^{-1} in the period 1999–2004, while its global emissions due to fossil fuel use are estimated to have increased from 6.5 to 7.2 GtC yr^{-1}. Carbon dioxide emissions associated with land use change are less well known but are estimated to have contributed 5 to 38% of its atmospheric growth in the 1990s. [2.3, 7.3]

- Current atmospheric methane concentrations are more than double their preindustrial values although growth rates have declined over the past two decades. The sum of anthropogenic plus natural sources of methane has not been increasing over this period but changes in emissions from different sources are not well determined. [2.3, 7.4].

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[1] *Climate change* in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, 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.

[2] *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. It is expressed in Watts per square meter (W m^{-2}). See Glossary for further details.

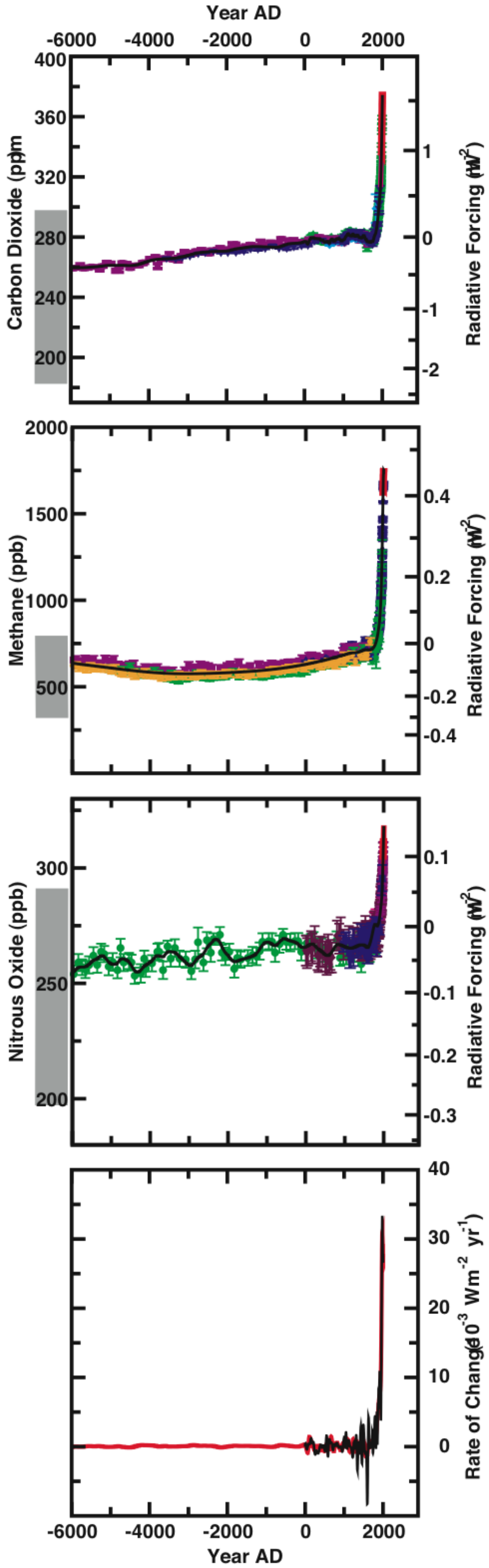

FIGURE SPM-1. Atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and the rate of change in their combined radiative forcing. In the upper three panels, symbols denote measurements from ice cores or atmospheric samples and smoothed values are denoted by a solid line. Grey bars show the ranges associated with changes from ice ages to intervening warm periods over the past 650,000 years. Estimated radiative forcings due to changes since 1750 are indicated on the right hand side. The rate of change in total radiative forcing from all three gases is shown in the bottom panel with different amounts of smoothing corresponding to the averaging occurring in low accumulation (red) and high accumulation (black) ice cores. [Figure 6.4]

Human activities since 1750 have very likely exerted a net warming influence on climate. (See Figure SPM-2.) [2.9]

- The radiative forcings of carbon dioxide, methane, and nitrous oxide are well understood and account for 1.63 ± 0.16 W m^{-2}, 0.48 ± 0.05 W m^{-2}, and 0.16 ± 0.02 W m^{-2}, respectively. Tropospheric ozone changes contribute 0.35 (+0.15, –0.1) W m^{-2}, while the contribution due to changes in the Montreal Protocol gases is 0.32 ± 0.03 W m^{-2}. Increases in greenhouse gases are the dominant cause of radiative forcing (2.9 ± 0.3 W m^{-2} total). (See Figure SPM-2, where smaller terms are also shown.) [2.3]

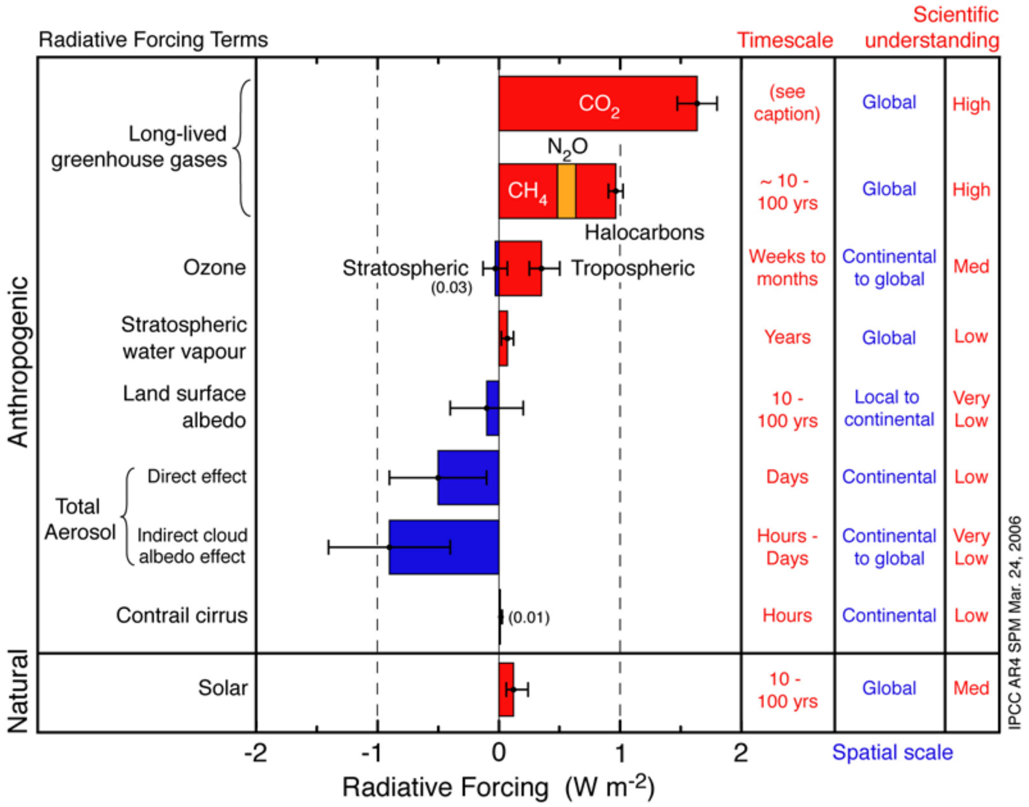

FIGURE SPM-2. Global-mean radiative forcings and their 65% (1 sigma) uncertainty range for various agents and mechanisms. Columns on the right hand side specify: (Timescale) the approximate duration of variation/change in the agent; (Spatial scale) typical geographical extent of the forcing; (Scientific understanding) scientific confidence level as explained in section 2.9. No CO_2 timescale is given as its removal from the atmosphere involves many processes and cannot be expressed accurately with a single lifetime. Errors for CH_4, N_2O, and halocarbons have been combined. [Figure 2.24]

- Aerosols produce a net negative direct radiative forcing (–0.5 ± 0.4 W m^{-2}), i.e. a cooling effect, with a greater contribution in the northern hemisphere than the southern hemisphere. This forcing is now better understood than at the time of the TAR due to improved *in situ*, satellite and ground-based measurements. Anthropogenic sulfate emissions have been decreasing over the past two decades. [2.4].

- Aerosol effects on cloud properties cause a further negative indirect radiative forcing (–0.9 ± 0.5 W m^{-2}). Aerosols also have additional effects on precipitation and the hydrological cycle. Aerosol and cloud interaction processes are poorly understood, causing substantial uncertainty in estimates of the overall impact of aerosols on climate change. [2.4, 2.9, 7.5]

- Global land-cover changes have increased surface reflection of sunlight, exerting a cooling effect on climate estimated to be –0.1 ± 0.3 W m^{-2}, with a very low level of scientific understanding. [2.5]

- Contributions to radiative forcing due to solar changes since 1750 are estimated to be 0.12 W m^{-2} with a factor of 2 uncertainty, based on improved measurements and modelling of solar irradiance and its variability. [2.7]

New studies of the 20th century and a wide range of past climates have increased confidence that radiative forcing changes affect global mean temperatures. [2.8, 9.4]

- Water vapor increases lead to a strong positive feedback that amplifies the global mean temperature response to increases in radiative forcing. New observational and modelling evidence confirms the importance of the expected feedbacks linked to water vapour[3], estimated to be approximately 1 W m^{-2} per °C of global average temperature increase, or a 40–50% amplification of global mean warming. [2.3, 3.4, 8.6, 9.4]

- Cooling associated with many large transitory volcanic eruptions are evident in the instrumental and paleoclimate records, demonstrating that forcing leads to global-scale climate responses. There is also high confidence that changes in forcing linked to the Earth's orbit around the Sun were the principal driver for past ice ages. Biogeochemical and biogeophysical feedbacks amplified the response to orbital forcing. [6.4, 6.6, 9.3]

DIRECT OBSERVATIONS OF CHANGES IN CURRENT CLIMATE

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

Observations of coherent warming in the global atmosphere, in the ocean, and in snow and ice now provide stronger joint evidence of warming. (See Figure SPM-3.) [3.2, 4.2, 5.5]

- 2005 and 1998 were the warmest two years on record. Five of the six warmest years have occurred in the last five years (2001–2005). [Will be updated to include 2006 before the final WG1 plenary in 2007.] [3.2]

- The global average surface temperature has increased since 1850. The linear warming trend over the 20th century was 0.6 ± 0.2°C in the TAR. For the period from 1901–2005 it is 0.65 ± 0.2 due to additional warm years. The record shows substantial variability. Most of the warming occurred from 1910–1945 (0.14°C per decade) and 1979–2005 (0.17°C per decade), Urban heat island effects are real but local, and do not influence these large-scale values. [3.2]

- New analyses of balloon-borne and satellite measurements of lower-tropospheric temperature show warming rates that are consistent with the surface temperature record within their respective uncertainties, representing an advance in understanding since the TAR. [3.2]

- In both hemispheres, air temperatures over land have risen at about double the rate of those over the ocean since 1979 (0.25ºC per decade versus 0.13°C per decade). [3.2]

- Global average water vapour content is increasing over land and ocean as well as in the upper troposphere, in a manner consistent with warming. [3.2]

[3] The feedback of water vapour together with feedback in the vertical profile of temperature [8.6]

- The average temperature of the global ocean to a depth of 3000 m has risen since 1955, equivalent to absorbing energy at an average rate of 0.2 W m^{-2} spread over the Earth's surface. [5.2]

- Global average sea level rose during 1961–2003 at an average rate of 1.8 ± 0.5 mm yr^{-1}. The rate during 1993–2003 was 3.1 ± 0.8 mm yr^{-1}. It is unclear whether this recent increase is due to an accelerating trend or variability on decadal timescales. Consistency between observed patterns of sea level rise and changes in ocean heat content from 1993–2003 strengthens evidence that thermal expansion is contributing to sea level rise. [5.5]

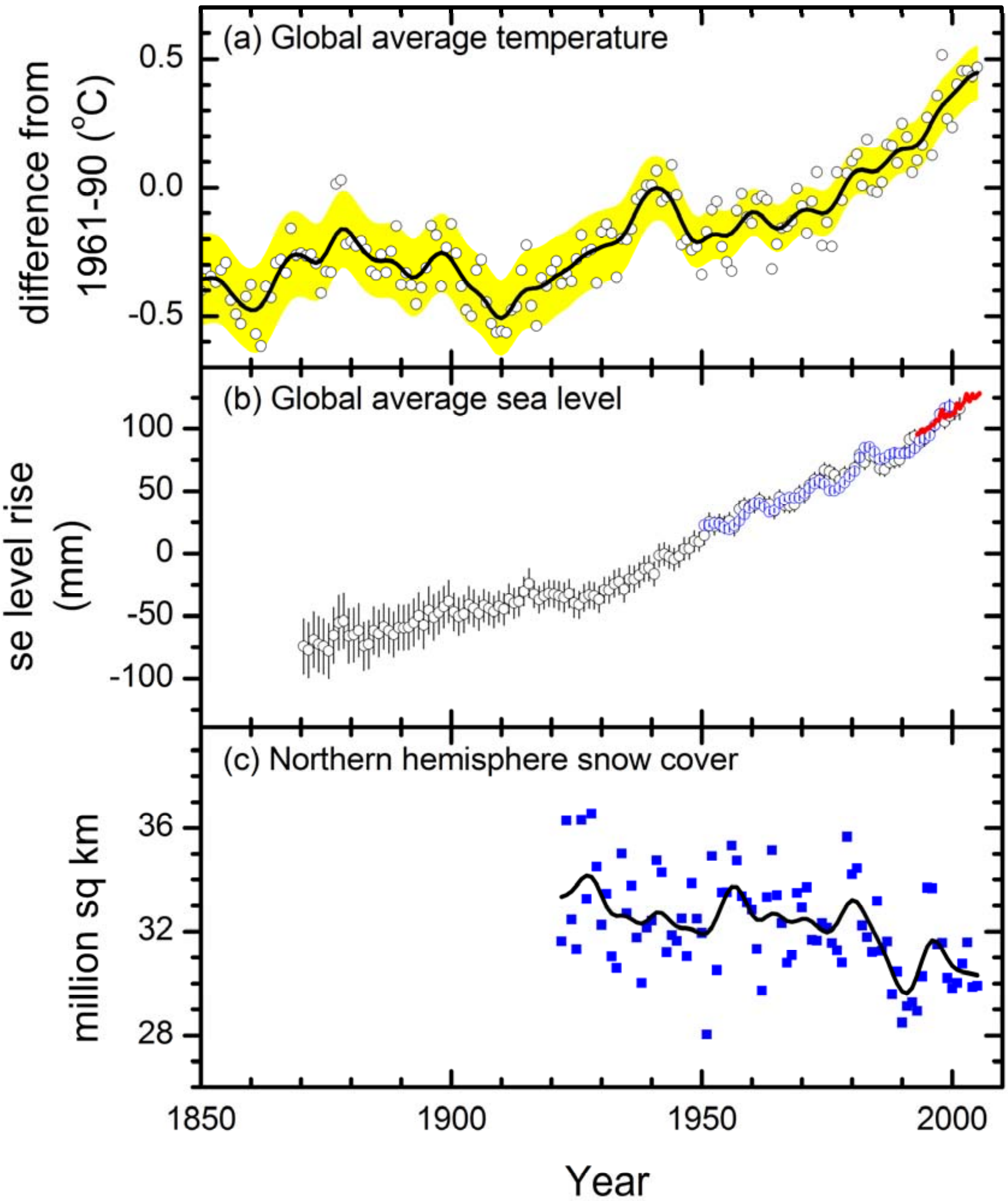

FIGURE SPM-3. Changes in global mean temperature, sea level, and snow cover area. Panel (a) shows global mean temperatures as annual values (open circles) and a smoothed curve (black line) with uncertainty in the smoothed curve shown as a yellow shaded area. The temperature change from the first 70 years of the instrumental record (1850–1919) to the last 5 years (2001–2005) is 0.78 ± 0.18ºC. Panel (b) shows global mean sea level rise from 1870 to 2001 from tide gauge data (black and blue circles) and recent satellite measurements (red line) as discussed in Section 5.5. Panel (c) shows estimates of April snow cover area in the northern hemisphere (blue squares) and smoothed values (black line). [Question 3.1, Figure 1, Figure 4.2.1 and Figure 5.5.1]

- There has been a general loss of land ice, although trends differ in some locations (particularly those that have experienced increased precipitation). Mountain glaciers are declining in area and volume averaged over both hemispheres. Decreases in glaciers and ice caps are estimated to have contributed 0.5 ± 0.3 mm yr^{-1} to the rate of global mean sea level rise between 1961 and 2003, and 0.8 ± 0.4 mm yr^{-1} between 1993 and 2003. [4.8]

- The extent of average April Northern Hemisphere (NH) snow cover decreased by about 5% during 1966–2004. Permafrost temperatures have increased on average and the maximum area covered by seasonally frozen ground has decreased by about 7% in the NH over the latter half of the 20th century. [4.7]

A broad range of climate variables shows evidence of systematic changes on both global and regional scales. [3.2, 3.3, 3.4, 3.5]

- Widespread increases in warm temperature extremes, and decreases in cold temperature extremes, have been observed. (See Table SPM-1.) [3.8]

- Changes in large-scale atmospheric circulation have affected mid- and high-latitude climate in both hemispheres. Changes have been observed in mid-latitude westerly winds, wintertime patterns of storm tracks, precipitation, and temperature, as well as wave height, and high sea level events. (See Table SPM-1.) [3.5, 3.6, 3.8]

- Satellite data since 1978 show that annual mean Arctic sea ice extent has shrunk by 2.7 ± 0.7% per decade, with larger decreases in summer of 7.4 ± 2.9% per decade. The smallest extent of summer sea ice was observed in 2005. Average Arctic temperatures have been rising since the 1960s, and 2005 was the warmest Arctic year. However, Arctic temperatures are variable, and a warm period was also observed from 1920–1945. Antarctic mean sea ice extent continues to show inter-annual variability but no consistent trends, consistent with temperatures and circulation there. [4.4]

- New observations allow a more quantitative evaluation of recent changes in Greenland and Antarctic ice sheets. Mass loss from the Greenland Ice Sheet is estimated to have contributed to raising global sea level by 0.21 ± 0.07 mm yr^{-1} from 1993–2003. Greater uncertainty exists for earlier periods and in Antarctica. Recent observations also show rapid changes in ice sheet flows. [4.6, 4.8]

- Droughts have increased, consistent with acceleration in the water cycle and greater continental evapotranspiration. Observed changes in sea surface temperatures (SST), circulation patterns, and decreased snowpack and snow cover are also linked to droughts. [3.3]

- Latitudinal patterns of precipitation trends are emerging, although identification is limited by the length and consistency of records. On average there has been less precipitation over land from 10°N to 30°N after about 1970, while increased precipitation has been observed poleward of about 30° in both hemispheres. Observations of trends in ocean salinity provide new and independent support for these changes. [3.3, 5.2]

- Widespread increases in heavy precipitation events have been observed, even in areas where there has been a reduction in total precipitation. [3.8, 3.9]

- There is no clear trend in the total numbers of tropical cyclones. There is evidence for a global trend towards more intense tropical cyclones in the satellite record since about 1970, correlated with observed changes in tropical SSTs. However, there are concerns about the quality of the historical tropical cyclone data. [3.5, 3.8]

Table SPM-1. Trends, attribution and projections of extreme weather and climate events for which there is evidence of an observed late 20th century trend. Colour coding groups phenomena with similar levels of likelihood of attribution of trend to human influence. Italics indicate cases where no formal detection and attribution study has been completed. [Tables 3.7, 3.8, 9.7.1, 11.3.3, and Section 5.5]

Phenomenon	***Likelihood that trend occurred in late 20th century (typically post 1960)***	***Likelihood that observed trend is due to human influence***	***Confidence[a] in trend predicted for 21st century***
Cool days / cool nights / frosts: decrease over mid- and high-latitude land areas	Very likely	Likely	High
Warm days / warm nights: increase over mid- and high-latitude land areas	Very likely	Likely (warm nights)	High
Warm spells / heat waves: increase	Likely	*More likely than not*	High
Proportion of heavy precipitation events: increase over many areas	Likely	*More likely than not*	High (but a few areas with projected decreases in absolute number of heavy events)
Droughts: increase over low-latitudes (and mid-latitudes in summer)	Likely	More likely than not	Moderate – mid-latitude continental interiors in summer (but sensitive to model land-surface formulation)
Tropical cyclones: increase in intensity	More likely than not since 1970	*More likely than not (but with low confidence)*	Moderate (few high-resolution models)
Mid- and high-latitude cyclones: increase in most intense storms; storm tracks move polewards	More likely than not	*Not assessed*	Moderate (intensity not explicitly analysed for all models)
High sea level events: increase (excludes tsunamis)	More likely than not	*Not assessed*	Moderate (most mid-latitude oceans)

Notes:
(a) Confidence terms for projected trends are as follows: "high" means consistency across model projections and/or consistent with theory and/or changes in mean; "moderate" indicates some inconsistencies across model projections or only a few relevant model projections available or analysed.

A Paleoclimatic Perspective

Paleoclimatic studies use changes in climatically sensitive indicators to infer past changes in climate on time scales ranging from thousands to millions of years. Proxy data (e.g., tree ring width) may be influenced by both local temperature and other factors such as precipitation, and are often representative of particular seasons rather than full years. Recent studies draw confidence from coherent behaviour across multiple indicators in different parts of the world, but uncertainties generally increase with time into the past due to the sparsity of relevant data.

- Some recent studies indicate greater variability in NH temperatures over the last 1000 years than reported in the TAR and imply a larger warming since the early 19th century. Average NH temperatures during the second half of the 20th century were very likely warmer than any other 50-year period in the last 500 years and likely the warmest in the past 1000 years. [6.6]

- During the last interglacial period, about 125,000 years ago, it is likely that large-scale retreat of the Greenland Ice Sheet and other Arctic ice fields contributed between 2 and 3.5 meters to a sea level rise above current levels. This is associated with estimated Arctic summer temperatures about 2–4°C higher than at present, and linked to forcing due to changes in the Earth's orbit around the Sun. [6.4]

UNDERSTANDING AND ATTRIBUTING CLIMATE CHANGE

Studies that attribute climate change to natural and human influences require observational data sets, climate models and statistical methods. Confidence in the assessment of the human contributions to recent climate change has increased considerably since the TAR, in part because of stronger signals emerging in longer records, as well as an expanded range of observations. There have also been improvements in the simulation of many aspects of climate and its variability on seasonal, interdecadal, and paleoclimate timescales, although uncertainties remain.

It is very likely that greenhouse gas forcing has been the dominant cause of the observed warming of globally averaged temperatures in the last 50 years. [9.4]

- It is likely that cooling effects due to volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place during the past 50 years. Anthropogenic warming of the climate system can be detected and attributed in temperature observations taken at the surface, in the free atmosphere and in the upper several hundred meters of the ocean. The observed pattern of tropospheric warming and stratospheric cooling can be attributed to the influence of anthropogenic forcing, particularly that due to greenhouse gas increases and stratospheric ozone depletion. [3.2, 3.4, 9.4, 9.5]

- The observed widespread warming of the atmosphere and ocean, together with ice mass loss jointly supports the conclusion that it is highly unlikely (<5%) that recent global climate change was caused by natural internal variability. [4.8, 5.2, 9.5]

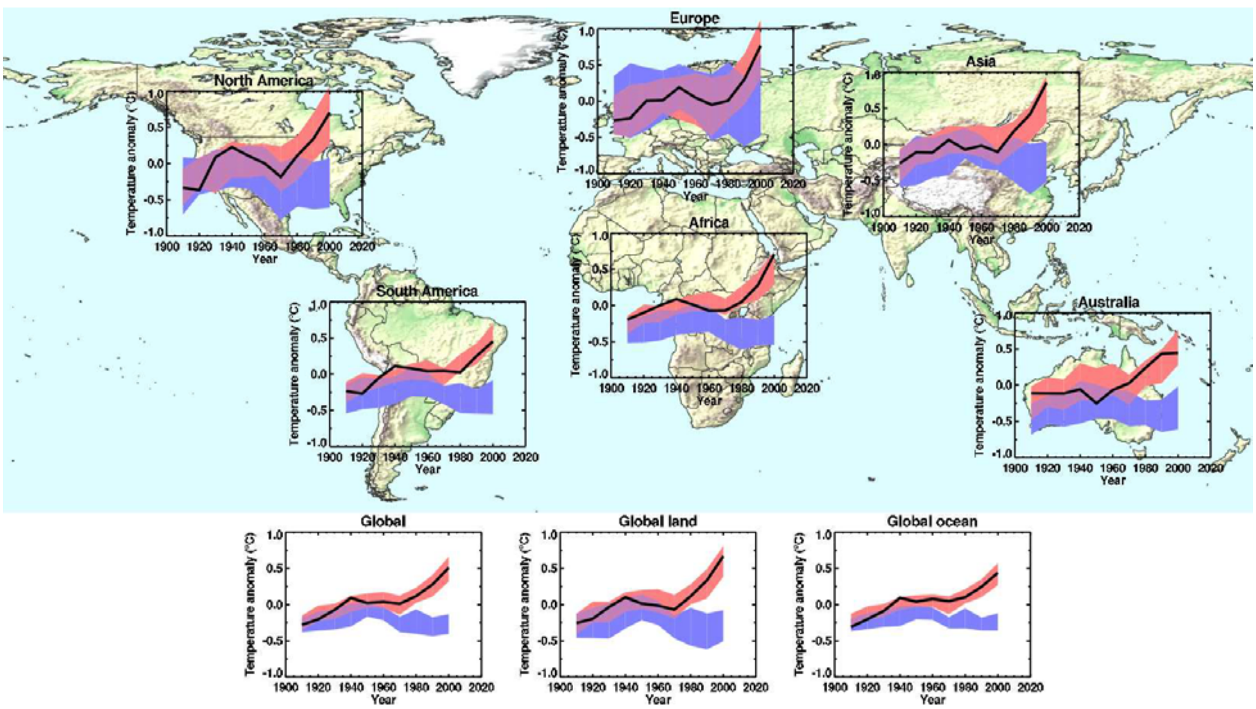

FIGURE SPM-4. Continental- and global-scale decadal surface air temperature anomalies for 1906–2005, relative to the 1901–1997 period, compared to model simulations. Black lines indicate observed changes. Blue bands show the 5–95% range for 19 simulations using only natural forcings and red bands show that range for 51 model simulations using both natural and anthropogenic forcings. [Question 9.2, Figure 1]

- An anthropogenic signal in surface temperature changes is indicated by contrasts between global land and ocean temperatures, and warming has likely been detected in all inhabited continents (see Figure SPM-4). The chance that these patterns are spurious is very small. Difficulties remain in simulating temperature changes in specific parts of the world. Climate variability linked to internal climate processes represents a physical limit in attribution studies that becomes more important at smaller scales relative to the predictable changes due to external forcings. [7.5, 9.4]

An increasing body of evidence suggests a discernible human influence on other aspects of climate including sea ice, heat waves and other extremes, circulation, storm tracks, and precipitation. [9.5]

- Anthropogenic forcing has likely contributed to recent decreases in Arctic sea ice extent. Improvements in the modelled representation of sea ice and of ocean heat transport strengthen the confidence in this conclusion. [4.4, 8.3, 9.5]

- In addition to temperature, human influences are likely to have contributed to changes in circulation patterns[4] and related variables including winds and precipitation in both hemispheres. However, differences in the magnitudes of model simulations and observed changes are not understood. [9.5, 10.3]

- Trends in surface temperature extremes including frost days, cold nights and cold days are likely to have been affected by anthropogenic forcing. Anthropogenic forcing may have increased the risk of heat waves. (See Table SPM-1) [9.4]

Proxy climate data and paleoclimate models have been used to increase confidence in understanding past and present influences on climate. [6.6, 9.3]

- A large fraction of Northern Hemisphere interdecadal variability in temperature reconstructions for the seven centuries before the mid-20th century is very likely attributable to natural external forcing, particularly to known volcanic eruptions, causing episodic cooling, and long-term variations in solar irradiance. [6.6, 9.3]

- Attribution studies considering the entire record of the past 700 years support the conclusion that it is likely that greenhouse gas forcing has been the dominant cause of the observed warming of the northern hemisphere over the last 50 years. Insufficient data are available to make a similar southern hemisphere evaluation. [6.6, 9.3]

PROJECTIONS OF FUTURE CHANGES IN CLIMATE

This assessment of climate change projections draws from an international effort involving 23 fully coupled atmosphere ocean general circulation models (AOGCMs) from 14 modelling groups, as well as models of intermediate complexity and simple climate models. The large number of simulations provides a quantitative probabilistic basis for estimating likelihoods of expected warming, representing a major advance over the TAR. Observations have also been used to provide important new constraints, and to identify model shortcomings. Model simulations consider the response of the physical climate system to a range of possible future conditions through use of idealised emissions or concentration assumptions. These include "commitment" experiments with greenhouse gases and aerosols held constant at year 2000 levels, carbon dioxide doubling and quadrupling experiments, SRES marker scenarios for the 2000–2100 period, and three "stabilisation" experiments with greenhouse gases and aerosols held constant after 2100, providing new information on the physical aspects of long term climate change and stabilisation. This Working Group I assessment does not consider the plausibility or likelihood of any specific emission scenario and is independent of the IPCC Working Group III assessment of new research on emission scenarios.

[4] Southern and Northern Annular Modes and related changes in the North Atlantic Oscillation [3.6, 9.5]

There is now increased confidence in projected near-term climate changes due to improved climate models, better understanding of commitments to further warming and more-detailed studies constraining uncertainties. [8.3, 9.4, 10.3]

- Model results consistently show that if the concentrations of all radiative forcing agents were to be stabilized, globally averaged temperatures would still increase. [10.3]

- Projections for 1990–2005 carried out for the IPCC's first and second assessment reports suggested global mean temperature increases of 0.29 and 0.15°C per decade, respectively[5]. This can now be compared to observed values of about 0.2°C per decade, providing confidence in such short-term projections. Some of this warming was due to commitments to changes linked to the known concentrations of greenhouse gases at the times of those earlier assessments. [1.2, 3.2]

- If the concentrations of all radiative forcing agents were stabilized today, a committed warming of about 0.1°C per decade would be expected in the next several decades due largely to the slow response of the oceans, unless there are large changes in volcanic eruptions or solar forcing. About twice as much warming (0.2°C per decade) would be expected if emissions follow those of the SRES scenarios. On these time scales this result is insensitive to the choice among the SRES marker scenarios, which do not consider any policy intervention (see Figure SPM-5). [10.5]

Further emissions of greenhouse gases would be expected to change the climate of the 21st century globally and regionally. (See Figure SPM-5.) [10.3]

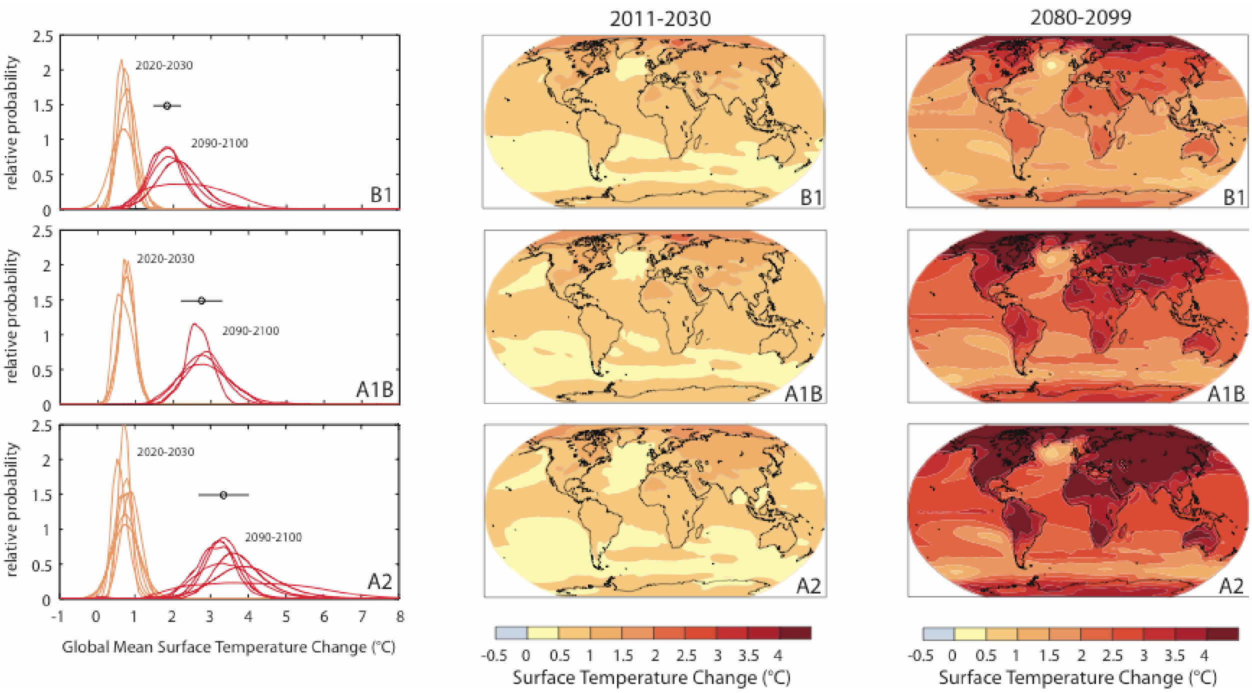

FIGURE SPM-5. Projected temperature changes for the early and late 21st century relative to the period 1980–1999. The central and right panels show the multi-model mean projections for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over 20-year periods 2011–2030 (central) and 2080–2099 (right). The left panel shows corresponding uncertainties as the relative probabilities in estimated global mean warming from several different studies for periods 2020–2030 and 2090–2100. [Figures 10.3.5 and 10.5.7.]

[5] See IPCC Second Assessment Report Summary for Policymakers.

- Projected 65% probability ranges (mean ± 1 standard deviation) for globally-averaged surface warming in 2100 compared to 1980–2000 and including carbon cycle feedback uncertainties are scenario dependent and estimated to be 1.5–2.8°C, 2.3–4.1°C, 3.0–5.0°C and 3.5–5.8°C for the B1, A1B, A2, and A1FI scenarios respectively. [10.5]

- Additional information on future temperature change is provided by studies of equilibrium climate sensitivity. Probabilistic analysis of models together with constraints from observations suggest that the climate sensitivity is likely to be in the range 2–4.5°C, with a most likely value of about 3°C. It is very unlikely to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement with observations is worse for those values. [9.3, Box 10.2]

- Projected future warming shows scenario-independent geographical patterns similar to those observed over the past 50 years. Warming is expected to be greatest at high northern latitudes and over land (roughly twice the global average), and least over the Southern Ocean and North Atlantic. [10.3]

- Sea ice shrinks both in the Arctic and Antarctic under all scenarios. This reduction is amplified by feedbacks in the Arctic where some models project sea ice to disappear for the A2 scenario by the latter part of the 21st century. [10.3]

- Glaciers, ice caps, and snow cover are projected to contract, and up to 90% of the upper layer of permafrost is projected to thaw in the A2 scenario by 2100. [10.3, 10.6]

- Recent studies do not suggest substantial future increases in the total number of tropical cyclones (typhoons and hurricanes) but do suggest future increased storm intensities, with larger peak wind speeds and more intense precipitation. The reported increase in the proportion of very intense storms since 1970 is in the same direction but much larger than simulated by current models. [9.5, 10.3]

- Projected changes in winter circulation patterns are now more consistent across models. Storm tracks are expected to move poleward, with consequent changes in wind, precipitation, and temperature patterns over the Arctic and Antarctic regions and surrounding mid-latitudes, continuing the broad pattern of observed trends over the last half-century. These changes are linked to fewer but more intense mid-latitude storms with associated damaging winds and extreme wave heights. [10.3]

- There is now greater confidence than at the time of the TAR in projected patterns of changes in precipitation with, in general, decreases in dry regions and increases in wet regions. (See Figure SPM-6.) [8.3, 9.5, 10.3, 11.3]

- Increasing atmospheric carbon dioxide concentrations lead directly to increasing acidification of the surface ocean. Projections based on SRES scenarios give reductions in pH of between 0.14 and 0.35 units in the 21st century (depending on scenario), adding to the present decrease of 0.1 units from pre-industrial times, and raising concerns for marine calcifying organisms. [Box 7.3, 10.4]

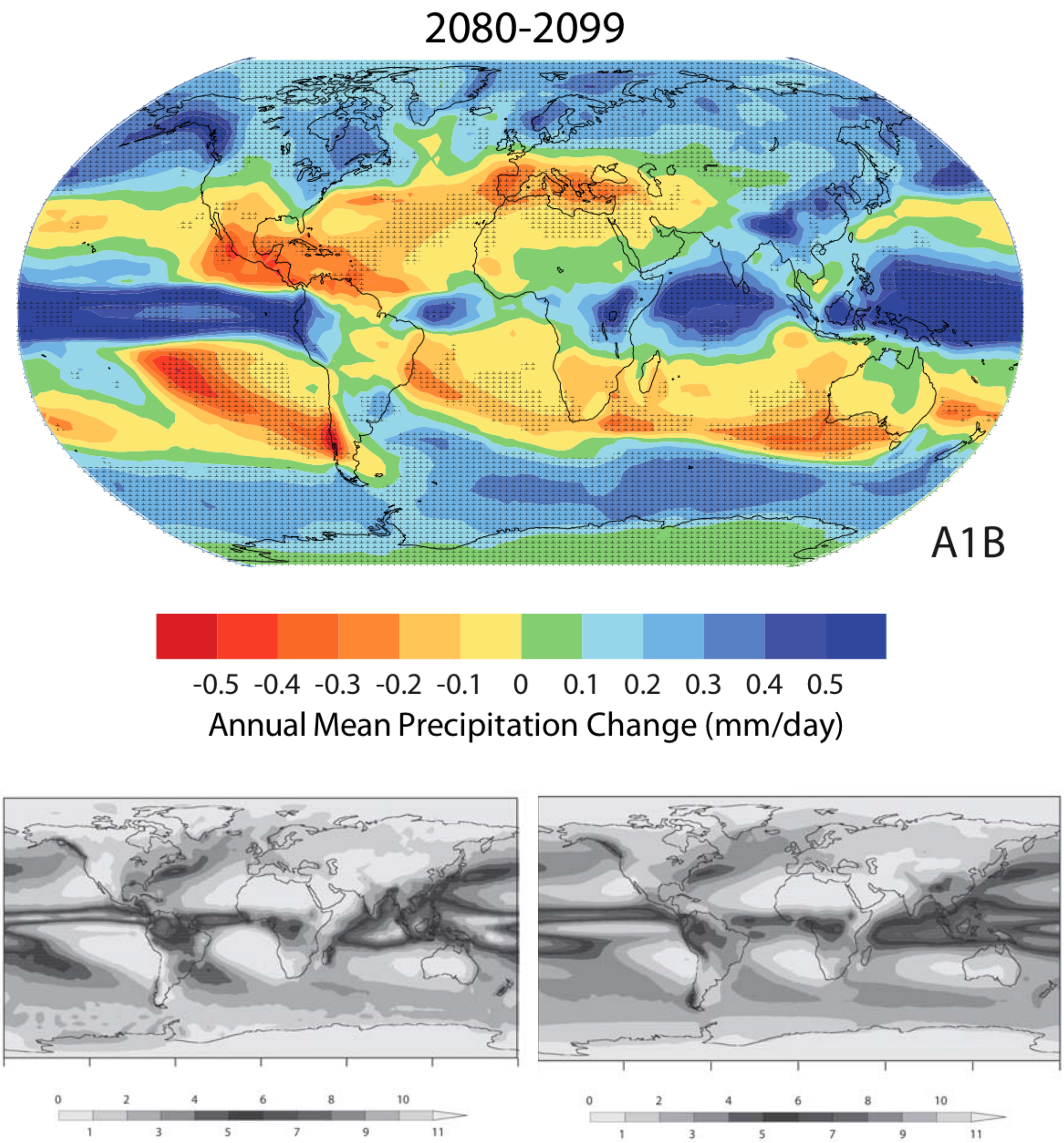

FIGURE SPM-6. Spatial patterns of observed annual mean precipitation rate (lower left panel) and model simulations (lower right panel) for the period 1979–1993 with the multi-model mean estimate for changes by the period 2080–2099 relative to 1980–1999 based on the SRES A1B scenario (upper panel). Units are mm per day and regions where 75% or more of the models used agree in the sign of precipitation changes are stippled. [Figures 8.3.4, 10.3.9, Box 11.1, Figure 2]

Current understanding of climate processes provides an important context for considering policy options that might lead to climate stabilization. [10.4, 10.5, 10.7]

- Very long-term projections of climate change are subject to more uncertainty due to lower levels of understanding of slow feedbacks and processes that operate over time scales of thousands of years. Despite this limitation, present scientific understanding provides useful input for policy options that consider long-term climate change. Observations and models show that climate is changing and is expected to continue to change. Stabilization of radiative forcing is a prerequisite for climate stabilization. Changes in sea level, ocean circulation and ice sheets will continue for centuries or longer. [10.7]

- The long lifetime of atmospheric carbon dioxide implies climate change commitments that persist for centuries. Increases in global temperatures are expected to progressively reduce the efficiency of the ocean and biosphere to absorb anthropogenic carbon dioxide emissions. This positive feedback effect could lead to as much as 1.2°C of added warming by 2100 for higher SRES emission scenarios. Alternatively it reduces the total emissions consistent with a given carbon dioxide stabilization level, although there are still uncertainties due, for example, to limitations in the understanding of biophysical interactions and feedbacks. [7.3]

- Human activities affect methane, nitrous oxide, tropospheric ozone, and aerosols. Interactions between tropospheric ozone, aerosols, air quality, and climate are likely to contribute to future climate changes but are subject to large uncertainties. [7.4, 7.5]

- Models suggest a weakening of the Atlantic meridional overturning circulation (MOC) ranging from small values up to 60% by 2100. Temperatures over the North Atlantic Ocean and Europe are projected to warm despite such changes, due to the much larger radiative effects of the increase of greenhouse gases. No models suggest an abrupt MOC shutdown during the 21st Century. The likelihood of longer-term changes cannot be evaluated with confidence. [10.3, 10.7]

- Sea level rise commitments have much longer timescales than warming commitments, owing to slow processes that mix heat into the deep ocean. By 2100, sea level rise is projected to range from 0.14–0.43 m for the A1B scenario concentrations for example, but would be expected to show larger increases (0.3–0.8 m due to thermal expansion) in the next two centuries even after stabilization at those concentrations. [10.6, 10.7]

- Changes in the ice sheets could significantly affect future sea level rise commitment. Models suggest that a global average warming of 3°C above present levels would cause widespread mass loss of the Greenland Ice Sheet if sustained for several centuries, initially contributing up to 0.4 m sea level rise per century. The melting rate would increase if dynamical processes increase the rate of ice flow, as suggested by some recent observations. This level of warming could occur during the 21st century depending upon the climate sensitivity and the emission scenario, and is comparable to that of the last interglacial period about 125,000 years ago, when paleoclimate data suggest that widespread Arctic melting contributed several meters of sea level rise. [10.7]

- The Antarctic Ice Sheet is projected to behave differently from that of Greenland because it is too cold for widespread surface melting. It is expected to gain ice through increased snowfall in the 21st century, acting to reduce global sea level rise by about 0.1 m per century. However, in response to weakening of ice shelves by ocean warming or surface melting at the margins, ice flow could accelerate. Such effects could offset or outweigh increased snowfall but are uncertain. [10.7]