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"CLIMATE CHANGE 2007, THE PHYSICAL SCIENCE BASIS"
WORKING GROUP I CONTRIBUTION TO THE IPCC FOURTH ASSESSMENT REPORT

DRAFT SUMMARY FOR POLICYMAKERS

(Submitted by the Co-chairs of Working Group I)

The draft Summary for Policymakers is submitted to the Tenth Session of Working Group I for approval. The approved Summary for Policymakers will be forwarded to the Twenty-Sixth Session of the IPCC (Bangkok, 4 May 2007) for acceptance.

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

Climate Change 2007: The Physical Science Basis

Summary for Policymakers

Note: The content of the Final Draft of the Working Group I contribution to the IPCC Fourth Assessment Report should not be cited or quoted, and is embargoed from coverage by the news media.

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INTRODUCTION

The Working Group I contribution to the IPCC Fourth Assessment Report describes the current scientific understanding of the dominant causes of climate change[1], observed climate change, climate processes and attribution, and a range of estimates of projected future climate change. It builds upon past assessments and incorporates new results from the past six years of research.

The basis for substantive paragraphs in this Summary for Policymakers can be found in the chapter sections specified in curly brackets.

HUMAN AND NATURAL DRIVERS OF CLIMATE CHANGE

Changes in the atmospheric abundance of greenhouse gases and aerosols, in solar radiation and in land surface properties 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[2], which is used to compare warming or cooling influences on global climate.

Current atmospheric concentrations of carbon dioxide and methane far exceed pre-industrial values determined from ice cores spanning the last 650,000 years. The increases in these greenhouse gases since 1750 (see Figure SPM-1) are due primarily to emissions from fossil fuel use, agriculture, and land-use changes. {2.3, 6.4, 7.3}

- Carbon dioxide is the most important anthropogenic greenhouse gas. Its atmospheric concentration increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005. Annual fossil carbon dioxide emissions[3] increased from an average of 6.4 [6.0 to 6.8][4] GtC yr^{-1} in the 1990s, to 7.2 [6.9 to 7.5] GtC yr^{-1} in 2000–2005. Average carbon dioxide emissions associated with land-use change in the 1990s are *likely*[5] to have been between 0.5 and 2.7 GtC yr^{-1}. {2.3, 7.3}

- The atmospheric methane concentration increased from a pre-industrial value of about 715 ppb to 1774 ppb in 2005. Growth rates have declined since 1993, consistent with total emissions being nearly constant during this period. Most methane emissions are due to human activities, predominantly agriculture and fossil fuel use, but relative contributions from different source types 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. 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}). See Glossary for further details.

[3] Fossil carbon dioxide emissions include those from the production, distribution and consumption of fossil fuels and from cement production.

[4] Assessed uncertainty ranges given in this Summary for Policymakers are 90% confidence intervals, i.e., there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range. Best estimates are given where available. Assessed confidence intervals are not always symmetric about the corresponding best estimate.

[5] In this Summary for Policymakers, the following terms have been used to indicate the assessed likelihood of an outcome or a result: *Virtually certain* > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Very unlikely* < 10%, *Extremely unlikely* < 5%.

- The atmospheric nitrous oxide concentration increased from a pre-industrial value of about 270 ppb to 319 ppb in 2005. The growth rate has been approximately constant since 1980. More than a third of all nitrous oxide emissions are anthropogenic and are primarily due to agriculture. {2.3,7.4}

CHANGES IN GREENHOUSE GASES FROM ICE-CORE AND MODERN DATA

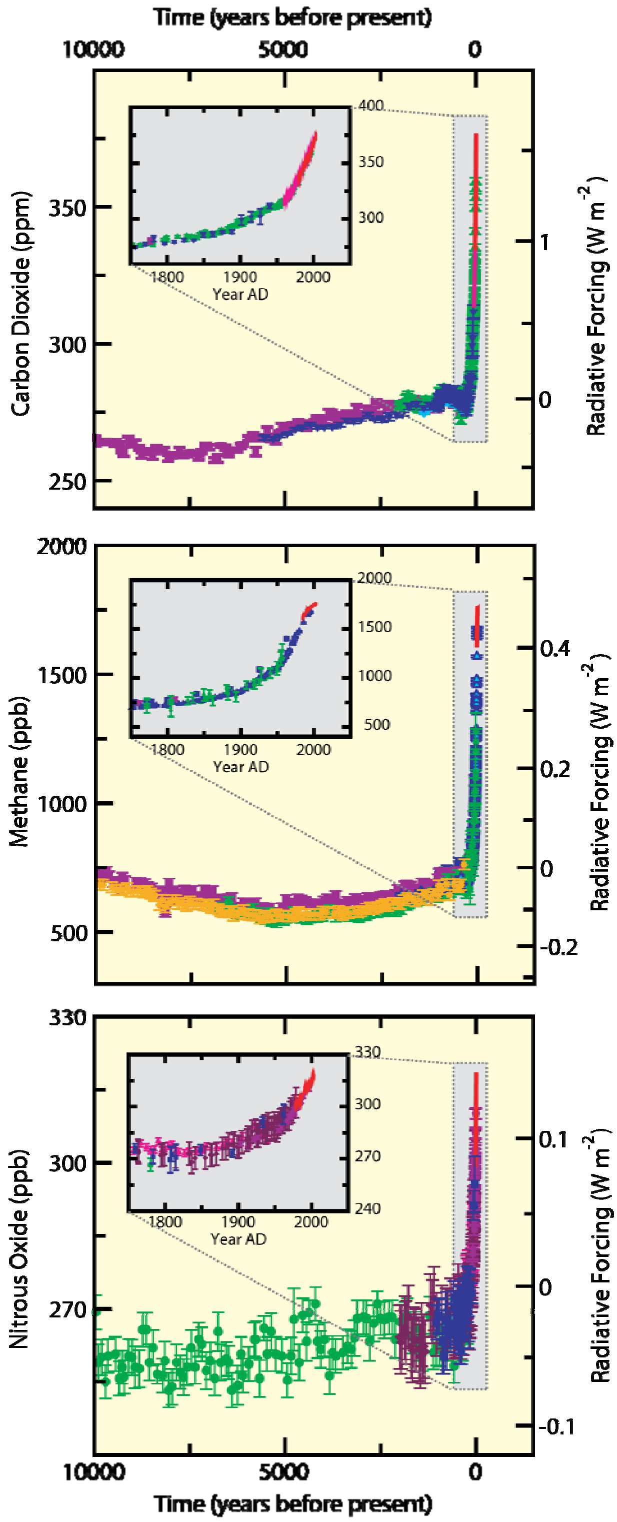

FIGURE SPM-1. Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (lines). The corresponding radiative forcings are shown on the right hand axes of the large panels. {Figure 6.4}

The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report (TAR), leading to 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}. This is *likely* to have been at least five times greater than that due to solar output changes. (see Figure SPM-2). {2.3. 6.5, 2.9}

- The combined radiative forcing due to increases in carbon dioxide, methane, and nitrous oxide 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 (see Figures SPM-1 and SPM-2). The CO_2 radiative forcing increased by 20% during the last 10 years (1995–2005), the largest change observed or inferred for any decade in at least the last 200 years. {2.3, 6.4}

- Anthropogenic aerosols (primarily sulphate, organic carbon, black carbon, nitrate and dust) together produce 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}. These forcings are now better understood than at the time of the TAR due to improved *in situ*, satellite and ground-based measurements and more comprehensive modelling, but remain the dominant uncertainty in net radiative forcing. Aerosols also influence cloud lifetime and precipitation. {2.4, 2.9, 7.5}

- Anthopogenic tropospheric ozone changes contribute +0.35 [+0.25 to +0.65] W m^{-2}, while the direct contribution due to changes in halocarbons is +0.34 [+0.31 to +0.37] W m^{-2}. {2.3}

RADIATIVE FORCING COMPONENTS

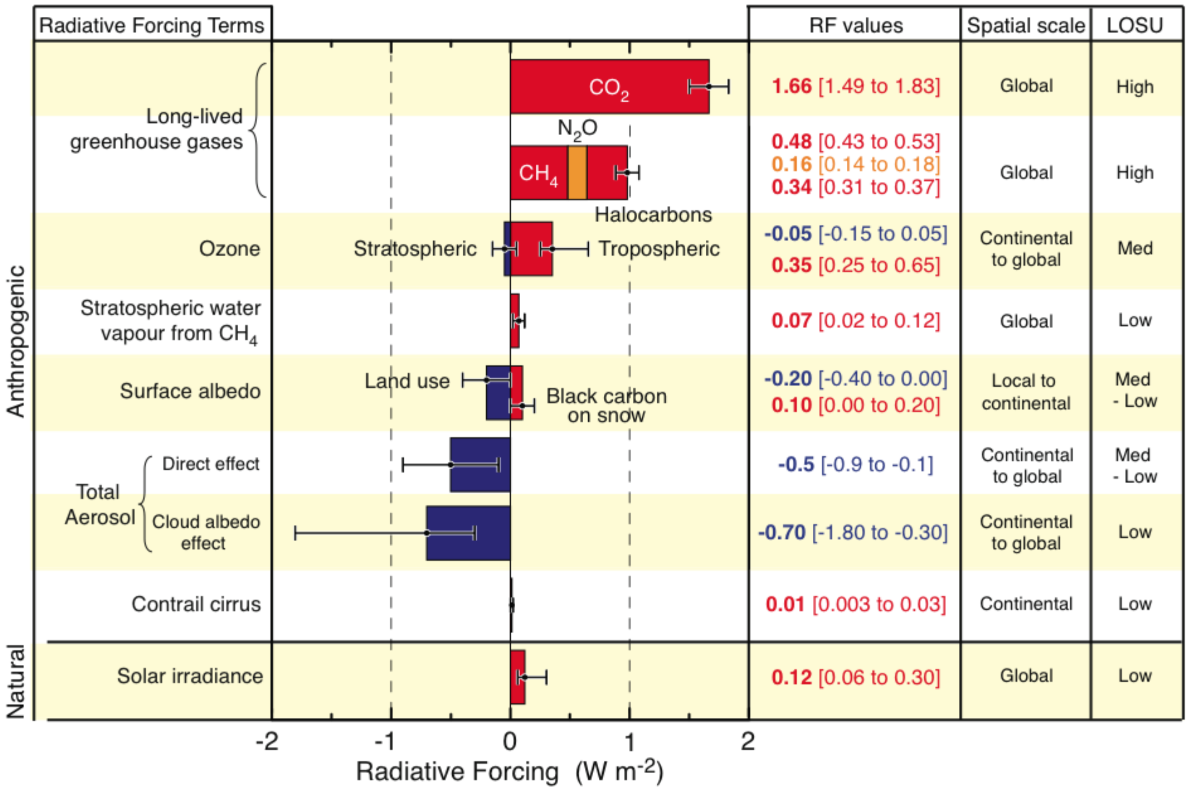

FIGURE SPM-2. Global-average radiative forcing (RF) estimates and ranges in 2005 for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. {2.9, Figure 2.20}

- Changes in surface albedo, due to land-cover changes and deposition of black carbon aerosols on snow, exert respective forcings of -0.2 [-0.4 to 0.0] and +0.1 [0.0 to +0.2] W m^{-2}. {2.5, 7.2}

- Changes in solar output 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. {2.7}

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 and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. Increasingly comprehensive observations are available for glaciers and snow cover since the 1960s, and for sea level and ice sheets since about the past decade.

Warming of the climate system is unequivocal, as is now evident from increases in global average air and ocean temperatures, melting of snow and ice, and rising sea level (see Figure SPM-3). {3.2, 4.2, 5.5}

CHANGES IN TEMPERATURE, SEA LEVEL AND NORTHERN HEMISPHERE SNOW COVER

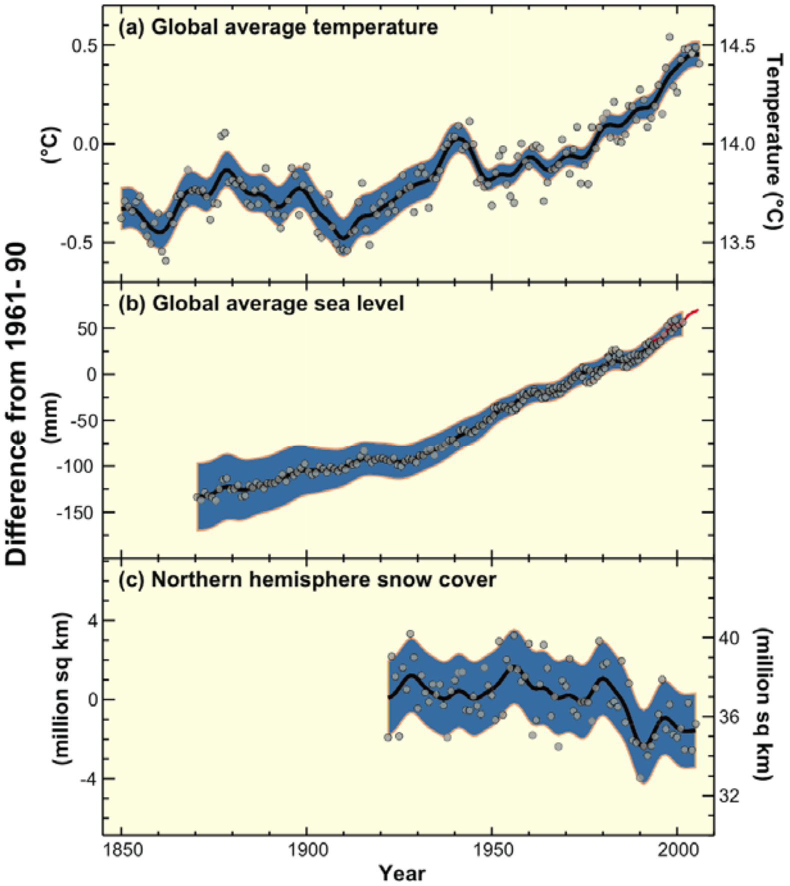

FIGURE SPM-3. Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves and shaded areas represent decadal averaged values and their assessed uncertainty intervals, while circles show yearly values. {Question 3.1, Figure 1, Figure 4.2 and Figure 5.13}

- Eleven of the last twelve years rank among the 12 warmest years in the instrumental record of global surface temperature[6] (since 1850) (*update for 2006 before final plenary*). The updated 100-year linear trend (1906–2005) of 0.74 [0.56 to 0.92]°C is therefore larger than the corresponding trend at the time of the TAR (1901–2000) of 0.6 [0.4 to 0.8]°C. The linear rate of warming averaged over the last 50 years (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the last 100 years. Urban heat island effects are real but local, and have a negligible influence on these values. {3.2}

- New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates that are similar to the surface temperature record and consistent within their respective uncertainties, largely reconciling a discrepancy noted in the TAR. {3.2, 3.4}

- The average atmospheric water vapour content has increased since at least the 1980s over land and ocean as well as in the upper troposphere. The increase is broadly consistent with the extra water that warmer air can hold. {3.4}

- Observations show that the average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been absorbing most of the heat added to the climate system. Such warming causes seawater to expand and is estimated to have contributed 0.42 [0.30 to 0.54] mm yr^{-1} to the average sea level rise from 1961 to 2003, and 1.6 [1.1 to 2.1] mm yr^{-1} from 1993 to 2003. {5.2, 5.5}

- Mountain glaciers and snow cover have declined on average in both hemispheres. Decreases in glaciers and ice caps[7] contributed to sea level rise by 0.50 [0.32 to 0.68] mm yr^{-1} from 1961 to 2003 and 0.77 [0.55 to 0.99] mm yr^{-1} from 1993 to 2003. {4.7, 4.8}

- Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm yr^{-1} over 1961 to 2003. The rate was faster over 1993 to 2003, about 3.1 [2.4 to 3.8] mm yr^{-1}, but tide gauge records indicate similar rates for other periods since 1950. Whether the faster rate for 1993 to 2003 reflects decadal variability or an increase in the longer-term trend is unclear. There is high confidence that the rate of observed sea level rise increased from the 19th to the 20th century, and the total 20th century rise is estimated to be 0.17 [0.12 to 0.22] m. {5.5}

Numerous changes in climate have been observed at the scales of continents or ocean basins. These include wind patterns, precipitation, ocean salinity, sea ice, ice sheets, and aspects of extreme weather. {3.2, 3.3, 3.4, 3.5, 3.6, 5.2}

- Average Arctic temperatures increased at almost twice the global average rate in the past 100 years. However, Arctic temperatures have high decadal variability. A warm period was also observed from 1925 to 1945, but appears to have had a different spatial distribution than the recent warming. {3.2}

- 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. {4.4}

- Taken together, shrinkage of the ice sheets of Greenland and Antarctica has contributed 0.41 [0.06 to 0.76] mm yr^{-1} to sea level rise over 1993 to 2003. Flow speed has increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior of the ice sheets. {4.6, 4.8, 5.5}

[6] The average of near surface air temperature over land, and sea surface temperature.

[7] Ice caps do not include contributions from the Greenland and Antarctic ice sheets.

- Temperatures at the top of the permafrost layer have increased by up to 3°C since the 1980s in the Arctic. The maximum area covered by seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900. {4.7}

- Long-term trends from 1900 to 2005 have been observed in precipitation amount over many large regions. Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Precipitation is highly variable spatially and temporally, and robust long-term trends have not been observed for other large regions. {3.3, 3.9}

- More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. Increased drying due to higher temperatures and decreased precipitation have contributed to these changes. Changes in sea surface temperatures (SST), atmospheric circulation patterns, and decreased snowpack and snow cover have also been linked to droughts. {3.3}

- Basin-scale changes in ocean salinity provide further evidence of changes in the Earth's water cycle. {5.2}

- The frequency of heavy precipitation events has increased, consistent with warming and observed increases of atmospheric water vapour. {3.8, 3.9}

- Widespread changes in extreme temperatures have been observed over the last 50 years. Cold days, cold nights and frost have become rarer, while hot days, hot nights, and heat waves have become more frequent (see Table SPM-1). {3.8}

- There is no clear trend in the annual number of tropical cyclones[8]. Satellite records suggest a global trend towards more-intense tropical cyclones since about 1970, correlated with observed warming of tropical SSTs. There are concerns about the quality of tropical cyclone data, particularly before the satellite era. {3.8}

Some important aspects of climate appear not to have changed. {3.2, 3.8, 4.4, 5.3}

- Data available since the TAR show that the average difference between day- and night-time temperatures has not changed since 1979, both having risen at about the same rate. {3.2}

- Antarctic sea ice extent continues to show inter-annual variability and localized changes but no statistically significant average trends, consistent with the lack of warming in atmospheric temperatures averaged across the continent. {3.2, 4.4}

- There is insufficient evidence to determine whether trends exist in some other variables, for example, the meridional overturning circulation of the global ocean on large-scales, and tornadoes, hail, lightning and dust-storms on small scales. {3.8, 5.3}

[8] Tropical cyclones include hurricanes and typhoons.

Table SPM-1. Recent trends, assessment of human influence on the trend, and projections for extreme weather and climate events for which there is an observed late 20th century trend. {Tables 3.7, 3.8, 9.4, Sections 3.8, 5.5, 9.7, 11.2-11.9}

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of discernible human influence on observed trend	Likelihood of continuation of trend based on projections for 21st century using SRES scenarios.
Warmer/fewer cold days/nights over most land areas.	*Very likely*[b]	*Likely*[d]	*Virtually certain*[d]
Warmer/more hot days/nights over most land areas.	*Very likely*[c]	*Likely (nights)*[d]	*Virtually certain*[d]
Warm spells / heat waves. Frequency increases over most land areas.	*Likely*	*More likely than not*	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas.	*Likely*	*More likely than not*	*Very likely*
Area affected by droughts increases.	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Number of intense tropical cyclones increases.	*Likely*, since 1970	*More likely than not*	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis).	*Likely*	*More likely than not*	*Likely*

Notes:
(a) See Table 3.7 for definitions
(b) Decreased frequency of cold days/nights (coldest 10%)
(c) Increased frequency of hot days/nights (hottest 10%)
(d) Warming of the most extreme days/nights each year

A Paleoclimatic Perspective

Paleoclimatic studies use changes in climatically sensitive indicators to infer past changes in climate on time scales ranging from hundreds to millions of years. Such 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 include additional data since the TAR and draw confidence from coherent behaviour across multiple indicators in different parts of the world. However, uncertainties generally increase with time into the past due to increasingly limited spatial coverage.

Paleoclimate information supports the unusual nature of the recent warming and suggests that past warming has driven large-scale ice sheet retreat and sea level rise. {6.4, 6.6}

- Some recent studies indicate greater variability in Northern Hemisphere temperatures than suggested in the TAR, particularly cooler periods in the 12 to 14th, 17th, and 19th centuries. Warmer periods are within the uncertainty range given in the TAR. Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* warmer than during any other 50-year period in the last 500 years and *likely* the warmest in at least the past 1300 years. {6.6}

- Global average sea level in the last interglacial period (about 125,000 years ago) was *likely* 4 to 6 m higher than during the 20th century, mainly due to retreat of polar ice. Ice core data indicate that average polar temperatures at that time were 3 to 5°C warmer than the 20th century, because of differences in the Earth's orbit. The Greenland ice sheet and other Arctic ice fields *likely* contributed no more than 4 m of the observed sea level rise, implying that there may also have been a contribution from Antarctica. {6.4}

UNDERSTANDING AND ATTRIBUTING CLIMATE CHANGE

Climate change is said to be detected when there is only a small likelihood that observed changes might have occurred solely due to natural variability. Attribution evaluates whether observed changes are consistent with quantitative responses to different forcings obtained in well-tested models, and are not consistent with alternative physically plausible explanations. The TAR concluded that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in greenhouse gas concentrations". The present assessment considers longer and improved records, an expanded range of observations, and improvements in the simulation of many aspects of climate and its variability.

It is *very likely* that anthropogenic greenhouse gas increases caused most of the observed increase in globally averaged temperatures since the mid-20th century. Discernible human influences now extend to other aspects of climate, including continental-average temperatures, atmospheric circulation patterns, and some types of extremes (see Figure SPM-4 and Table SPM-1). {9.4, 9.5}

- It is *likely* that greenhouse gases alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place. {2.9, 7.5, 9.4}

- 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 fifty years was caused by unforced variability alone. {4.8, 5.2, 9.4, 9.5, 9.7}

- Warming of the climate system has been detected and attributed to anthropogenic forcing in surface and free atmosphere temperatures, in temperatures of the upper several hundred meters of the ocean and in contributions to sea level rise. The observed pattern of tropospheric warming and stratospheric cooling can be largely attributed to the combined influences of greenhouse gas increases and stratospheric ozone depletion. {3.2, 3.4, 9.4, 9.5}

- It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica (see Figure SPM-4). The observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are simulated by models that include anthropogenic forcing. {3.2, 9.4}

GLOBAL AND CONTINENTAL TEMPERATURE CHANGE

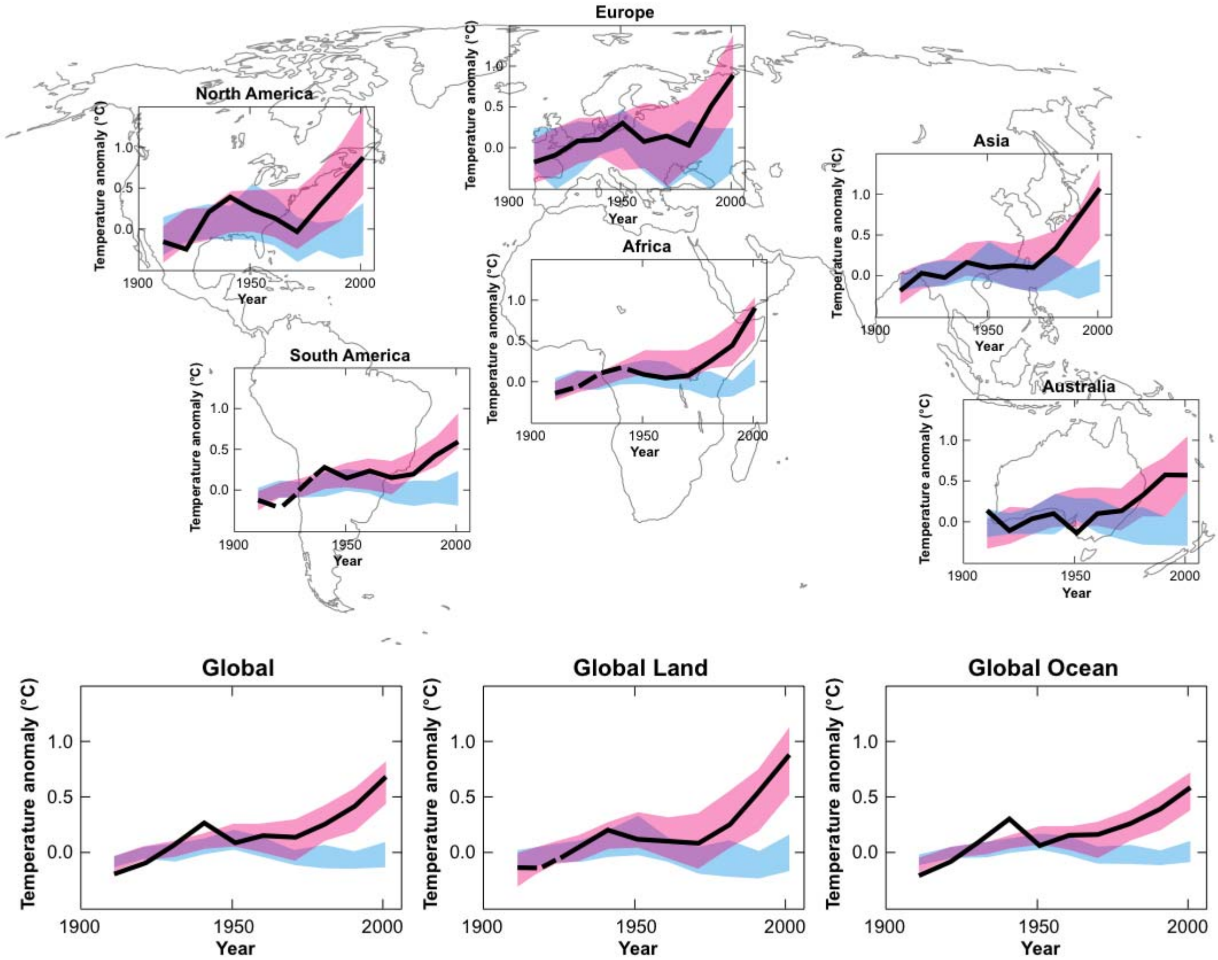

FIGURE SPM-4. Changes in continental- and global-scale decadal surface air temperature for 1906–2005, relative to the corresponding average for the 1901–1950 period, compared with model simulations. Black lines indicate observed changes and are dashed where spatial coverage is less than 50%. Blue bands show the 5–95% range for 19 simulations from 5 climate models using only natural forcings, and red bands show the 5–95% range for 58 model simulations from 14 climate models using both natural and anthropogenic forcings. The changes shown are unadjusted model output in regions where observations are available. {FAQ 9.2, Figure 1}

- Difficulties remain in reliably simulating and attributing observed temperature changes at smaller scales. Unforced variability becomes more important for sub-continental or smaller scales. This together with uncertainties in local forcings and feedbacks make it difficult to estimate the contribution of greenhouse gas increases to observed small-scale temperature changes. {8.3, 9.4}

- Human influences are *likely* to have contributed to changes in atmospheric circulation[9], affecting storm tracks, winds, and temperature patterns in both hemispheres. However, the observed changes in the Northern Hemisphere circulation are larger than simulated. {3.5, 3.6, 9.5, 10.3}

[9] In particular, the Southern and Northern Annular Modes and related changes in the North Atlantic Oscillation {3.6, 9.5, Box TS.3.1}

- Temperatures of the most extreme hot nights, cold nights and cold days are *likely* to have increased due to anthropogenic forcing. Anthropogenic forcing may have increased the risk of heat waves (see Table SPM-1). {9.4}

There is now increased confidence in the understanding of the climate system response to radiative forcing. {6.6, 8.6, 9.6. Box 10.2}

- Analysis of models together with constraints from observations suggest that the equilibrium global average warming expected if carbon dioxide concentrations were to be sustained at 550 ppm[10] is *likely* to be in the range 2 to 4.5°C above pre-industrial values, with a best estimate of about 3°C. This warming 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. Water vapour changes dominate the feedbacks affecting climate sensitivity and are now better understood than in the TAR, while cloud feedbacks remain the largest source of uncertainty. {8.6, 9.6, Box 10.2}

- It is *very likely* that climate changes of at least the seven centuries prior to 1950 were not due to unforced variability alone. A significant fraction of the reconstructed Northern Hemisphere interdecadal temperature variability over those centuries is *very likely* attributable to volcanic eruptions and changes in solar output, and it is *likely* that anthropogenic forcing contributed to the early 20th century warming evident in these records. {2.7, 2.8, 6.6, 9.3}

PROJECTIONS OF FUTURE CHANGES IN CLIMATE

A major advance of this assessment of climate change projections compared with the TAR is the large number of simulations available, which together with new approaches to constraints from observations provide a quantitative basis for estimating likelihoods of expected warming. Model simulations consider a range of possible futures including idealised emission or concentration assumptions. These include SRES[11] illustrative marker scenarios for the 2000–2100 period and model experiments with greenhouse gases and aerosol concentrations held constant after year 2000 or 2100. This Working Group I assessment does not consider the plausibility or likelihood of any specific emission scenario.

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. If concentrations had been stabilized at year 2000 levels, a committed warming of 0.1°C per decade would be expected. {9.4, 10.3}

- Since IPCC's first report in 1990, assessed projections have suggested global averaged temperature increases between about 0.15 and 0.3°C per decade for 1990 to 2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections. {1.2, 3.2}

- Model experiments in which all radiative forcing agents are held constant at year 2000 levels show that a committed warming trend would continue in the next two decades at a rate of about 0.1°C per decade, due mainly to the slow response of the oceans. About twice as much warming (0.2°C per decade) would be expected if emissions are within the range of the SRES scenarios, none of which

[10] The equilibrium climate sensitivity; see Glossary for further details.

[11] SRES refers to the IPCC Special Report on Emission Scenarios (2000). The SRES scenario families and illustrative cases, which did not include additional climate initiatives, are summarized in a box at the end of this Summary for Policymakers. Approximate CO_2 equivalent concentrations corresponding to the computed radiative forcing due to anthropogenic greenhouse gases and aerosols in 2100 (see p. 823 of the TAR) for the SRES B1, A1T, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550 ppm respectively.

considered climate initiatives. Best-estimate projections from models indicate that decadal-average warming over each inhabited continent by 2030 is insensitive to the choice among SRES scenarios and is *very likely* to be at least twice as large as the corresponding model-estimated natural variability during the 20th century. {9.4, 10.3, 10.5, 11.2–11.7, Figure TS-36}

Continued greenhouse gas 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. {10.3}

- Projected globally-averaged surface warming for the end of the 21st century (2090–2099) is scenario-dependent so that the actual warming will be significantly affected by the actual emissions that occur. Warmings relative to 1980–1999 for six SRES scenarios, given as best estimates and corresponding *likely* ranges in °C, are: B1: 1.7 [1.0 to 2.7]°C; A1T: 2.4 [1.4 to 3.8]°C; B2: 2.4 [1.4 to 3.8]°C; A1B: 2.7 [1.6 to 4.3]°C; A2: 3.2 [1.9 to 5.1]°C; A1FI: 4.0 [2.4 to 6.3]°C. {10.5}

- Warming tends to reduce land and ocean uptake of atmospheric carbon dioxide, increasing the fraction of anthropogenic emissions that remains in the atmosphere. For the A2 scenario, the carbon dioxide feedback increases the corresponding global average warming at 2100 by more than 1°C. Assessed uncertainty ranges for temperature projections are larger than in the TAR because a broader range of models and climate carbon-cycle feedbacks have been considered. {7.3, 10.5}

- Projected globally-averaged sea level rise at the end of the 21st century in metres, relative to 1980–1999 for the six SRES marker scenarios are: B1: 0.28 [0.19 to 0.37] m; A1T 0.33 [0.22 to 0.44] m; B2: 0.32 [0.21 to 0.42] m; A1B: 0.35 [0.23 to 0.47] m; A2: 0.37 [0.25 to 0.50] m; A1FI: 0.43 [0.28 to 0.58] m. Thermal expansion contributes about 60 to 70% to these estimates. {10.6}

- Projections of sea level rise are smaller than given in the TAR, mainly due to improved estimates of ocean heat uptake. Smaller assessed uncertainties in glacier and ice cap[7] changes also contribute to a reduced upper bound. However, these ranges do not include uncertainties in carbon-cycle feedbacks or ice flow processes because a basis in published literature is lacking. If recently observed increases in ice discharge rates from the Greenland and Antarctic ice sheets were to grow linearly with global average temperature change, that would add 10 to 25% of the central estimate to each scenario, but understanding of these effects is too limited to assess their likelihood. {10.6}

- Increasing atmospheric carbon dioxide concentrations lead to increasing acidification of the ocean. Projections based on SRES scenarios give reductions in pH[12] of between 0.14 and 0.35 units in the 21st century, extending the present decrease of 0.1 units since pre-industrial times. Ocean acidification would eventually lead to dissolution of shallow-water carbonate sediments. {Box 7.3, 10.4}

There is now higher confidence in projected patterns of warming and other regional-scale features, including changes in circulation patterns, precipitation, and some aspects of extremes and of ice. {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 50 years. Warming is expected to be greatest over land and at high northern latitudes, and least over the Southern Ocean and North Atlantic (see Figure SPM-5). {10.3}

[12] Decreases in pH correspond to increases in acidity of a solution. See Glossary for further details.

AOGCM PROJECTIONS OF SURFACE TEMPERATURES

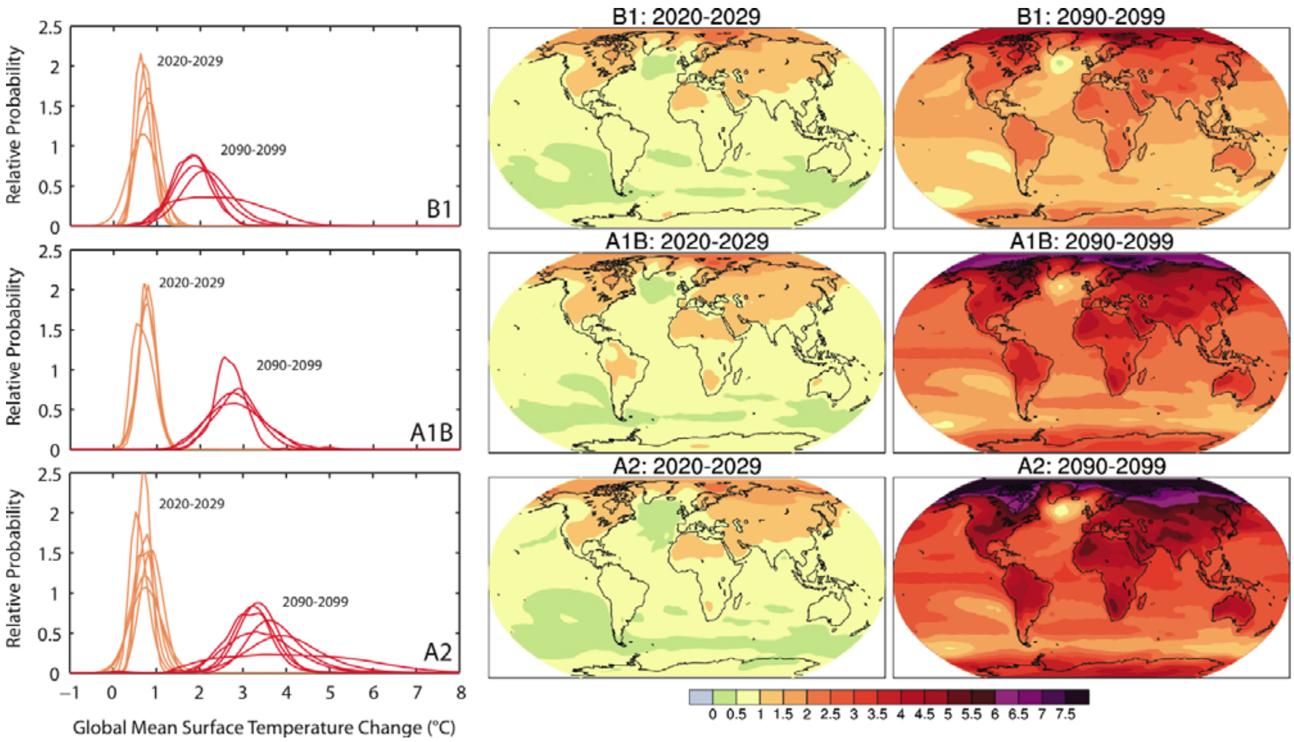

FIGURE SPM-5. Projected global average temperature changes for the early and late 21st century relative to the period 1980–1999. The central and right panels show the AOGCM multi-model average projections for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over decades 2020–2029 (center) and 2090–2099 (right). The left panel shows corresponding uncertainties as the relative probabilities of estimated global average warming from several different studies for the same periods. {Figures 10.8 and 10.28}

- Snow cover is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. {10.3, 10.6}

- Sea ice is projected to shrink in both the Arctic and Antarctic under all SRES scenarios. Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century in some projections. {10.3}

- It is *very likely* that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent. {10.3}

- The number of tropical cyclones (typhoons and hurricanes) per year is projected to decrease but their intensity is expected to increase, with larger peak wind speeds and more intense precipitation. The apparent increase in the proportion of very intense storms since 1970 is much larger than simulated by current models for that period. {9.5, 10.3, 3.8}

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

- 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, see Figure SPM-6), continuing observed patterns in recent trends. {3.3, 8.3, 9.5, 10.3, 11.2 to 11.9}

PROJECTED PATTERNS OF PRECIPITATION CHANGES

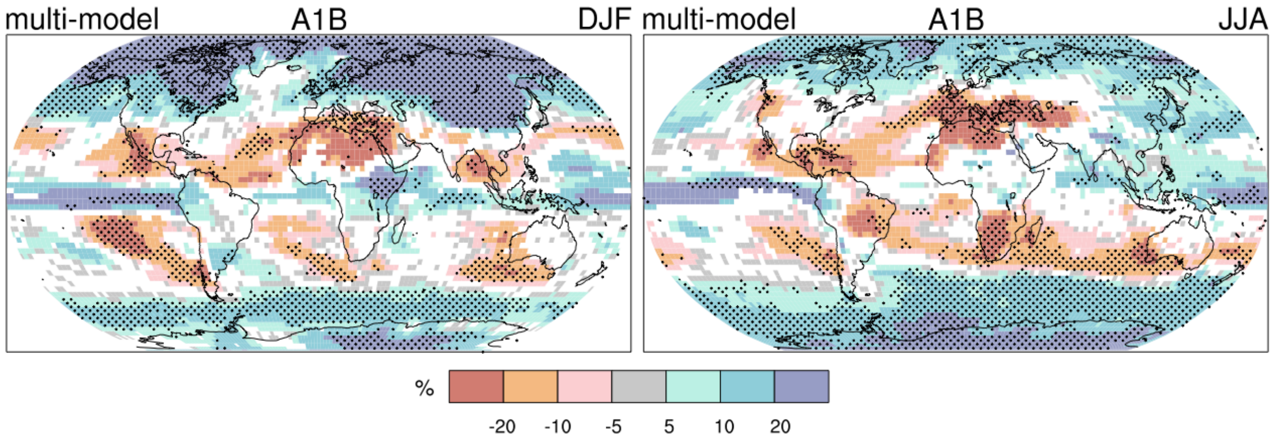

FIGURE SPM-6. Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}

- It is *very likely* that the Atlantic meridional overturning circulation (MOC) will slow down during the 21st century, with an average model-estimated reduction by 2100 of 25% (range from zero to more than 50%). Temperatures in the Atlantic region are projected to increase despite such changes due to the much larger warming associated with projected increases of greenhouse gases. It is *very unlikely* that the MOC will undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence. {10.3, 10.7}

Climate processes, feedbacks, and their timescales imply that anthropogenic warming and sea level rise would continue for centuries even if greenhouse gas concentrations were to be stabilized. {10.4, 10.5, 10.7}

- Uncertainty in the magnitude of the positive feedback between climate change and the carbon cycle leads to uncertainty in the trajectory of carbon dioxide emissions required for a particular stabilization level. A number of models suggest that this feedback effect would require reductions in cumulative emissions in the 21st century, compared with simulations that do not include carbon cycle feedback, by 105 to 300 GtC and by 165 to 510 GtC for stabilization at 450 and 1000 ppm respectively. {7.3, 10.4}

- Stabilization of radiative forcing in 2100 at B1 or A1B levels[11] would be expected to lead to further committed warming of about 0.5°C, mostly in the following century. {10.7}

- If radiative forcing were to be stabilized in 2100 at A1B levels[11], thermal expansion alone would lead to 0.3 to 0.8 m of sea level rise by 2300 (relative to 1980–1999) and would continue at decreasing rates for many centuries, due to the time required to mix heat into the deep ocean. {10.7}

- Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest that a global average warming (relative to pre-industrial values) of 1.9 to 4.6°C would lead to virtually complete elimination of the Greenland ice sheet and a resulting sea level rise of about 7 m, if sustained for millennia. These temperatures are comparable to those inferred for the last interglacial period 125,000 years ago, when paleoclimatic information suggests reductions of polar ice extent and 4 to 6 m of sea level rise. {6.4, 10.7}

- Dynamical processes 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. {4.6, 10.7}

- Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and is expected to gain in mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance. {10.7}

- 21st century anthropogenic carbon dioxide emissions will contribute to warming and sea level rise for more than a millennium, due to the timescales required for removal of this gas. {7.3, 10.3}

The Emission Scenarios of the IPCC Special Report on Emission Scenarios (SRES)[13]

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

[13] This box summarizing the SRES scenarios is exactly as used in the TAR and has been subject to prior line by line approval by the Panel.