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INDEPENDENT SUMMARY FOR POLICY MAKERS of the Text of the IPCC Fourth Assessment Report

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INDEPENDENT SUMMARY FOR POLICY MAKERS
of the Text of the IPCC Fourth Assessment Report

INTRODUCTION

This is an Independent Summary for Policy Makers (ISPM) of the Fourth Assessment Report (AR4), Working Group 1, of the Intergovernmental Panel on Climate Change (IPCC). In producing it we have worked independently of the IPCC, using the Second Order Draft of the IPCC report, as circulated after revisions were made in response to the first expert review period in the winter and Spring of 2006. Section references will be checked against the final IPCC version, to be released in the winter of 2007. If, in preparing the final draft of the AR4, the IPCC substantially rewrites the Assessment text, such that the key summary materials presented herein need to be re-worded, this will be done and an Appendix published to that effect.

Rationale

The IPCC involves a lot of experts in the preparation of its reports. The resulting reports tend to be reasonably comprehensive and informative, and merit close attention. However, chapter authors are frequently asked to summarize current controversies and disputes in which they themselves are directly involved, creating a conflict of interest. Also, chapter authors may be in a position to promote their own published work by presenting it in a prominent or flattering light. Some research that contradicts the hypothesis of greenhouse gas-induced warming may be under-represented, and some controversies may be treated in a one-sided way.

A further problem is that the Summary for Policy Makers attached to the IPCC Report is produced, not by the scientific writers and reviewers, but by a process of negotiation among unnamed bureaucratic delegates from sponsoring governments. Their selection of material may not reflect the priorities and intentions of the scientific community itself. Consequently it is useful to have independent experts read the underlying report and prepare a summary of the most pertinent elements of the report.

Finally, while the IPCC enlists many expert reviewers, no indication is given as to whether they disagreed with some or all of the material they reviewed. Many expert reviewers have lodged serious objections with the IPCC only to find that while their objections are ignored, they are acknowledged in the final document, giving the impression that they endorsed the final product.

The ISPM addresses these concerns as follows.

- The ISPM was prepared by experts who are fully qualified and experienced in their fields, but who are not themselves IPCC chapter authors.
- The ISPM focuses on summarizing the most important elements of the science, regardless of whether it is given the same level of focus in the IPCC's Summary documents. There is no attempt to downplay or re-word uncertainties and limitations in the underlying science, hence the summary paragraphs in the ISPM may not be identical to those of the Summary produced by the IPCC.
- If a chapter of the AR4 introduces its topic by briefly elaborating on deep uncertainties, then presents results at length as if the uncertainties were not there, the ISPM may devote proportionally more attention to understanding the uncertainties than summarizing all the

results, where this is deemed a more pertinent way to characterize the underlying state of knowledge.

- Where the underlying IPCC chapter fails to cover important recent topics, or fails to convey essential uncertainties, Supplementary Information is provided in sidebar form, and in some cases reference to a forthcoming Supplementary Analysis Series paper is provided.
- The ISPM was subject to peer review by the reviewers listed at the end. Their responses to review questions are tabulated so readers can see to what extent the reviewers agree with the contents of this Summary.

Supplementary Information

In a number of places the writing team felt the treatment of a topic was inadequate in the Fourth Assessment Report, or some additional comments were needed for perspective. These are noted in separate sidebars. Also, the Fraser Institute will publish a series of short supplementary papers to provide more detailed critical discussion of some technical subjects. These are noted at various points in the ISPM as well.

Format Notes

- 'TAR' refers to the IPCC Third Assessment Report, Working Group I.
- Section references in brackets, e.g. [3.4.3.1], refer to the IPCC Fourth Assessment Report, Second Order Draft, Working Group 1.
- Section references will be checked against the final WG1 Report.

BRIEF PRÉCIS

Observed changes in factors that may influence the climate

The climate is subject to potential influence by both natural and human forces, including greenhouse gas concentrations, aerosols, solar activity, land surface processes, ocean circulations and water vapor. Carbon dioxide is a greenhouse gas, and its atmospheric concentration is increasing due mainly to human emissions.

The IPCC gives limited consideration to aerosols, solar activity and land-use change for explaining 20th century climate changes. Aerosols have a large impact on climate but their influence is poorly understood. Some evidence suggests that solar activity has increased over the 20th century to historically high levels. Land use changes are assumed to have only a minor role.

Observed changes in weather and climate

Globally-averaged temperature data collected at the surface show an increase from 1900 to 1940 and again from 1979 to 1999, but not necessarily thereafter. Estimates from satellite data since 1979 show an average increase of 0.04 °C to 0.20 °C per decade over this period, at the low end of the IPCC estimate of future warming.

There is no globally-consistent pattern in long-term precipitation trends, snow-covered area, or snow depth. Most places have observed a slight increase in rain and/or snow cover. There is insufficient data to draw conclusions about increases in extreme temperature and precipitation. Current data suggest a global mean sea-level rise of 2 mm to 3 mm per year over the past several decades. In the tropics, there is evidence of increased cyclone intensity but a decrease in total tropical storms, and no clear global pattern since 1970.

Arctic sea ice showed an abrupt surface area loss prior to the 1990s, and the loss stopped shortly thereafter. There is insufficient data to conclude that there are any trends in Antarctic sea ice thickness. Glaciers have retreated in most places and the loss accelerated in the 1990s.

Climatic Changes in a Paleoclimate Perspective

Paleoclimate refers to the Earth's climate prior to the start of modern instrumental data sets. There are historical examples of large, natural global warming and cooling in the distant past. The Earth is currently within a warm interglacial period, and it has been inferred that temperatures during the last interglacial period were warmer than present.

Natural climate variability and the uncertainty associated with paleoclimate studies are now believed to be larger than previously estimated. In general, data are sparse and uncertain, and many records have been questioned for their ability to show historical temperature variability. These uncertainties matter for assessing the ability of climate models to simulate realistic climate changes over historical intervals.

Climate Models and Their Evaluation

Some broad modeling predictions made 30 yeas ago are consistent with recent data, but there remain fundamental limitations of climate models that have not improved since the 2001 IPCC report. Many models are incapable of simulating important aspects of the current climate, and models differ substantially in their prediction of future climate. It is not possible to say which, if any, of today's climate models are reliable for climate prediction and forecasting.

Global and Regional Climate Projections

Models project a range of future forecasts, and uncertainty enters at many steps in the process. Forecasts for the coming century are inherently uncertain, especially at the regional level.

Current models predict: an increase in average surface temperature; an increased risk of drought and heat waves; an increased chance of intense precipitation and flooding; longer growing seasons; and an average sea levels rise of about 30 cm over the next 100 years.

Glacier mass is projected to decrease. An abrupt change in ocean circulation is very unlikely. Tropical cyclone intensity may increase or decrease.

Attributing the Causes of Climate Change

Attributing an observed climate change to a specific cause like greenhouse gas emissions is not formally possible, and therefore relies on computer model simulations. As of yet, attribution studies do not take into account the basic uncertainty about climate models, or all potentially important influences.

Increased confidence that a human influence on the global climate can be identified is based the proliferation of attribution studies since the 2001 IPCC report. Models used for attributing recent climate change estimate that natural causes alone would not result in the climate that is currently observable.

Overall Conclusions

The following concluding statement is not in the AR4, but was agreed upon by the ISPM writers based on their review of the current evidence.

The Earth's climate is an extremely complex system and we must not understate the difficulties involved in analyzing it. Of particular concern is the limited data available on processes known to have significant climatic influence, such as time-varying ocean circulations. Despite the many data limitations and uncertainties, knowledge of the climate system continues to advance based on improved and expanding data sets and improved understanding of meteorological and oceanographic mechanisms.

The climate in most places has undergone minor changes over the past 200 years, and the land-based surface temperature record of the past 100 years exhibits warming trends in many places. Measurement problems, including uneven sampling, missing data and local land-use changes, make interpretation of these trends difficult. Other, more stable data sets, such as satellite, radiosonde and ocean temperatures yield smaller warming trends. The actual climate change in many locations has been relatively small and within the range of known natural variability. There is no compelling evidence that dangerous or unprecedented changes are underway.

The available data over the past century can be interpreted within the framework of a variety of hypotheses as to cause and mechanisms for the measured changes. The hypothesis that greenhouse gas emissions have produced or are capable of producing a significant warming of the Earth's climate since the start of the industrial era is credible, and merits continued attention. However, the hypothesis cannot be proven by formal theoretical arguments, and the available data allow the hypothesis to be credibly disputed.

Arguments for the hypothesis rely on computer simulations, which can never be decisive as supporting evidence. The computer models rely upon approximations for many of the smaller scale processes of the oceans and atmosphere and these approximations are tuned to produce a credible simulation of global climate statistics. However there are too many degrees of freedom in tunable models for them to serve as supporting evidence for any one tuning scheme, such as that associated with a strong effect from greenhouse gases.

There is no evidence provided by the IPCC in its Fourth Assessment Report that the uncertainty can be formally resolved from first principles, statistical hypothesis testing or modeling exercises. Consequently, there will remain an unavoidable element of uncertainty as to the extent that humans are contributing to future climate change, and indeed whether or not such change is a good or bad thing.

1: OBSERVED CHANGES IN FACTORS THAT MAY INFLUENCE THE CLIMATE

1.1 "RADIATIVE FORCING" AS A CONCEPTUAL TOOL FOR COMPARING CLIMATIC EFFECTS

[1.1a] "Radiative Forcing" (RF) is a modeling concept that attempts to summarize the climatic effect of diverse changes in the environment. It is not directly measured, nor is it related to the "greenhouse effect," and overall remains poorly quantified.

- RF is a concept that arose from early climate studies using simple radiative-convective models. It is not directly measured, instead it is calculated by simplified climate models under the assumption that a comparison can be made between equilibrium states of the climate. The climate does not reach equilibrium, but reflects transient responses to external and internal changes. The RF relationship to transient climate change is not straightforward. To evaluate the overall climate response associated with a forcing agent its time evolution and its spatial and vertical structure need to be taken into account. Further, RF alone cannot be used to assess the potential climate change associated with emissions, as it does not take into account the different atmospheric lifetimes of the forcing agents. [2.2]
- RF itself is not directly related to the "greenhouse" effect as associated with greenhouse gases [2.3.8].
- Measurement of RF in Watts/square meter is a convention, but RF itself is not a measured physical quantity. Instead it is computed by assuming a linear relationship between certain climatic forcing agents and particular averages of temperature data. The various processes that it attempts to approximate are themselves poorly quantified. [2.2]
- An observed decrease in radiative flux at the characteristic radiation bands of CO_2 and methane between 1970 and 1997 has been associated with changing concentrations. This is what is meant by the term "enhanced greenhouse effect", but is not itself related to the "Radiative Forcing" concept [2.3.8].

Supplementary Information: The term 'Greenhouse Effect' is misleading

The Earth does not act like a greenhouse, and so-called 'greenhouse gases' do not "trap heat". These common metaphors are misleading when used to describe the action of infrared-active gases like water vapour and carbon dioxide, because they leave out the complexities arising from the nonlinear, dynamic processes of our climate system, namely evaporation, convection, turbulence and other forms of atmospheric fluid dynamics, by which energy is removed from the Earth's surface. Simplistic metaphors are no basis for projecting substantial surface warming due to increases of human-caused carbon dioxide concentration in the atmosphere. While problems of radiative transfer can in many cases be solved directly from first principles (including the question of why a *real* greenhouse warms up), problems in turbulent fluid dynamics are often not solvable and, in the case of climate analysis, involve intractable computational complexities. By referring to the ‘greenhouse’ effect, the simplicity of the greenhouse mechanism is inappropriately attached to the issue of enhanced infrared absorption in the atmosphere.

This problem is explored in the forthcoming Fraser Institute AR4 Supplementary Series report, “Why the ‘Greenhouse’ Metaphor is Misleading.”

1.2 GREENHOUSE GASES

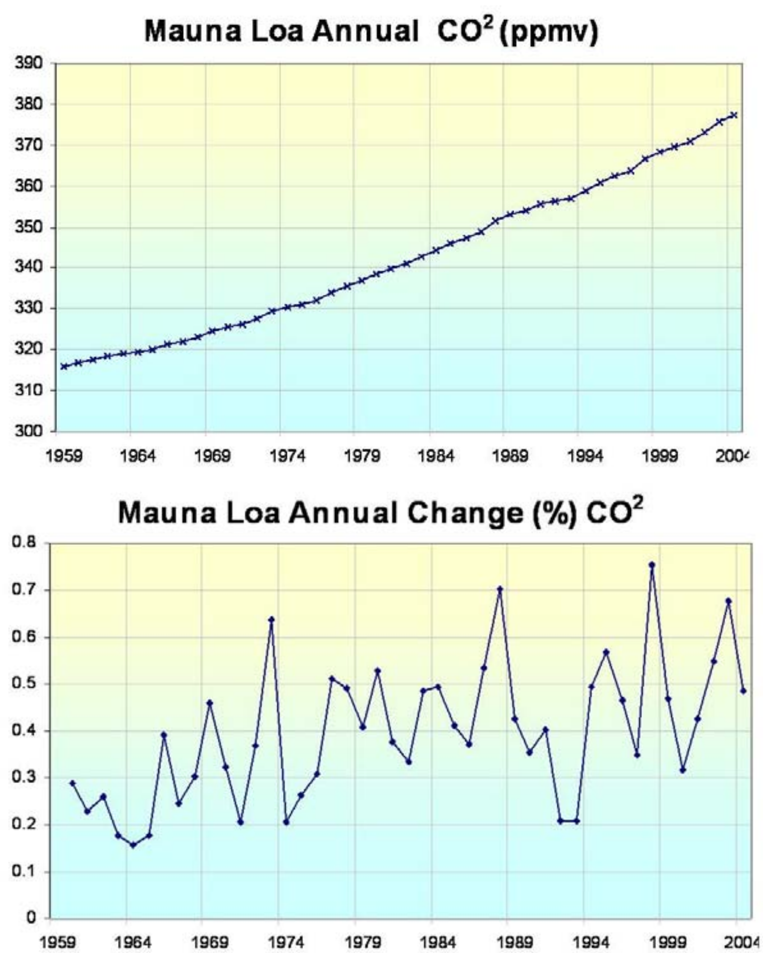


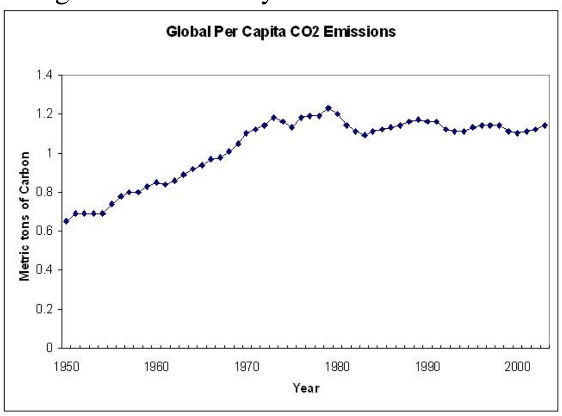
Figure ISPM-1: Carbon Dioxide Concentrations. Top: Annual average atmospheric carbon dioxide concentration since 1958. Source: Marland et al. (2006). Bottom: annual percentage rate of change.

[1.2a] Carbon dioxide (CO_2) levels in the atmosphere are rising at approximately 0.5% per year.

- Figure ISPM-1a shows the atmospheric CO_2 concentration since the late 1950s. This rate has been constant since the early 1990s, up from an average of about 0.4% per year in the 1970s and 1980s (Figure ISPM 1b).
- The main driving forces of this accumulation are fossil fuel burning, cement production, gas flaring, and, to a lesser extent, land-use changes such as deforestation [2.3.1].
- Human activities contribute about 7 Gigatonnes carbon equivalent to the atmosphere each year, up from around 6 Gigatonnes in 1990. [2.3.1]

Supplementary Information: Per capita emissions have not grown for 30 years

The growth rate of CO_2 emissions is equal to or slightly below the growth rate of world population. Global per capita CO_2 emissions peaked at 1.23 tonnes per person in 1979 and the per-person average has declined slightly since then. As of 2003 the global average is 1.14 tonnes per capita, an average that has not changed since the early 1980s.



(Source: Marland et al. 2006, http://cdiac.esd.ornl.gov/ftp/ndp030/global.1751_2003.ems.)

[1.2b] Ice core records indicate that the atmospheric CO_2 levels were constant at about 280 parts per million (ppm) for at least several thousand years prior to the mid-1800s.

- This implies a post-industrial accumulation in the atmosphere of about 100 ppm, yielding the current level of nearly 380 ppm [2.3.1].
- CO_2 variations over the last 420,000 years broadly followed Antarctic temperature, typically with a time lag of several centuries to a millennium (i.e. atmospheric carbon dioxide levels rise several centuries after the air temperature rises). [6.4.1]

Supplementary Information:

Analysis of historical atmospheric CO_2 levels is also done by examination of fossilized tree leaf and needle stomata. These provide annual estimates of CO_2 levels back to the end of the last ice age 10,000 years ago. The leaf and needle stomata records suggest the natural variability of CO_2 is much higher than is suggested by ice core records. Natural fluctuations of 60-80 ppm are observed over decadal time spans, and pre-industrial concentrations reach as high as 350 ppm from natural processes (van Hoof et al 2005; Wagner et al 2001).

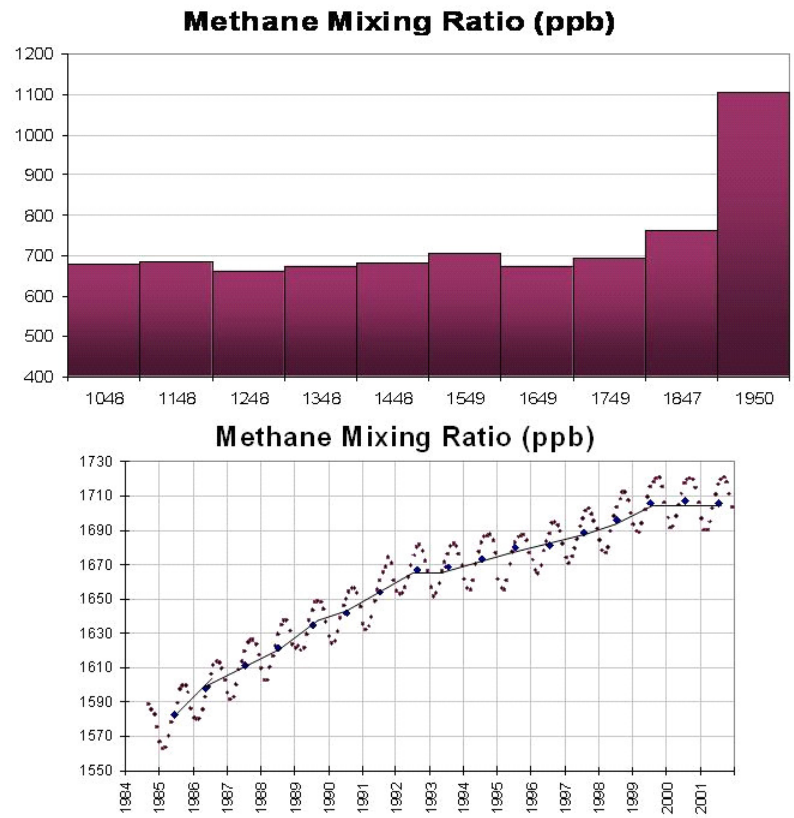


Figure ISPM-2: Methane Concentrations. Top Panel: Long Term (1048 AD to 1950 AD) atmospheric methane levels (parts per billion). Source: Etheridge et al., http://cdiac.esd.ornl.gov/ftp/trends/atm_meth/EthCH498A.txt.
Bottom: Cape Grim Australia methane record since 1984. Source: Steele et al. http://cdiac.esd.ornl.gov/ftp/trends/atm_meth/csiro/cgrimch4_mm.dat.

[1.2c] Atmospheric methane (CH_4) levels stopped growing in the late 1990s and have declined somewhat in recent years. Sources of methane emissions are poorly understood, but the total appears to be declining. This contradicts the view that emissions would increase due to atmospheric temperatures increases.

- Ice core records indicate pre-industrial methane levels were about 700 ppb, prior to about 1700. The methane level grew over the next three centuries, and is about 1,780 ppb currently (see Figure ISPM-2).
- Overall sources of methane emissions to the atmosphere are poorly known, but are thought to include wetlands, rice agriculture, biomass burning and ruminant animals.
- Emissions from anthropogenic sources remain the major contributor to atmospheric methane budgets [7.4.1.2].

- Atmospheric methane concentrations peaked several years ago and are flat or declining since then [Fig 2.5, see Figure ISPM-2b]. The reason for the recent decline is not understood. [2.3.2].
- The atmospheric concentration of methane is tied to atmospheric temperature, as total emissions increase with atmospheric warming. Total emissions from sources are suggested to have decreased since the time of TAR, as nearly zero growth rates in atmospheric methane concentrations have been observed with no change in the sink strengths. The decrease in emissions seems to contradict expectations based on continued warming of the Earth's surface and the atmosphere [7.4.1.2].

[1.2d] HCFCs and CFCs are presently covered by other emission control legislation, and are declining.

- HCFCs and CFCs are covered by the Montreal Protocol on ozone-depleting substances. Global emission have fallen radically since 1990 and their atmospheric levels are slowly declining [2.3.4]

[1.2e] Other infrared active gases (N_2O, HFCs) are accumulating slowly in the atmosphere, or are at levels that imply very low climatic effects. [2.3.3]

1.3 AEROSOLS

[1.3a] Aerosols play a key role in the Earth's climate, with an impact more than three times that of anthropogenic carbon dioxide emissions, but their influence remains subject to low or very low scientific understanding.

- Aerosols have a significant presence in the global atmosphere. The combined Direct Radiative Effect of natural and anthropogenic sources on climate, is estimated to be about -5.3 Watts/m^2, more than three times the estimated Radiative Forcing of anthropogenic CO_2 [2.4.2.1.2].
- It is very challenging to distinguish natural and anthropogenic aerosols in satellite data. Validation programs for these advanced satellite-data products have yet to be developed and initial assessments indicate some systematic errors. [2.4.2.1]
- The climatic effect of each type of aerosol consists of both direct and indirect effects, the latter including influences on cloud formation. Overall direct and indirect effects are subject to wide uncertainties, and some important semi-direct effects were not included in the Third Assessment Report [2.4].
- Effects on cloud formation are not well understood and the magnitude of the effects are not reliably estimated at this time, in part because of the lack of satellite data to support model development and testing [2.4.6].
- Modelling the cloud albedo indirect effect from first principles has proven difficult because the representation of aerosol-cloud interactions and of clouds themselves in climate models are still crude [2.4.6.5].
- Although there is agreement about the quality of the basic evidence (data), there is no consensus about the direct climatic (radiative forcing) effect of aerosols on climate, and the overall picture is categorized as Low Scientific Understanding [Table 2.11].

- All categories of indirect aerosol effect on climate, are characterized by: no consensus; varying confidence in the basic empirical evidence, and Low or Very Low Scientific Understanding. [Table 2.11]

[1.3b] Aerosols can affect both cloud lifetime and cloud albedo (reflectivity), though models contradict one another on which effect is larger.

- Whereas some models concluded that the cloud albedo effect is four times as important as the cloud lifetime effect, other models simulate a cloud lifetime effect that is larger than the cloud albedo effect [7.5.4.2].

[1.3c] It is generally assumed that aerosols exert an overall cooling effect on the climate. Quantitative estimates of the overall effect vary by a factor of 10.

- The global mean total anthropogenic aerosol effect (direct, semi-direct and indirect cloud albedo and cloud lifetime effect), defined as the change in net radiation at the top of the atmosphere from pre-industrial times to present-day, ranges from –0.2 Wm^{-2} to –2.3 Wm^{-2}. This implies aerosol emissions exert an overall cooling effect, but it is unknown whether the effect is large or small. [7.5.2.4]

[1.3d] Studies that attribute observed global warming to greenhouse gases are based on models that assume that aerosols exert a large cooling effect.

- The models used for AR4 assume a large cooling effect from aerosols [Table 2.12]
- The effect is assumed to be strongest in the Northern hemisphere [Figure 9.2.1e]

1.4 CHANGES IN THE SUN AND SOLAR-CLIMATE CONNECTIONS

[1.4a] Some long term reconstructions of solar activity suggest that the sun's irradiance levels over the past 70 years are high, and possibly exceptionally high, compared to the previous 8,000 years.

- Some recent work has found evidence of exceptionally high levels of solar activity in the past 70 years, relative to the preceding eight thousand years. Other reconstructions find current levels of solar activity to be historically high, but not exceptionally so [2.7.1.2.1].

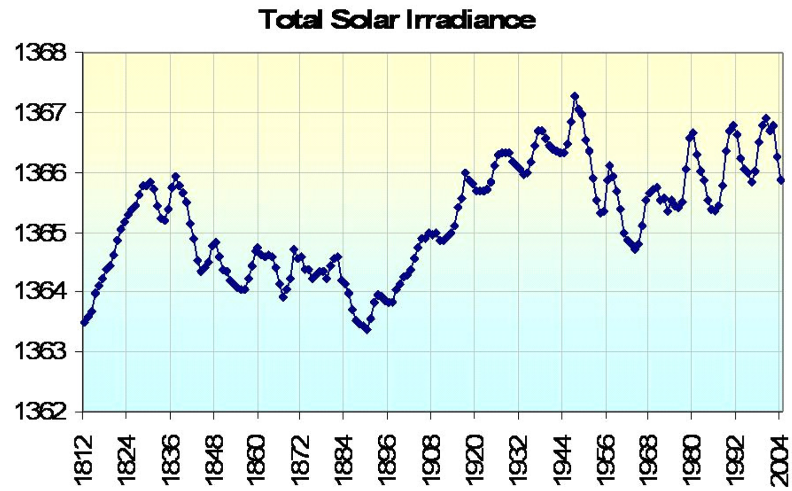


Figure ISPM-3: Total Solar Irradiance (Watts per square meter) since 1812. Source: Hoyt and Schatten 2005.

[1.4b] There may be an upward trend in recent total solar irradiance, depending on which of several data sets is used.

- Different composite records of total solar irradiance have been constructed from different combinations of the direct radiometric measurements. The gross temporal features of two widely-cited composite irradiance records are very similar, but the linear slopes differ. One series exhibits a notably higher trend, suggesting that contemporary solar output is following a general upward trend [2.7.1.1.2].

[1.4c] New evidence has emerged that the highly variable UV portion of the solar spectrum may have indirect effects on climate.

- Although solar UV radiation represents only a small fraction of the energy from total irradiance, UV radiation is more variable by at least an order of magnitude. Since TAR[1] new studies have confirmed and advanced the plausibility of indirect effects on the climate system involving the modification of the stratosphere by solar UV irradiance variations (and possibly by solar-induced variations in the overlying mesosphere and lower thermosphere), with subsequent dynamical and radiative coupling to the troposphere.
- The actual mechanisms involved are as yet not known [2.7.1.3].

[1.4d] For the purpose of explaining recent global warming, IPCC modelers assume changes in solar output have contributed very little to observed climate changes.

- The Fourth Assessment Report takes the low end of irradiance growth estimates, and assumes no indirect effect, implying a climatic influence of just over one-tenth that of CO_2 [2.7.1.2.2]

[1] Here and elsewhere, "TAR" refers to the Third Assessment Report of the IPCC, published in 2001.

Supplementary Information: The sun and climate change

Studies of the sun's effect on climate in recent years have raised plausible grounds for a substantial solar influence on climate change, going beyond that which is presented in the IPCC report.

This topic is explored in the forthcoming Fraser Institute AR4 Supplementary Series report, "Solar Changes and the Climate."

1.5 CHANGES TO THE LAND SURFACE

[1.5a] Changes in the land surface over the 20th century has likely had large regional and possibly global effects on the climate, but the effects do not fit into the conceptual model used for assessing anthropogenic climate change.

- Changes to the land surface act as anthropogenic perturbations to the climate system and will fall at least partly within the "forcing" component of the forcing-feedback-response conceptual model. But it is difficult to quantify the pure forcing component as distinct from feedbacks and responses. No quantitative metric separating forcing from feedback and response has yet been implemented for climatic perturbation processes which do not act directly on the radiation budget. [2.5.1]
- Attempts to use climate models to convert land use changes into RF measures have yielded a wide range of results, with some estimates of the local RF effects of agricultural change in North America and Eurasia considerably larger than that from CO_2 in the atmosphere [2.5.3]. However the data for parameterizing basic RF effects are not consistent and the uncertainties remain large [2.5.3].

[1.5b] Many studies have found that urban areas are warmer than the surrounding countryside, introducing a "non-climatic" warm bias into local long term weather records. If true, this would imply IPCC climate data overstate the recent global warming trend. Some studies have asserted, however, that urbanisation is adequately in the globally-averaged data. All IPCC analysis assumes this latter to be the case.

- The urban heat island effect is real, and causes temperature records from urban and suburban areas to have an upward trend unrelated to climatic changes. [3.2.2.2]
- Some studies have argued that the global climate data sets, which compile urban, suburban and rural records into regional averages, are not contaminated by such upward biases. [3.2.2.2]
- All IPCC usage of climatic data operates on the assumption of no contamination. However many studies have shown that changes in land use and land cover can have large regional effects on the climate, and the large numbers of such studies collectively demonstrate a potentially important impact of human activities on climate, especially local climate, through land use modification. [7.2.4.4]

- Detection and attribution studies do not account for urbanization, data quality problems or other non-climatic effects in the temperature data. All observed changes in the data are assumed to be due to climatic changes [9.4.1.2]

Supplementary Information: Problems with the surface temperature record

Research on the nature of the surface thermometer network has put into some doubt the claim of the IPCC that the surface temperature record is free of biases due to non-climatic effects, such as land-use change, urbanization and changes in the number of stations worldwide.

This is explored in the forthcoming Fraser Institute AR4 Supplementary Series report, “Problems in the Surface Thermometer Network.”

2: OBSERVED CHANGES IN WEATHER AND CLIMATE

2.1 LARGE-SCALE TEMPERATURE AVERAGES

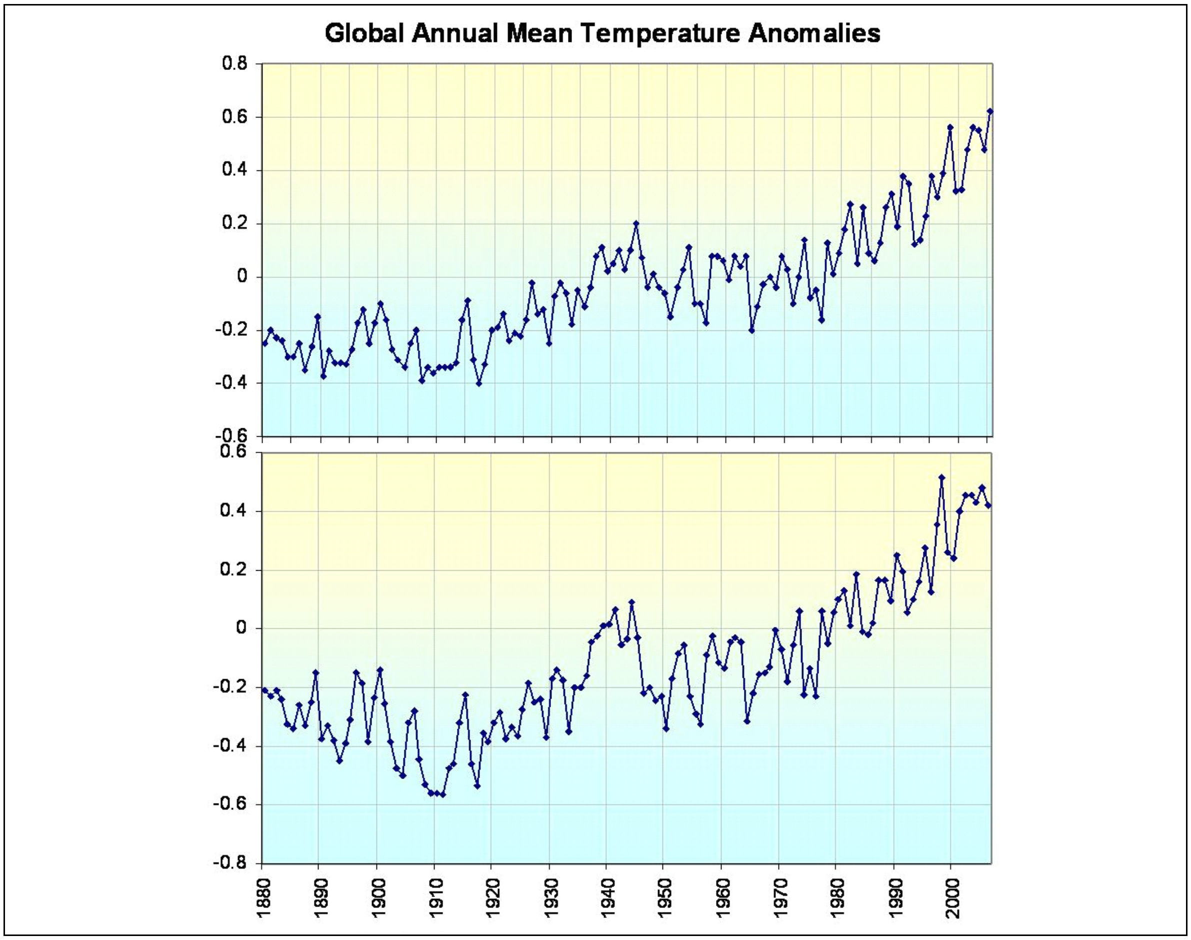


Fig ISPM-4: Annual average mean temperature anomalies measured at the Earth's surface (^oC). Sources: Top panel: Goddard Institute of Space Studies; Bottom panel: Hadley Center.

[2.1a] A global average of temperature data collected over land, combined with ocean surface measurements from ships and buoys, with local means removed and some adjustments applied to control for uneven sampling and other potential problems, exhibits an upward trend from 1900 to 1940, and again from 1979 to 1999, but not necessarily thereafter.

- The statistic is commonly called the global mean temperature anomaly or "global temperature" for short.
- The global temperature statistic produced by the GISS and NCDC groups was slightly higher in 2005 than at any time since 1998, while that produced by the Hadley Center

group peaked in 1998 and has been slightly lower ever since (See Figure ISPM Figure 4) [3.2.2]

- See also Section [2.1e] below.

	1850–2005	1901–2005	1910–1945	1946–1978	1979–2005
Land: Northern Hemisphere					
CRU (Brohan et al., 2006)	**0.063 ± 0.018**	**0.089 ± 0.030**	**0.142 ± 0.057**	–0.038 ± 0.064	**0.330 ± 0.108**
GHCN (Smith and Reynolds, 2005)		**0.072 ± 0.031**	**0.127 ± 0.065**	–0.040 ± 0.074	**0.344 ± 0.121**
GISS		**0.083 ± 0.030**	**0.166 ± 0.061**	–0.053 ± 0.062	**0.294 ± 0.090**
Lugina et al. (2005) up to 2004		**0.074 ± 0.032**	**0.144 ± 0.074**	–0.051 ± 0.061	**0.278 ± 0.096**
Land: Southern Hemisphere					
CRU (Brohan et al., 2006)	*0.034 ± 0.033*	**0.078 ± 0.054**	*0.091 ±0.076*	0.031 ±0.063	**0.135 ± 0.087**
GHCN (Smith and Reynolds, 2005)		**0.057 ± 0.020**	*0.091 ± 0.069*	0.054 ± 0.072	**0.220 ± 0.114**
GISS		**0.056 ± 0.015**	0.033 ± 0.042	*0.060 ± 0.052*	*0.085 ± 0.067*
Lugina et al. (2005) up to 2004		**0.056 ± 0.013**	**0.064 ± 0.046**	0.014 ± 0.052	*0.074 ± 0.062*
Land: Globe					
CRU (Brohan et al., 2006)	**0.054 ± 0.020**	**0.084 ± 0.026**	**0.125 ±0.042**	-0.016 ±0.055	**0.268 ± 0.084**
GHCN (Smith and Reynolds, 2005)		**0.068 ± 0.029**	**0.116 ±0.057**	–0.013 ±0.061	**0.315 ± 0.108**
GISS		**0.069 ± 0.020**	**0.102 ± 0.041**	0.003 ± 0.046	**0.188 ± 0.084**
Lugina et al. (2005) up to 2004		**0.065 ± 0.024**	**0.108 ± 0.043**	- 0.021 ± 0.059	**0.183 ± 0.075**

Table ISPM-1: Linear trends of temperature (^{o}C /decade). Reproduction of Table 3.2 from AR4. Top block is Northern Hemisphere Land, Middle Block is Southern Hemisphere Land and Bottom Block is Globe-Land. Each cell shows the IPCC-estimated trend and 2-standard error confidence interval. 'CRU' denotes Climatic Research Unit; GHCN denotes Global Historical Climatology Network; GISS denotes Goddard Institute of Space Studies. **Bold** denotes a statistically significant (1%) trend in IPCC methodology, *italics* denotes significant (1-5%): but see [2.1d].

[2.1b] Post-1979 trends in temperature data averaged over land areas in the Southern Hemisphere are small compared to those from the Northern Hemisphere, and statistically less significant.

- Temperature trends in land-based data for the Northern and Southern Hemispheres from 1979-2005 are shown in Table ISPM-1, reproducing IPCC Table 3.2. In all cases the SH trend is small compared to the NH trend.
- In two of the four surface data sets the SH trend is less than one-third as large as the NH trend and is statistically less significant. [Table 3.2]
- Both data sets that merge land-based data with relatively sparse and uncertain sea surface temperature data show SH trends less than half those in the NH. [Table 3.2]

[2.1c] The TAR drew attention to the declining Diurnal Temperature Range (DTR) as evidence of global warming (WG1 Summary for Policy Makers, page 1). The decline in the DTR has now ceased, and appears to be growing in most places.

- The DTR declined after 1950, but stopped declining as of the mid-1990s. [3.2.2.7, Fig 3.2.2]
- Over the 1979 to 2004 interval, many locations on all continents show increasing DTR rates, especially NA, Europe, Australia and SA. [Fig 3.2.11]

[2.1d] The significance of trends in temperature and precipitation data is likely to have been overstated in previous analyses.

- The climate system responds to change slowly over time, and past changes accumulate through long term persistence to influence ongoing trends. As a result the trend estimation techniques used in recent IPCC Assessments likely overstate the statistical significance of observed changes, and the results of trend analysis often depend on the statistical model used [3.2.2.1].

> Supplementary Information: Long Term Persistence and Trend Analysis
>
> Methods for estimating trends, and assessing their statistical significance, have undergone considerable advance in the past decade. The technical terms for the new issues being raised are *nonstationarity* and *Long Term Persistence*. While the literature on these issues originated in econometrics, finance and statistics, it has begun to be applied to climate data sets as well. This work is not reviewed by the IPCC, but is briefly mentioned in Section 3.2.2.1. The main findings are that proper treatment of long term processes in climate data will likely require a major reinterpretation of the significance of recent trends, as it assigns more of the observed changes in climate data to natural variance.
>
> This is explored in the forthcoming Fraser Institute AR4 Supplementary Series report, "Long Term Persistence in Geophysical Data."

[2.1e] Satellite data are also used to measure atmospheric temperature. Different teams produce slightly different results based on different assumptions about the way to interpret the data.

- Satellites measure atmospheric radiation from two layers, denoted T2 and T4.
- T2 radiation mostly comes from the surface and lower troposphere, whereas T4 mostly emanates from the stratosphere. From these radiation readings, temperature averages can be inferred based on an assumed set of weights. [3.4.1.2.2]
- The "true" weights cannot be known with certainty. The weights that yield results most closely matching data from weather balloons shows the least amount of tropospheric warming. [Fig. 3.4.3]

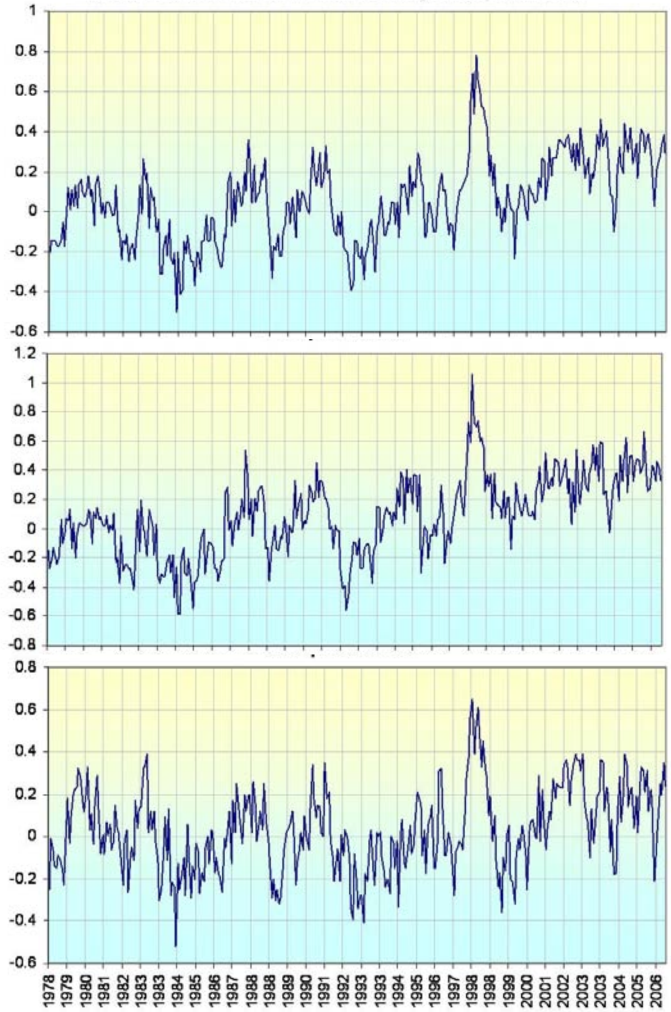


Figure ISPM-5: Satellite-measured mean global temperature anomalies since 1979 (^oC). Top: Global average; Middle: Northern Hemisphere; Bottom: Southern Hemisphere. Source: GHCC-UAH.

[2.1f] The spread of recent satellite-based trends in global average temperatures from the lower atmosphere ranges from nearly zero up to the low end of computer-based projections.

- Three different teams of analysts have examined satellite-based radiation data spanning 1979 to the present.
- Depending on assumptions about instrument calibration, area-weighting and merging across datasets, the average temperature trend in the lower atmosphere over the period 1979-2004 ranges from 0.04 ^oC/decade to 0.20 ^oC/decade. [3.4.1.2.1]
- On a century scale this compares to the low end of IPCC warming projections (1.4 to 5.8 ^oC/decade) as presented in the TAR. [3.4.1.2.1].

[2.1g] There is no significant warming in the tropical troposphere, which accounts for half the world's atmosphere. This is where models that assume a strong influence of greenhouse gases forecast the most rapid warming should occur.

- The tropics accounts for half the world's atmosphere. In none of the available data sets is significant warming observed in the tropical troposphere [Fig 3.4.3]. One of the available satellite data sets yields trends consistent with increased warming at higher altitude in the tropics [3.4.1.2.2], while others do not.
- Climate models run on the assumption that greenhouse gases drive climate change predict the strongest warming should be observed in the troposphere over the tropics [Fig 10.3.4]. This pattern is predicted to be evident early in the forecast period and the pattern is simulated consistently among the models. [10.3.2.1]

[2.1h] There are differences in linear trends of tropospheric temperatures between the high latitudes of the Northern and Southern Hemispheres that are not consistent with computer model projections.

- Geographical patterns of the linear trend in tropical temperature show coherent warming over the Northern Hemisphere but areas of cooling over the Southern Hemisphere (3.4.1.2.2, Fig. 3.4.4)

[2.1i] Earth's climate is characterized by many modes of variability, involving both the atmosphere and the oceans, and also by the cryosphere and the biosphere [1.4.6]. There is an increasing recognition that changes in the oceans may be playing a role in climate change.

- Our understanding of the variability and trends in different oceans is still developing, but it is already apparent they are quite different. The Pacific is dominated by the El-Nino/Southern Oscillation cycle and is modulated by the Pacific Decadal Oscillation, which may provide ways of transporting heat from the tropical oceans to higher latitudes and from the ocean to the atmosphere.
- Since 1900, North Pacific Sea Surface Temperatures (SST) show warm mode phases from 1925-1946 and 1977 to 2005 [3.6.3]
- Since the 1850s, North Atlantic SSTs show a 65–75 year variation, with apparent warm phases at roughly 1860–1880 and 1930–1960 and cool phases during 1905–1925 and 1970–1990. This feature has been termed the Atlantic Multidecadal Oscillation (AMO). The cycle appears to have returned to a warm phase beginning in the mid-1990s and tropical Atlantic SSTs were at record high levels in 2005. [3.6.6.1]
- The AMO has been linked to multi-year precipitation anomalies over North America, as well as Atlantic hurricane formation, African drought frequency, winter temperatures in Europe, sea ice concentration in the Greenland Sea and sea level pressure over high northern latitudes. [3.6.6.1]
- The multidecadal variability in the Atlantic is much longer than the Pacific but it is noteworthy that all oceans exhibit a warm period around the early 1940s. [3.2.2.3].

<u>Supplementary Information</u>: Major Ocean-Atmosphere Climate Oscillations

An important theme in recent meteorological research is the identification of some large-scale atmospheric cycles that operate on time spans of 30 years or more. These oscillations arise from the interaction of the oceans and atmosphere, and are typically measured using pressure gradients across large regions of the Earth's surface. Representation of the oceans in climate models as truly dynamic systems (as opposed to the earlier "slab" ocean models) is only beginning. A comprehensive description of the atmospheric and ocean circulations has been delayed by lack of observations from the high atmosphere and deep oceans.

Major oscillation systems have been shown to have significant explanatory power for recent climatic changes, including trends in temperature and precipitation. The El Niño-Southern Oscillation (ENSO) is a coupled air-sea phenomenon that has its origins in the Pacific Ocean but affects climate globally. The mechanisms and predictive skill of ENSO are still under development. The North Atlantic Oscillation is a phenomenon that affects weather and climate and is associated with variability and latitudinal shifts of the westerly winds and jet streams. Despite a long history of observation and research it remains poorly understood. The low-frequency variability of the phenomenon that is important for climate.

The IPCC discusses some of these, but does not provide adequate detail about the connection between these systems and recent weather changes.

This topic is explored in the forthcoming Fraser Institute AR4 Supplementary Series report, "Major Climatic Oscillations and Recent Weather Changes."

2.2 PRECIPITATION AND SNOW COVER

[2.2a] There is no globally-consistent pattern in long-term precipitation trends, though most places have observed slight increases in rain and/or snow cover.

- Precipitation in North and South America has risen slightly over the past century in many places, though in some regions it has fallen. [3.3.2.2]
- The drying trend noted in the Sahel in the 1980s has since reversed considerably. [3.3.2.2].
- Rainfall in India increased from 1901 to 1979 then declined through to the present [3.3.2.2], and there is no overall trend [3.3.2.2].
- Australian precipitation trends vary by region and are closely linked to the El Nino cycle [3.3.2.2].

[2.2b] There is no globally-consistent pattern in snow-covered area (SCA) or snow depth.

- In the Northern Hemisphere, mean observed snow cover in April declined somewhat from the 1950s to the 1970s, declined rapidly in the 1980s and has increased slightly since 1990 [Fig 4.2.1].
- Over the 1966 to 2004 interval, mean NH snow cover in October showed a statistically insignificant decline. But over the entire span of available data (1922 to 2004) the mean NH snow cover in October shows a statistically significant increase [Table 4.2.1].
- Over the 1966 to 2004 interval, mean NH snow cover trended downward in spring and summer, but not substantially in winter [Table 4.2.1]

- In North America the trend in SCA over the 20th century is upward overall, with a recent downward trend especially in Western NA [4.2.2.2.1].
- SCA in mountainous areas of Switzerland and Slovakia has declined since 1931, but not in Bulgaria [4.2.2.2.2].
- Lowland areas of central Europe have exhibited decreased SCA, while increased snow depth has been recorded in the former Soviet Union, Tibet and China [4.2.2.2.2].
- In South America a long term increasing trend in snow days has been observed in the eastern central Andres [4.2.2.3.1].
- In Southeastern Australia, late-winter snow depth has declined considerably, though winter precipitation has decreased only slightly [4.2.2.3.2].

[2.2c] In areas north of 55N, snowfall has increased over the past 50 years. Trends in the frequency of heavy snowfall events vary by region.

- At high latitudes, winter precipitation has increased in the past 50 years [3.3.2.3] and there has been little change in the fraction falling as snow rather than rain [3.3.2.3].
- In North America, the incidence of heavy snowfall events has increased in Northern Canada and in the lee of the Great Lakes, but decreased in the lower Missouri river basin [3.3.2.3]

[2.2d] Rising temperatures have generally resulted in rain rather than snow in locations and seasons where climatological average (1961-1990) temperatures were close to 0C (32F).

- In some areas, namely Southern Canada and western Russia, the earlier onset of Spring over the past 50 years has meant an increasing fraction of precipitation falls as rainfall [3.3.2.3]. However other data has shown an overall increase in snowfall in parts of Southern Canada [3.3.2.3].

<u>Supplementary Information: Recent North American snowfall records</u>

"Record-breaking" local hot weather events are sometimes promoted as evidence of global warming. What does that imply if record-breaking cold weather events begin to accumulate in some local data?

New York City's Central Park has a January (their coldest month) average temperature of 32.1F and winter average of 33.8F. For the first time since records began in the 1860s, Central Park reported four successive years of 40 inches of snow or more ending in the winter of 2005/06. On February 11-12, 2006, Central Park broke the all-time single snowstorm record with 26.9 inches of snow. Also in 1995/96, Central Park and most other cities in the central and eastern US had all-time record seasonal snowfall. In Central Park, that winter brought 75.6" of snow.

Not far to the north in Boston, MA where the winter averages 31.9F, the 12 year average snowfall in the winter ending 2004/05 was 51.3 inches, the highest in their entire record going back into the 1800s. A new all-time single snowstorm record was set on February 17-18, 2003 with 27.5 inches and a new all-time seasonal snowfall record of 107.6 inches was set in 1995/96. In the last dozen years, Boston has recorded their 1st, 3rd, 5th, 7th and 12th snowiest winters.

Data Source: National Weather Service

2.3 STORMS AND EXTREME WEATHER

[2.3a] Perceptions of increased extreme weather events are potentially due to increased reporting. There is too little data to reliably confirm these perceptions.

- People tend to hear about extreme events more now because of technology. Pictures shot by camcorders on the news may foster a belief that weather-related extremes are increasing in frequency. [3.8.1]
- Global studies of temperature and precipitation extremes over land suffer from a scarcity of data. In various parts of the globe, there is a lack of homogeneous (i.e. subject to consistent quality control and constant sampling conditions) daily observational records. Inhomogeneity has been attributed to, among other things, changes in observing practices or urban heat island effects. [3.8.1]
- Identification of changes in extremes is also dependent on the statistical analysis technique employed [3.8.1].
- Global studies of daily temperature and precipitation extremes over land suffer from both a scarcity of data and regions with missing data. [3.8.1]
- Analyses of trends in extremes are also sensitive to the analysis period; e.g., the inclusion of the exceptionally hot European summer of 2003 may have a marked influence on results if the period is short. [3.8.1]

[2.3b] Since 1970, there is some evidence of increased tropical cyclone intensity in both hemispheres, but a decrease in total tropical storm numbers, and no clear global pattern.

- A number of recent studies suggest that cyclone activity over both hemispheres has changed over the second half of the 20th century. General features include a poleward shift in storm track location and increased storm intensity, but a decrease in total storm numbers [3.5.3]
- Station pressure data over the Atlantic-European sector (where records are long and consistent) show a decline of storminess from high levels during the late-19th century to a minimum around 1960 and then a quite rapid increase to a maximum around 1990, followed again by a slight decline [3.5.3]
- Data suggest that cyclone activity in the NH mid-latitudes has increased during the past 40 years, whereas there have been significant decreases in cyclone numbers, and increases in mean cyclone radius and depth, over the southern extratropics over the last two or three decades. [3.5.3]
- With respect to storm data generally, data uncertainties compromise evidence for trends. [3.7.3]
- The considerable inter-decadal variability reduces significance of any long-term trends. Careful interpretation of observational records is therefore required.
- The overall power of cyclones has been characterized using the Accumulated Cyclone Energy (ACE) index and the Power Dissipation Index (PDI). The ACE is proportional to

the square of the wind speed and the PDI is proportional to the wind speed cubed. The PDI for the world as a whole shows an upward trend since the 1970s, but because of its cubic exponent it is very sensitive to data quality. Pre-1970 data are particularly uncertain [3.8.3]. The ACE index is available in some regions back to 1948 and shows no overall trend over the entire interval. The ACE shows an upward trend after 1980 in the North Atlantic, but a downward trend post-1980 in the West North Pacific, East North Pacific, Australian-South Pacific, North Indian and South Indian regions, i.e. everywhere else [Fig 3.8.4]. At the global level, the ACE Index values for 2004 and 2005 are about average for the whole post-1980 interval [3.8.3].

[2.3c] Data are too sparse, and trends inconsistent, to identify a pattern in extratropical cyclones.

- As with tropical cyclones, detection of long-term changes in extratropical cyclone measures is hampered by incomplete and changing observing systems. Some earlier results have been questioned because of changes in the observation system. [3.8.4.1]
- An increase in the number of deep cyclones is apparent over the North Pacific and North Atlantic, but only the North Pacific trend is statistically significant. Significant decreases have been noted in cyclone numbers over the southern extratropics over the last two or three decades, along with increases in mean cyclone radius and depth [3.8.4.1].

[2.3d] Evidence for changes in temperature variability is sparse and insignificant.

- Evidence for changes in observed interannual variability is still sparse. Seasonal mean temperature in central Europe showed a weak increase in summer and decrease in winter, for the time period 1961 to 2004. These changes are not statistically significant at the 10% level. [3.8.2.1].
- Regional studies from several continents show patterns of changes in extremes consistent with a general warming, although the observed changes of the tails of the temperature distributions are not consistent with a simple increase in the entire temperature distribution. [3.8.2.1]
- For the period 1951–2003, three-quarters of the global land area sampled showed a significant decrease in the annual occurrence of cold nights; while a significant increase in the annual occurrence of warm nights took place over 72% of the area. This implies a positive shift in the distribution of daily minimum temperature throughout the globe. Changes in the occurrence of cold days and warm days show warming as well, but generally less marked. This is consistent with the increase in minimum as opposed to maximum temperature. [3.8.2.1]

2.4 OCEAN TEMPERATURES AND SEA LEVELS

[2.4a] Regarding the Gulf Stream and the global Meridional Overturning Circulation (MOC), it is very likely that the MOC has changed on annual and decadal time scales, but evidence for overall weakening is mixed and uncertain, and the connection to surface climate is not well understood.

- The global Meridional Overturning Circulation (MOC) consists primarily of dense waters that sink to the seafloor at high-latitudes in the North Atlantic Ocean and near Antarctica. This influences global ocean currents and may influence wind patterns, including the Gulf Stream. [Box 5.1]
- Only indirect estimates of the MOC strength and variability exist, and the best evidence for observational changes in the overturning circulation comes from the North Atlantic. [Box 5.1]
- There is evidence for a link between MOC and abrupt changes in surface climate during the past 120,000 years, although the exact mechanism is not clear. [Box 5.1]
- One recent study concluded that the MOC transport in the North Atlantic at 25°N has decreased by 30% between 1957 and 2004, indicating a stronger mid-ocean return flow in the upper km, though not a decrease in Gulf Stream strength. Note however that this result is based on 5 snapshots in time, and it is not clear whether the trend estimate can be viewed as robust in the presence of considerable variability. [Box 5.1]
- Two other studies examined a model-based relation of MOC transport with interdecadal Sea Surface Temperature patterns and concluded that the MOC has increased since the 1970s. [Box 5.1]
- There is only a low level of confidence that the strength of deep limb of the MOC in the North Atlantic MOC has actually decreased. [Box 5.1]

<u>Supplementary Information: Questions about the MOC Mechanism</u>

It is not necessarily the case that deep-water formation drives the MOC. Others have argued (e.g. Wunsch, C. 2002) that the MOC is a largely wind-driven circulation, where the wind field provides the mechanical energy necessary to overcome the natural stratification of the ocean.

[2.4b] Regarding sea levels, a critical issue concerns how the records are adjusted for vertical movements of the land upon which the tide gauges are located. Current data suggest global mean sea level rise of between 2 and 3 millimeters per year.

- Tide gauges provide sea level variations with respect to the land on which they lie. However, the Earth's crust is subject to various vertical motions due to tectonics, local subsidences etc.; these motions need to be removed from the tide gauge measurement to extract the sea level signal. [5.5.1]
- Sea level change based on satellite altimetry measurements is measured with respect to the earth's center of mass, and thus is not distorted by land motions, except for a small component due to large scale deformation of ocean basins from Glacial Isostatic Adjustment (GIA). [5.5.1]
- Recent global tide gauge estimates are corrected for Glacial Isostatic Rebound (GIR) using models but not for other land motions. Adjusted rates could be underestimated by several tenths of millimeters per year in analyses which employ extrapolations of geological data obtained near the gauges [5.5.2.1]

- Tide gauge data suggests a rise in mean sea level over 1961-2003 of about 1.8 mm/year, ±0.5 mm. [5.5.2.1].
- Satellite estimates of mean sea level yield an accuracy of ±5 mm. Satellite data show a rate of sea level rise of +3.1 ± 0.8 mm per year over 1993–2005. The accuracy of this estimate is partly dependent on the calibration against vertical land motions as measured by tide gauges. [5.5.2.1]
- By comparison, satellite observations show a 15 mm rise and fall of mean sea level l and 0.4°C rise and fall of global mean sea surface temperature accompanying the 1997–1998 El Niño-Southern Oscillation (ENSO) event. [5.5.2.1]

[2.4c] Regional trends in sea level are quite varied and some regions are experiencing declining sea levels. Changes in air pressure and wind account for some observed sea level increase.

- While global sea level rose by ~120 m during the several millennia that followed the end of the last glacial maximum, it stabilized between 3000 and 2000 years ago. Since then, paleo sea level indicators suggest that global sea level did not change significantly: the average rate of change from 2000 and ~ 100 years ago is near zero. [Question 5.1]
- Although regional variability in coastal sea level change had been reported from tide gauge analyses, the global coverage of satellite altimetry provides unambiguous evidence of non-uniform sea level change in open oceans. [5.5.2.2]
- For the past decade, the western Pacific and eastern Indian oceans shows the highest magnitude sea level rise, however, sea level has been dropping in the eastern Pacific and western Indian Oceans. [5.5.2.2]
- Except for the Gulf Stream region, most of the Atlantic Ocean shows sea level rise during the past decade. [5.5.2.2]
- Northeast Atlantic sea level records are notable for their lower 20th century trends than the global average. Explanations include GIA, and air pressure and wind changes associated with North Atlantic Oscillation (NAO) [5.5.2.6.1].
- Arctic Ocean sea level time series have well pronounced decadal variability which corresponds to the variability of the NAO Index. In this particular region, wind stress and atmospheric pressure loading contribute to nearly half of the observed Arctic sea level rise [5.5.2.6.2].

[2.4d] There is very little sea-level data from Pacific Ocean islands. The available series appear to indicate less than one millimeter sea level rise per year.

- There are only four Pacific island stations with more than 50 years of data, which yield an average rate of sea-level rise (relative to the Earth's crust) of 1.6 mm/year. 22 Pacific island stations have greater than 25 years data and they yield an average sea level rise less than half that: 0.7 mm/year. However, these data suffer from poorly quantified vertical land motions. [5.5.2.6.3]

[2.4e] Changes in extreme sea level are due to changes in sea level and storminess. 20th century trends differ by location.

- The annual maximum high water surge at Liverpool since 1768 was larger in the late-18th, late-19th and late-20th centuries than for most of the 20th century. [5.5.2.7]

- The tide gauge record at Brest from 1860 to 1994 shows an increasing trend in storm surges (as measured by maxima and top-1% groups), but shows a decreasing trend during the period 1953–1994. [5.5.2.7]
- Extreme winter surges at San Francisco have exhibited a significant increasing trend since about 1950. [5.5.2.7]
- The rise in extreme sea level along the US east coast is closely correlated to that in mean sea level. [5.5.2.7]
- A long term increase in the number and height of extreme dailies has been noted at Honolulu, but no evidence indicates an increase relative to the underlying upward mean sea level trend. [5.5.2.7]

[2.4f] Sea level increases over the past decade are not uniform, and it is presently unclear whether they are attributable to natural variability.

- The instrumentally-based estimates of modern sea level change show evidence for onset of acceleration at the end of the 19th century. Recent estimates for the last half of the 20th century (1950–2000) give ~2 mm/year global mean sea level rise. New satellite observations show that since 1993 sea level has been rising at a rate of 3.1 mm/year [Question 5.1]
- Satellite data also confirm that sea level is not rising uniformly over the world. [Question 5.1]
- It is presently unclear whether the higher rate of sea level rise in the 1990's indicates an acceleration due to anthropogenic global warming, or a result of natural climate variability, or a combination of both effects. [Question 5.1]

> Supplementary Information: Historical Storm Surges
> The greatest storm surge in historical time was 13.6 meters and occurred in 1876 in the Bay of Bengal. The second highest on record was 13 meters in the Bathurst Bay in Australia in 1899. Since 1876, the maximum surge in the Bay of Bengal was about 9 meters in 1970 and 1999. By comparison, the maximum surge by Hurricane Katrina of August 2005 was 8.5 meters.

2.5 GLACIERS, SEA ICE AND ICE CAPS

[2.5a] Glacier archives indicate that most of the Earth's alpine glaciers receded or disappeared during a warm interval 9,000-6,000 years ago.

- Most archives from the Northern Hemisphere and the tropics show small or absent glaciers between 9,000 and 6,000 years ago [Box 6.3].
- Glaciers began growing thereafter, up to the 1800s [Box 6.3].
- This tendency is primarily related to changes in the Earth's orbit, however shorter, decadal-scale, regionally diverse glacier responses must have been driven by other causes which are complex and poorly understood. [Box 6.3]

[2.5b] Glaciers in most places have retreated since the 1800s

- General retreat of glacier termini started after 1800, with considerable mean retreat rates in all regions after 1850 lasting throughout the 20th century. A slowdown of retreats between about 1970 and 1990 is evident in the raw data. Retreats were again generally rapid in the 1990s; though advances of glaciers have been observed in Western Scandinavia and New Zealand [4.5.2]
- Glacier data tends to be isolated and incomplete. When areal weighting and spatial interpolation are used to estimate large-scale patterns from the available data, the 1990s trend towards glacier retreat appears to have leveled off or reversed after 1998. [Fig 4.5.2]

[2.5c] Over the last half century, global mean winter accumulation and summer melting of glacier ice have both increased.

- At least in the northern hemisphere, winter accumulation and summer melting correlate positively with hemispheric air temperature, whereas the net balance correlates negatively with hemispheric air temperature. An analysis of 21 Northern Hemisphere glaciers found a rather uniformly increased mass-turnover rate, qualitatively consistent with moderately increased precipitation and substantially increased low-altitude melting. [4.5.2]

[2.5d] While the loss of glacier mass accelerated in the 1990s, loss of Arctic sea ice mass stopped at the same time

- In the NH, the rate of glacier mass loss was twice as rapid in 1990s compared to 1960s-1990 [4.5.2]
- An early study of Arctic ice found that ice draft in the mid 1990s was less than that measured between 1958 and 1977 at every available location (including the North Pole). The decline averaged about 42% of the average 1958–1977 thickness. Subsequent studies indicate that the reduction in ice thickness was not gradual, but occurred abruptly before 1991, with no evidence of thinning along 150°W from six springtime cruises during 1991–1996. Springtime observations from 1976 to 1994 along the same meridian indicated a decrease in ice draft sometime between the mid 1980s and early 1990s, with little subsequent change. [4.4.3.2]

[2.5e] On a regional basis the pattern of glacier regimes remains complex. Precipitation and solar changes appear to be the driving factors, especially in the tropics, including Kilimanjaro.

- Although reports on individual glaciers or limited glacier areas support the global picture of ongoing strong ice shrinkage in almost all regions, some exceptional results indicate the complexity of both regional to local scale climate and respective glacier regimes. [4.5.3]
- Whereas Himalayan glaciers have generally shrunk at varying rates, several high glaciers in the central *Karakoram* are reported to have advanced and/or thickened at their tongues, probably due to enhanced transport of moisture to high altitudes. [4.5.3]

- Norwegian coastal glaciers advanced in the 1990s and started to shrink around 2000 as a result of almost simultaneous reduced winter accumulation and greater summer melting. Norwegian glacier termini farther inland have retreated continuously at a more moderate rate. [4.5.3]
- Glaciers in the New Zealand Alps advanced during the 1990s, but have started to shrink since 2000. Increased precipitation may have caused the glacier growth. [4.5.3]
- Tropical glaciers, being in principle very sensitive to both temperature changes and those related to atmospheric moisture, have shrunk mostly in response to regional changes in atmospheric moisture content and related energy and mass balance variables such as solar radiation, precipitation, albedo, and sublimation during the 20^{th} century. Inter-annual variation in moisture seasonality strongly dominates the behaviour of tropical glaciers [4.5.3]
- Glaciers on Kilimanjaro behave exceptionally. Even though the thickness of the tabular ice on the summit plateau has not changed dramatically over the 20th century, the ice has shown an incessant retreat of the vertical ice walls at its margins, for which solar radiation is identified as the main driver. The mass balance on the horizontal top ice surfaces is governed by precipitation amount and frequency and associated albedo, and has sporadically reached positive annual values even in recent years. In contrast to the plateau ice, the shrinkage of the glaciers on Kilimanjaro's slopes is constantly decelerating. [4.5.3]

[2.5f] It is not possible to attribute the abrupt decrease in sea ice thickness inferred from submarine observations entirely to the (rather slow) observed warming in the Arctic.

- Some of the dramatic decrease may be a consequence of wind-driven redistribution of ice volume over time. [4.4.3.4]
- Low-frequency, large-scale modes of atmospheric variability (such as interannual changes in circulation connected to the Northern Annular Mode) affect both wind-driving of sea ice and heat transport in the atmosphere, and therefore contribute to interannual variations in ice formation, growth and melt. [4.4.3.4]

[2.5g] Sea ice thickness is one of the most difficult geophysical parameters to measure on large-scales and, because of the large variability inherent in the sea-ice-climate system, evaluation of ice thickness trends from the available observational data is difficult.

- On the basis of submarine sonar data and interpolation of the Arctic basin average sea ice thickness from a variety of physically-based sea ice models, it is very likely that the average sea ice thickness in the central Arctic has decreased by up to 1 metre since the late 1980s, and that most of this decrease occurred between the late 1980s and 1990s. [4.4.3.7]
- This recent decrease however occurs within the context of longer term decadal variability, with strong maxima in Arctic ice thickness in the mid-1960s and around 1980 and 1990, due to both dynamic and thermodynamic forcing of the ice by circulation changes associated with low-frequency modes of atmospheric variability. [4.4.3.7]

- Ice thickness varies considerably from year to year at a given location and so the rather sparse temporal sampling provided by submarine data makes inferences regarding long-term change difficult. [4.4.3.2]
- There are insufficient data to draw any conclusions about trends in the thickness of Antarctic sea ice. [4.4.3.7]

[2.5h] Estimates of Greenland ice cap changes indicate near coastal-thinning and inland thickening.

- Many recent studies have addressed Greenland mass balance. They yield a broad picture of slight inland thickening and strong near-coastal thinning, primarily in the south along fast-moving outlet glaciers. [4.6.2.2]
- Assessment of the data and techniques suggests overall mass balance of the Greenland Ice Sheet ranging between growth by 25 Gigatonnes per year (Gt a^{-1}) and shrinkage by 60 Gt a^{-1} for 1961–2003.
- This range changes to shrinkage by 50 to 100 Gt a^{-1} for 1993–2003 (translates to 0.1-0.2 mm per year sea level rise) and by even higher rates between 2003 and 2005. However, interannual variability is very large, driven mainly by variability in summer melting and sudden glacier accelerations. Consequently, the short time interval covered by instrumental data is of concern in separating fluctuations from trends.

[2.5i] The ice sheet in Eastern Antarctica appears to have grown while that in Western Antarctica appears to have shrunk. The overall change may be positive or negative depending on assumptions about ice dynamics.

- Assessment of the data and techniques suggests overall Antarctic ice-sheet mass balance ranging from growth by 50 Gt a^{-1} to shrinkage by 200 Gt a^{-1} from 1993–2003. [4.6.2.2]
- The pattern of East Antarctic thickening and West Antarctic thinning was observed across several independent studies [4.6.2.2].
- Assigning all ice-thickness change to low-density firn produces growth of the monitored portions of the ice sheet by 45 ± 8 Gt a^{-1}; if all change were ice, this growth would be 105 ± 20 Gt a^{-1}. Following the suggestion that the East Antarctic changes are from increased snow accumulation and the West Antarctic changes are more likely to be ice-dynamical would yield growth of monitored regions of 33 ± 9 Gt a^{-1}. [4.6.2.2]
- There is no implication that the midpoint of this range provides the best estimate. Lack of older data complicates a similar estimate for the period 1961–2003. [4.6.2.2]
- Acceleration of mass loss is likely to have occurred, but not so dramatically as in Greenland. [4.6.2.2]
- Considering the lack of estimated strong trends in accumulation rate, assessment of the possible acceleration and of the slow time scales affecting central regions of the ice sheets, it is reasonable to estimate that the behavior from 1961–2003 falls between ice-sheet growth by 100 Gt a^{-1} and shrinkage by 200 Gt a^{-1}. [4.6.2.2]

[2.5j] Summing changes in Greenland and Antarctic indicates either a gain or a loss of ice mass over the 1961-2003 interval.

- Simply summing the 1993–2003 contributions from Greenland and Antarctica produces a range from balance (0 Gt a^{-1}) to shrinkage by 300 Gt a^{-1}, or contribution to sea-level rise of 0 to 0.8 mm per year. [4.6.2.2]

- For 1961–2003, the same calculation spans growth by 125 Gt a^{-1} to shrinkage by 260 Gt a^{-1}. [4.6.2.2]

2.6 HUMIDITY AND RADIATION FLUX

[2.6a] Changes in mid and upper tropospheric relative humidity are proposed as an important potential amplifier of climate change, but there is no detectable trend over the past two decades.

- Water vapour in the mid and upper troposphere accounts for a large part of the atmospheric greenhouse effect and is believed to be an important amplifier of climate change [3.4.2.2].
- The hypothesis that increased specific humidity in the upper troposphere (resulting from tropospheric temperature rise and constant relative humidity) will cause an amplification of the greenhouse effect over that caused by carbon dioxide increase is seemingly plausible but not verified. Satellite data indicate that specific humidity in the upper troposphere increased over the period 1982-2004, consistent with the temperature rise at constant relative humidity. [3.4.2.2]

[2.6b] Observed changes in radiation flux at the top of the atmosphere are small and equivocal, and may simply reflect natural variability.

- Although there is independent evidence for decadal changes in top-of-atmosphere (TOA) radiative fluxes over the last two decades, the evidence is equivocal. [3.4.4]
- Changes in the planetary and tropical TOA radiative fluxes are consistent with independent global ocean heat storage data, and are expected to be dominated by changes in cloud radiative forcing. To the extent that they are real, they may simply reflect natural low-frequency variability of the climate system. [3.4.4]

3. CLIMATIC CHANGES IN PALEOCLIMATE PERSPECTIVE

3.1 GEOLOGICAL EVIDENCE OF WARMING AND COOLING EPISODES

[3.1a] Research has identified a range of variations and instabilities in the climate system that have occurred both during the past 2 million years of glacial and interglacial cycles and in the super-warm period of 50 million years ago. They reveal a wide range of climate processes that need to be understood in terms of 21st century climate change.

- Abrupt climate change refers to events of large amplitude regionally, typically a few degrees C, and that occur on time scales significantly shorter than 1,000 years. [1.4.2]
- Abrupt temperature changes were first detected in deep ice cores from Greenland. By the end of the 1990s it became clear that abrupt climate changes, as found in the Greenland ice cores during the last ice age, were numerous, indeed abrupt, and of large amplitude. [1.4.2]
- The importance of internal variability and processes was reinforced in the early 1990s with the analysis of records with high temporal resolution: new ice cores, ocean cores with high sedimentation rate, lacustrine sediments, and also cave stalagmites. Reconstruction of the thermohaline circulation of deep and surface water shows the participation of the ocean in these abrupt changes. [1.4.2]
- There are many examples of abrupt changes that are regional rather than global in extent. [1.4.2]
- Abrupt climate change during both ice age and warm epochs alters the notion of relative climate stability, as previously suggested. Rather there is a coherent picture of an unstable ocean-atmosphere system of global extent. [1.4.2]

[3.1a] There are examples of large, natural global warming and cooling episodes in the distant past.

- Approximately 55 million years ago, an abrupt global warming (in this case occurring on the order of ten thousand years) by several degrees C is observed in several paleoclimate indicators. The warmth lasted approximately 100,000 years. [6.3.3]
- Paleoclimatic records document a sequence of glacial-interglacial (ice age) cycles covering the last 650,000 years in ice cores, and several million years in deep oceanic sediments. The last 450,000 years, which are the best documented, are characterized by approximately 100,000 year-long cycles of very large amplitude, as well as large climate changes at other orbital frequencies, and at millennial time scale. Long ice ages are interrupted by shorter interglacial warm periods lasting for 10,000 to 30,000 years. There is clear evidence for interglacial warm periods prior to 450,000 years, but these were apparently colder than the typical recent interglacials. [6.4.1]

[3.1b] The intervals between ice ages were sometimes warmer than the present interglacial period.

- Globally, there was less glacial ice and higher sea level on Earth during the Last Interglacial (LIG, 129,000–116,000 years ago) than now. This suggests significant meltback of the Greenland and possibly Antarctica ice sheets occurred. The climate of the

LIG has been inferred to be warmer than present, although the evidence is regional and not neccessarily synchronous globally. Proxy data indicate warmer-than-present coastal waters in the Pacific, Atlantic, and Indian Oceans and in the Mediterranean Sea, greatly reduced sea ice in the coastal waters around Alaska, and extension of boreal forest into areas now occupied by tundra in interior Alaska and Siberia, during the early LIG. Ice core data indicate Greenland and Antarctic temperatures were 4–5°C warmer than present. [6.4.1.6]

[3.1c] The current warm interval began about 20,000 years ago. Climate has not been stable during that time.

- The most recent ice age began about 116,000 years ago. Glaciation reached a maximum about 21,000 years ago. Deglaciation, or the transition to a warm interval, took place between 20,000 and 10,000 years ago. The current warm interval is called the Holocene. [6.4.1.2]
- Large, widespread, abrupt climate changes have occurred repeatedly throughout the ice age/post-glacial interval. Abrupt temperature events were larger and more widespread during the ice age then during the warm Holocene. The most dramatic of these abrupt climate changes are characterised by a warming in Greenland by 8 to 16ºC within a few decades, followed by much slower cooling over centuries. Another type of abrupt change is the Heinrich event, involving sea surface cooling that lasts several thousands of years, followed by abrupt warming over several decades. At the end of the last ice age, as the climate warmed and ice sheets melted, climate went through a number of abrupt cold phases, notably the Younger Dryas and the 8.2 kyr event. [6.4.2.1]

[3.1d] The causes of large-scale climate variations on the century and longer time scales are not well-understood.

- Based on the correlations between changes in climate proxy records and production of cosmogenic isotopes – assumed to relate to solar activity changes – some authors argue that solar activity, through cosmic radiation and cloud nucleation, may be the driver for centennial to millennial variability. Correlations between climate proxy records and geomagnetic field variations suggest further influence on climate by cosmic radiation on millennial and greater time scales. The possible importance of internal climate variability, for instance related to the deep ocean circulation, has also been highlighted. [6.5.1.6]
- However, in many records, there is no apparent consistent pacing at specific centennial to millennial frequencies through the Holocene period, but rather shifts between different frequencies. [6.5.1.6]
- The current lack of consistency between various data sets makes it difficult, based on current knowledge, to attribute the century and longer time scale large-scale climate variations solely to solar activity, episodes of intense volcanism, or variability internal to the climate system. [6.5.1.6]

3.2 GLOBAL CLIMATE RECONSTRUCTIONS OVER THE PAST 2,000 YEARS

[3.2a] Natural climatic variability is now believed to be substantially larger than was estimated in the TAR, as is the uncertainty associated with paleoclimate studies.

- The TAR placed considerable emphasis on the "hockey stick" climate reconstruction, which suggested the late 20th century climate was unusual in the context of the past 1,000 years. This graph has subsequently been subject to considerable criticism [6.6.1.1]
- When viewed together (Fig ISPM-6), the currently available reconstructions indicate generally greater variability in centennial time scale trends over the last 1000 years than was apparent in the TAR.
- Proxy evidence cannot characterize the mean Northern Hemisphere temperature to within at least ±0.5C, and over significant stretches of time the available reconstructions differ by 0.7-1.0C [Figure 6.10].

<u>Supplementary Information: Recent refutations of hockey stick millennial paleoclimatic methods and conclusions.</u>
Two recent, detailed reviews of the methodology of paleoclimatic reconstructions (National Research Council 2006, Wegman et al. 2006) both concluded that there were methodological errors in the "hockey stick" graph of Mann et al. which was prominently promoted in the TAR (Summary for Policy Makers Fig 1). Both reports concluded that the data and methods did not support the assertions that the 1990s were the "warmest decade of the millennium" and 1998 the "warmest year" of the millennium (NRC p. 109; Wegman et al. p.49). The National Research Council Report also concluded that uncertainties of published paleoclimate reconstructions have been generally underestimated (NRC p. 91).

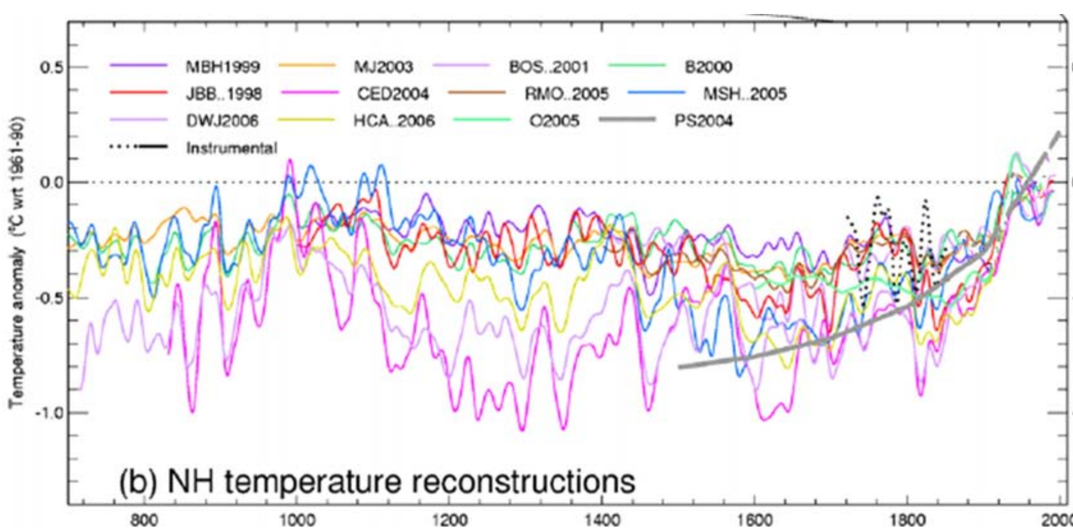


FIG ISPM-6: Some recent paleoclimate temperature reconstructions over past 1300 years. Source: Reproduction of IPCC Figure 6-10b. Note instrumental splice post-1850 has been removed (see Supplementary Information Box below).

<u>Supplementary Information: It is invalid to splice modern thermometer data to paleoclimatic proxies.</u>

McIntyre and McKitrick (2005) showed that the hockey stick graph incorrectly asserted a statistically significant relationship between climatic proxies and modern thermometer ("instrumental") data. The National Research Council report (NRC p. 107) cited this finding and endorsed its conclusion, referring also to additional evidence in Wahl and Ammann (2006). The AR4 cites both McIntyre and McKitrick (2005) and Wahl and Ammann (2006) [6.6.1.1] but does not mention this finding. The National Research Council (p. 91) points out that the particular statistical failure involved indicates a reconstruction "can be seen to be unreliable in an objective way."

The main implication is that instrumental data cannot be spliced to proxy series as if to suggest one is a continuation of the other. The proxy series prior to the start of the instrumental data (approx. 1860) provides little or no reliable basis for extrapolating temperatures back in time. Proxy data may contain some climatologically information, but it is statistically invalid to splice an instrumental series onto a proxy-based series as if the two are interchangeable.

For this reason, Figure ISPM-6 reproduces IPCC Figure 6-10b with the black instrumental series removed.

A number of recent studies (Briffa et al. 2001, Wilson et al. 2006) have shown that, on average, proxy records extending to the present diverge from instrumental temperature series. While instrumental averages rise post-1980, the proxy records in many places are trending downwards, indicating a fundamental uncertainty over whether tree ring records could have detected warming trends in the past.

[3.2b] Paleoclimatic proxy data are sparse and uncertain, and many appear to be sensitive only to summer temperature, or to precipitation.

- In the Northern Hemisphere as a whole there are relatively few long and well-dated climate proxies, particularly for the period prior to the 17th century. Those that do exist are concentrated in extra-tropical, terrestrial locations, and many have greatest sensitivity to summer rather than winter (or annual) conditions. [6.6.1.1]
- There are markedly fewer well-dated proxy records for the Southern Hemisphere compared to the Northern Hemisphere, and consequently little evidence of how large-scale average surface temperatures have changed over the past few thousand years. [6.6.2]
- There are very few strongly temperature-sensitive proxies from tropical latitudes. Stable isotope data from high-elevation ice cores provide long records and have been interpreted in terms of past temperature variability, but recent studies indicate a dominant sensitivity to precipitation changes, at least on seasonal to decadal timescales, in these regions. [6.6.1.1]
- Very rapid and apparently unprecedented melting of tropical ice caps has been observed in recent decades, possibly associated with enhanced warming at high elevations, but other factors besides temperature can strongly influence tropical glacier mass balance. [6.6.1.1]

- In most multi-centennial length coral series, the late 20th century is interpreted as being warmer than any time in the last 100–300 years. [6.6.1.1]

<u>Supplementary Information: Regional paleoclimatic indicators.</u>

The AR4 provides a very small survey of regional paleoclimatic evidence from the Southern Hemisphere [6.6.2]. The available literature on location-specific paleoclimatology is very large, and in many locations in both the Northern and Southern Hemispheres indicates periods of anomalous warmth exceeding that in the late 20th century. Little of this information is surveyed in the IPCC Report.

The literature is explored in the forthcoming Fraser Institute AR4 Supplementary Series report, "Paleoclimatic Indicators of Medieval Climate Conditions."

[3.2c] Uncertainties in paleoclimate reconstructions affect climate modeling work since models are tested against results from paleoclimate reconstructions.

- Testing models with paleoclimatic data is important, as not all aspects of climate models can be tested against modern instrumental climate data. Good performance for present climate is not a conclusive test for a realistic sensitivity to carbon dioxide. To test this, simulation of a climate with very different CO_2 levels can be used. [6.2.2]
- Also, many empirical parameterizations describing sub-grid scale processes (e.g., cloud parameters, turbulent mixing) have been developed using present-day observations; hence climate states not used in model development provide an independent benchmark for testing models. [6.2.2]
- Paleoclimate data are therefore key to evaluating the ability of climate models to simulate realistic climate change. [6.2.2]

4. CLIMATE MODELS AND THEIR EVALUATION

4.1 FUNDAMENTAL LIMITATIONS OF CLIMATE MODELS

[4.1a] Early climate models provided some qualitative conjectures at the global scale that are consistent with some observed changes.

- At the global scale, some broad predictions made 30 years ago about the possible response to increased CO_2 concentration in the atmosphere, namely increased average tropospheric temperature, decreased average stratospheric temperature and more a rapid hydrological cycle, are consistent with data that have emerged since then. [8.1.1]

[4.1b] The fundamental limitations of climate modeling have not changed since the TAR.

- Climate models employ approximations to basic physical processes, some of which are known (e.g. those based on Newtonian mechanics) and some of which are not known (e.g. fundamental convection processes). [8.1.3]
- “Parameterization” is the process of tuning the numerical coefficients that make up a model. Because coefficient values are tuned to force the model to match observations, an ability to represent observed conditions cannot be cited as grounds for confidence in the model’s physical realism. [8.1.3]

SUPPLEMENTARY INFORMATION: Basic Modeling uncertainties
The following observation, made in the TAR, remains just as true today:

“In climate research and modeling, we should recognize that we are dealing with a coupled non-linear chaotic system, and therefore that the long-term prediction of future climate states is not possible. The most we can expect to achieve is the prediction of the probability distribution of the system’s future possible states by the generation of ensembles of model solutions. (TAR CH 14.2.2.2)

An extended discussion of this is provided in the forthcoming Fraser Institute Supplementary Analysis Report “Fundamental Uncertainties in Climate Modeling.”

[4.1c] A model’s ability to accurately simulate the current mean climate state does not imply it is reliable for projecting future climate changes.

- Multimodel evaluations have shown that when a group of climate models of intermediate complexity can all replicate observed mean ocean temperature and salinity, and mean atmospheric temperature and humidity, they can nonetheless depart substantially from one another in their future predictions [8.1.2].
- Models tuned to “perfectly” reproduce an observed mean climate state have nonetheless shown only a weak ability to predict subsequent climatic conditions. It is not possible to say which, if any, of today’s climate models are reliable for climate prediction and forecasting. [8.3]

[4.1d] It is not formally known if today's climate models are a suitable basis for projecting climate.

- If the number of degrees of freedom in the tunable parameters of a GCM exceeds the number of degrees of freedom in the observed climate system then the use of GCMs to forecast climate change is not justifiable. There has been no formal evaluation of this question to date [8.1.3.1].

[4.1e] Some climate models now obey the law of conservation of mass, but it is not known if this is an improvement.

- Numerical advection schemes have been introduced in some cases that do not violate conservation of mass, a fundamental law of nature. However there is no consensus on whether they are better than the alternatives [8.2.1.1]

[4.1f] The strength of the coupling between land processes and the atmosphere is not known.

- Models strongly disagree on this important feedback. There is insufficient data at the global level to evaluate this feature of GCMs. [8.2.3.2]

[4.1g] Glaciers are not modeled in any coupled climate models, nor are atmospheric chemistry components that govern aerosol and non-aerosol processes. [8.2.4.1, 8.2.5].

5. GLOBAL AND REGIONAL CLIMATE PROJECTIONS

5.1 REPRODUCTION OF THE PRESENT CLIMATE

[5.1a] Quantitatively, climate models are typically unable to reproduce the observed mean surface temperature to better than +/- 3K, with worse performance near the poles. They are also unable to reproduce the onset of ice ages. The margin of present-day error rivals the size of the projected global warming trend over a century.

- Errors in polar regions average over 4K, and on average all climate models overestimate mean Antarctic temperatures by at least 5K. [8.3.1]
- The extent to which these errors detract from the models' ability to accurately simulate climate change in response to external perturbation (e.g. GHG emissions) may be significant. [8.3.1, Figure 8.3.1].
- Climate models are not able to successfully simulate the onset of an ice age [6.4.1.7], though are able to reproduce some features of the end of an ice age [6.4.2.3].
- Models are used to evaluate greenhouse-induced changes that are about 0.3 K/decade, a tenth the size of the annual margin of error for most regions.

5.2 FORECASTS FOR THE COMING CENTURY ARE INHERENTLY UNCERTAIN

[5.2a] The spread of model outcomes shown in the AR4 forecast ensembles does not span the full range of uncertainty.

- For future climate change in the 21st century, a subset of three scenario simulations have been selected from the six commonly used ones. This subset constitutes a "low", "medium", and "high" scenario among the marker scenarios, and this choice is solely made by the constraints of available computer resources that did not allow for the calculation of all six scenarios. This choice, therefore, does not imply a qualification of, or preference over, the six marker scenarios. By the same argument, it is not within the remit of this report to assess the realism and likelihood of emission scenarios. [10.1]
- Even though the ability to simulate present day mean climate and variability, as well as observed trends, differs across models, all submitted models are weighted equally in the mean. Since the ensemble is strictly an 'ensemble of opportunity', without sampling protocol, the spread of models is unable to span the full possible range of uncertainty, and a statistical interpretation of the model spread is therefore problematic. [10.1]

[5.2b] Uncertainties enter model projections at every step in the process.

- First, there are multiple emission scenarios for the 21st century, and even at this first stage there is uncertainty with regards to what will be the future time-evolution of emissions of various forcing agents such as greenhouse gases. Then these emissions must be converted to concentrations of constituents in the atmosphere. Gas cycle models must be employed, and these models include their own set of parameterisations, assumptions and caveats. Then the concentrations in the atmospheric models produce radiative forcing that acts on the climate system within the atmospheric model components, each with their own radiation schemes and other formulations that affect radiative forcing. Finally, the modelled coupled climate system takes those radiative forcings and produces a future simulated climate. The components of the atmosphere, ocean, sea ice and land surface in each model interact with their sets of strengths and weaknesses to produce a spread of outcomes for future climate. [10.1]

- Thus at every step in this process, there are uncertainties and assumptions that must be made to proceed from emissions, to concentrations, to radiative forcing, and eventually to simulated climate changes and impacts. [10.1]

[5.2c] Few of the climate models used for AR4 forecasts account for solar changes, land-use changes and indirect aerosol effects.

- Only two out of 23 models account for the effects of time-varying solar changes. [Table 10.2.1]
- Only two out of 23 models account for effects of land-use changes. [Table 10.2.1]
- Only nine out of 23 models include the first indirect effect of aerosols, only six include the second indirect effect and only four include both. [Table 10.2.1]

Supplementary Information: Defining 'Climate Change'

The IPCC assumes that climate change can be defined as a change in the mean state of the climate. This assumes that means of climatic variables are stationary and well-defined, something recent research has put into question. If the climate is nonstationary, a change in the mean is consistent with an 'unchanged' climate since the observed mean is dependent on the time period over which the observations are collected. Also the concept of variability is problematic since the variance of a nonstationary process is mathematically undefined. For more on this topic see the forthcoming Fraser Institute Supplementary Report "Long Term Persistence in Geophysical Data."

5.3 MODEL-GENERATED GLOBAL WARMING FORECASTS

[5.3a] Climate models predict warming is occurring everywhere on Earth.

- The average across models shows warming is forecast to occur everywhere on Earth, starting in the current decade. [Figure 10.3.5]
- The polar regions and areas over land are forecast to warm relatively faster [Fig. 10.3.5].
- Post-1979 trends as measured by weather satellites show warming is not happening everywhere, is not stronger in polar regions and is not stronger over land [Figure 3.4.4]

[5.3b] On average, models that assume strong greenhouse warming project the tropical troposphere to warm faster than the surface, and the diurnal temperature range to decrease in most places. Current data do not support these forecasts.

- The tropical troposphere is forecast to warm faster than the surface [Fig 10.3.4].
- This conflicts with current data (see [2.1g]).
- The diurnal temperature range (day-night difference) is forecast to decline in most places. [Fig 10.3.8]

- This conflicts with current data (see [2.1c]).

[5.3c] All climate models used for the AR4 are tuned on the assumption that the average surface temperature will increase between about 2.0 and 4.5 C in response to a doubling of the atmospheric carbon dioxide concentration.

- The "equilibrium climate sensitivity" is a model's assumed increase in global surface temperature following a doubling of the atmospheric equivalent CO_2 concentration. [10.5.2.1]
- The suite of models used for AR4 simulations apply an equilibrium climate sensitivity of between approximately 2.0 and 4.5C. [Figure 10.5.1].

[5.3c] Models generate many specific global forecasts based on assumptions of significant greenhouse warming.

- GLOBAL MEAN TEMPERATURE: Climate models run on the assumption that atmospheric carbon dioxide levels double over the next century predict that global average surface temperature will increase by between about 2.0 and 4.5 C [Fig 10.5.2].
- SEA ICE: Models show a range of responses in northern hemisphere sea ice areal extent ranging from very little change to a dramatic, and accelerating reduction over the 21st century. Seasonal ice cover is rather robust and persists to some extent throughout the 21st century in most (if not all) models. In 20th and 21st century simulations, Antarctic sea ice cover decreases more slowly than in the Arctic. Overall models have poor agreement on the amount of thinning of sea ice and the overall climate change in the polar regions. [10.3.3.1; Figure 10.3.10a,b Fig 10.3.11]
- OCEAN CIRCULATION: Models initialized at the year 1900 have difficulty producing late 20^{th} century values of the Meridional Overturning Circulation (MOC) in the observed range. Of the model simulations consistent with the late 20th century observational estimates, no simulation shows an increase of MOC during the 21st century; reductions range from indistinguishable within the simulated natural variability to 60% relative to the 1960–1990 mean; none of the models projects an abrupt transition to an off state of the MOC. The best estimate of sea level from 1993–2003 associated with the slight net negative mass balance from Greenland is 0.1–0.2 mm/yr. The corresponding amount of sea water, even when added directly and exclusively to the North Atlantic, has been suggested to be too small to affect the North Atlantic MOC. Taken together, it is likely that the MOC will reduce, but very unlikely that the MOC will undergo an abrupt transition during the course of the 21st century. [10.3.4, Fig 10.3.13].
- TEMPERATURE VARIABILITY: Climate models predict a decrease in temperature variability during the cold season in the extratropical Northern Hemisphere and a slight increase of temperature variability in low latitudes and in warm season northern mid latitudes. [10.3.5.1]
- MONSOONS: Climate models demonstrate that pronounced warming over the tropics in the middle-to-upper troposphere would result in a weakening of monsoon circulations. Also, atmospheric moisture buildup due to increased GHGs and consequent temperature increase results in a larger moisture flux and more precipitation for the Indian monsoon. [10.3.5.2]
- PRECIPITATION: Climate models predict an increased chance of summer drying in most parts of northern subtropics and midlatitudes and an associated increased risk of drought. Associated with the risk of drying is also an increased chance of intense

precipitation and flooding. Though somewhat counter-intuitive, this is because precipitation is concentrated into more intense events, with longer periods of little precipitation in between. Increases in the frequency of dry days does not necessarily mean a decrease in the frequency of extreme high rainfall events depending on the threshold used to define such events. The change in the frequency of extreme precipitation at an individual location can be difficult to estimate definitively due to model parameterization uncertainty. Climate models continue to confirm the earlier results that in a future climate warmed by increasing GHGs, precipitation intensity increases over most regions. [10.3.6.1]

- TEMPERATURE EXTREMES: The TAR concluded that models project that there is very likely a risk of increased temperature extremes, with more extreme heat episodes in a future climate. This result has been confirmed in subsequent climate model simulations. Several recent studies have found that climate models predict that in a future climate there is an increased risk of more intense, longer-lasting and more frequent heat waves [10.3.6.2] though the change does not become strong until after 2020 [Figure 10.3.17].
- CYCLONES: There have been a number of climate change experiments with global models that can begin to simulate some characteristics of individual tropical cyclones, though studies with classes of models with 100 km resolution or higher cannot simulate observed tropical cyclone intensities. Global climate models with 100 km resolution or higher predict a decrease in tropical cyclone frequency globally, and no change or slight decreases in intensity of cyclones, but some regions may differ. Studies performed with models that use a high resolution (down to 9 km) mesoscale hurricane model predict future tropical cyclones will be more intense. [10.3.6.3]
- GROWING SEASON: Globally, models project an increase in the average growing season length by three to five standard deviations by mid-century [Figure 10.3.17].
- OCEAN SURFACE ACIDITY: Increasing atmospheric CO_2 concentrations lowers oceanic pH and carbonate ion concentrations, thereby increasing acidity. Surface ocean pH today is already 0.1 unit lower than preindustrial values. By the end of the century, models predict it may decline by another 0.13 to 0.34 pH units. Experimental evidence suggests that if these trends continue, key marine organisms – such as corals and some plankton – will have difficulty maintaining their external calcium carbonate skeletons. [10.4.2, Figure 10.4.5]
- SEA LEVELS: Models project that a doubling of CO_2 levels in the atmosphere, if accompanied by a warming of 2—4.5C, will cause a sea level increase of about 30 centimeters, plus or minus 15 cm over the next 100 years [10.6.5; Fig 10.6.1]. However the spatial pattern is not uniform, and some areas experience a decline in sea levels. The geographical patterns of sea level change from different models are not generally similar in detail, but they the differences are not as large as they were in the TAR. Even still the largest spatial correlation coefficient between any pair is 0.76, and only 20% of correlation coefficients exceed 0.5. [10.6.2]
- GLACIERS: Since their mass balance depends strongly on their altitude and aspect, use of data from climate models to make projections requires a method of downscaling, because individual glaciers are too small to be handled in typical GCMs. Statistical relations can be developed between GCM and local meteorology but they may not continue to hold in future climates. [10.6.3] Models predict overall loss of glacier volume, but there is uncertainty about how to estimate the dynamics. [10.6.3.3]

[5.3d] Models have also been used to generate regional forecasts, though the uncertainties are substantial.

- Important details about climate change pertain to geographical details too small to be resolved in global models. Hence regional models have been developed, which involve schemes for downscaling the information from a global model. [11.1.1]
- Downscaling can be done two ways. "Dynamical downscaling" involves feeding information from a global model into a regional climate model, using the data from the global model to impose boundary conditions on the regional model. However this does not necessarily yield a better match to observations [11.2.1.1.1]
- "Statistical downscaling" involves applying empirical estimates between local variables and global variables to estimate changes in the local variables based on global model forecasts. This requires the assumption that the relationships are stationary—i.e. that the empirical relationship is steady over time and under different climatic conditions. Stationarity remains a concern with statistical downscaling, as to whether the cross scale relationships are valid under future climate regimes. This is only weakly assessed through cross-validation tests. [11.2.1.1.2]
- Most sources of uncertainty on regional scales are similar to those on the global scale, but there are both changes in emphasis and new issues that arise in the regional context. Of the climate forcing agents, uncertainty in aerosol forcing adds especially to regional uncertainty because of the spatial inhomogeneity of the forcing and the response. Land use/cover change has an inherently regional scope as well. When analyzing studies involving further layers of models too add local detail, the cascade of uncertainty through the chain of models used to generate regional or local information has to be considered. A major component of uncertainty is the representation in climate models of the response of the climate system to anthropogenic emissions and other perturbations to drivers of the system. These include uncertainties in: the conversion of projected future emissions into concentrations of radiatively active species (i.e., via atmospheric chemistry and carbon-cycle models); the radiative forcing for known concentrations (particularly large for aerosols); other response of the physical climate system to these forcings resulting from incomplete representations of resolved processes (e.g., moisture advection) and parameterizations of sub-grid-scale processes (e.g., clouds, precipitation, planetary boundary layer, land surface), e.g. the strength of feedback mechanisms on the global and regional scale. The degree to which these uncertainties influence the projections of different climate variables is not uniform. For example models agree more readily on the sign and magnitude of temperature changes than of precipitation changes. Evaluation of uncertainties at regional and local scales is complicated by the smaller ratio of the signal to the internal variability on small scales, especially for precipitation. The discrimination of a response is thus more difficult. Also, the climate may itself be poorly known on regional scales in many data-sparse regions. Thus evaluation of model performance as a component of an analysis of uncertainty can itself be problematic. [11.2.2.1]

6. ATTRIBUTING THE CAUSES OF CLIMATE CHANGE

6.1 MEASURING AND ANALYZING CLIMATE CHANGE

[6.1a] There is reliance on computer models both to identify what might be the scales of internal variability and the magnitude of natural forcing, as well as the form of the anthropogenic-forcing signal. It is against these basic shortcomings that attribution studies must be assessed [1.3.3].

- Detection and attribution of climate change are separate processes [1.3.3]
- Detection of climate change is the process of demonstrating that climate has changed in some statistical sense, without providing a reason for that change. Attribution of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence [1.3.3]
- Both detection and attribution rely on observational data as well as model output. [1.3.3]
- In practical terms, attribution of anthropogenic climate change is understood to mean:
    - detection;
    - demonstration that the detected observed change is consistent with computer model predictions of the climate change "signal" that is calculated to occur in response to anthropogenic forcing; and
    - demonstration that the detected change is not consistent with alternative physically plausible explanations of recent climate change that exclude anthropogenic forcing. [1.3.3]
- Estimates of century-scale natural climate fluctuations are not available from the observations because of the relatively short length of records. [1.3.3]

[6.1b] The definition of climate change assumes stationarity of the climate system.

- *Climate change* "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" [9.1.1]

[6.1c] The climate is subject to natural variability on all time scales, from days up to centuries.

- Natural climate variability results from internal climate processes and the climate's response to natural external forcing. Internal variability is present on all time scales from virtually instantaneous (e.g., the triggering of convection) up to years (e.g., tropospheric-stratospheric or inter-hemispheric exchange). Other components of the climate system, such as the ocean and the large ice-sheets tend to operate on longer time scales of decades to centuries. These components produce internal variability directly and by integrating variability from the rapidly varying atmosphere. In addition, internal variability is also produced by coupled interactions between components, such as is the case with the El-Niño Southern Oscillation. [9.1.1.]

[6.1d] Internal variability and climate change are inherently difficult to estimate, and usually requires use of climate models.

- The climate's internal variability is difficult to estimate because all climate observations are influenced, at least to some extent, by variations in external forcing. However estimates can be obtained from observations or models under certain conditions. [9.1.1.]
- The methods used to identify change in observations are based on the expected responses to external forcing, either from physical understanding or as simulated by climate models. An identified change is *detected* in observations if its likelihood of occurrence by random chance by internal variability alone is determined to be small. A failure to detect a particular response might occur for a number of reasons, including the possibility that the response is weak relative to internal variability, or that the metric used to measure change is insensitive to the expected change. [9.1.2]
- The detection of an effect of external forcing on the climate does not necessarily imply that it has an important impact on the environment, biota, or human society. [9.1.3]

6.2 DIFFICULTIES IN ATTRIBUTING OBSERVED CLIMATE CHANGE TO SPECIFIC CAUSES.

[6.2a] Detection of climate change relies on model-generated predictions of the response of the climate to external forcing, such as greenhouse gas emissions, and as such can never be absolutely certain.

- Many studies use climate models to predict the expected responses to external forcing, and these predictions are usually represented as patterns of variation in space, time, or both. Such patterns, which are commonly referred to as *fingerprints*, are usually derived from changes simulated by a climate model in response to forcing. [9.1.2]
- The spatial and temporal scales used to analyze climate change are carefully chosen so as filter out internal variability and enable the separation of the responses to different forcings. The choice of filter criteria introduces a bias and may prejudice the findings. [9.1.2]
- Because detection studies are necessarily statistical in nature, the inferences that can be made about whether an external influence has been detected can never be absolutely certain. It is always possible that a significant result at, say, the 5% level, could simply reflect a rare event that would have occurred in any case with less than 1 chance in 20 in an unchanged climate. Corroborating lines of evidence providing a physically consistent view of the likely cause for the changes reduce the risk of such spurious detection. [9.1.2]

[6.2b] Investigation of the causes of observed climate change can be biased due to "self-selection" phenomena.

- While the approach used in most detection studies assessed in the AR4 is to determine whether observations exhibit the expected response to external forcing, for many decision-makers a question posed about a particular observed phenomenon may be more pertinent. Such questions are difficult to respond to because of a statistical phenomenon known as "selection bias". The fact that the questions are "self selected" from the observations (only large observed climate anomalies in a historical context would be likely to be the subject of such a question) makes it difficult to assess their statistical significance from the same observations. [9.1.2]

[6.2c] Attribution of the cause in climate change is not formally possible.

- Detection does not imply attribution of the detected change to the assumed cause. *Attribution* "of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence". As noted in the SAR (IPCC, 1996) and the TAR (IPCC, 2001), unequivocal attribution would require controlled experimentation with our climate system. That, of course, is not possible. [9.1.2]

[6.2d] The term "attribution" means consistency with a climate model-generated scenario, rather than formal proof of causality. The same data could be consistent with contradictory hypotheses, including large or small greenhouse warming.

- From a practical perspective, attribution of anthropogenic climate change is understood to mean the detected change is "consistent with the estimated responses to the given combination of anthropogenic and natural forcing" [9.1.2]
- Any assessment of observed climate change that compares simulated and observed responses will be affected by errors and uncertainties in the forcings prescribed to a climate model and its corresponding responses. [9.2.3]
- Assessment of the consistency between an observed change and the estimated response to a hypothesized forcing is often achieved by determining whether the amplitude of the hypothesized pattern of change estimated from observations is statistically consistent with expectations based on climate model predictions, as measured by some statistical tests. [9.1.2]
- Attribution also requires evaluating the possibility that the observed change is consistent with alternative explanations that exclude important elements of a given combination of forcings that are hypothesized to have influenced the climate. Statistical analysis requires that the separate influences on climate are properly accounted for. For instance, the attribution of recent warming to greenhouse gas emissions becomes more reliable if the influences of other external forcings, for example solar forcing, are explicitly accounted for in the analysis. [9.1.2]
- This is an area of research with considerable challenges because different forcing factors may lead to similar large-scale spatial patterns of response. [9.1.2]
- If it is not possible to distinguish the spatial pattern of greenhouse warming from that of fossil-fuel related aerosol cooling, the observed warming over the last century could be explained by large greenhouse warming balanced by large aerosol cooling or alternatively by small greenhouse warming with very little or no aerosol cooling. [9.2.3]

[6.2e] Attribution studies rely on the validity of model-generated estimates of the climatic response to forcing, and model-generated estimates of natural variability.

- All three aspects of attribution require knowledge of the internal climate variability on the timescales considered, usually decades or longer. The residual variability that remains in instrumental observations after the estimated effects of external forcing have been removed is sometimes used to estimate internal variability. However, these estimates are uncertain because the instrumental record is short relative to the timescales of interest, and because of uncertainties in the forcings and the estimated responses. Thus internal climate variability is also estimated from long control simulations from coupled climate models. [9.1.2]

- Subsequently, an assessment is usually made of the consistency between the residual variability referred to above and the model based estimates of internal variability. Confidence depends on the ability of models to simulate the various modes of observed variability, comparisons between variability in observations and climate model data and by comparison between proxy reconstructions and climate simulations of the last millennium. [9.1.2]

[6.2f] The reported uncertainties in attribution studies do not take into account basic uncertainty about climate model parameters. These uncertainties can be considerable.

- Model and forcing uncertainties are important considerations in attribution research. Ideally, the assessment of model uncertainty should include uncertainties in model parameters, and in the representation of physical processes in models (structural uncertainty). Such an assessment is not yet available, although research with that goal in mind is underway. [9.1.2]
- The effects of forcing uncertainties, which can be considerable for some forcing agents, such as solar and aerosol forcing, also remain difficult to evaluate, despite advances in research. [9.1.2]
- There are also very large uncertainties in the temporal forcing associated with solar radiation changes, particularly on timescales longer than the 11-year cycle. Previous estimates have used sun spot numbers to determine these slow changes in solar irradiance over the last few centuries, but are not necessarily supported by current understanding. In addition, the magnitude of radiative forcing associated with major volcanic eruptions is uncertain and differs between reconstructions [9.2.2.3]
- Detection and attribution results that are based on several models or several forcing histories do provide information on the effects of model and forcing uncertainty that leads towards a more reliable attribution of climate change to a cause. Such results suggest the attribution of a human influence on temperature change during the latter half of the 20th century is robust. [9.1.2]
- In addition to substantial uncertainty in the timing and amplitude of solar variations on timescales of several decades to centuries, uncertainty also arises because the spatial response of surface temperature to solar forcing resembles that due to anthropogenic forcing. These uncertainties in interpretation of the role of different forcings reflects substantial uncertainties in our knowledge about the size of past volcanic forcing and of the timing and size of long-term variations in solar forcing, as well as differences in the way these effects are taken into account in model simulations. [9.3.3.2]
- There remains considerable uncertainty in the forcings that are used in climate models. Estimates of the uncertainties in reconstructions of past solar forcing have increased since 2001, and chemical and dynamical processes associated with the atmosphere's response to solar irradiance are omitted or not adequately resolved in many climate models used in detection studies. Furthermore, some models include the indirect effects of sulphate aerosols on clouds whereas others consider only the direct radiative effect. [9.4.1.8]

6.3 ASSUMPTIONS NEEDED TO ATTRIBUTE CLIMATE CHANGE TO ANTHROPOGENIC CAUSES.

[6.3a] Evidence for a human influence on climate relies on model-based detection studies.

- The evidence that was available at the time of the TAR consisted of results from a range of detection studies of the instrumental record, relying on output from several climate models for fingerprints and estimates of internal climate variability. On this basis the TAR stated that warming over the 20th century was "very unlikely to be due to internal variability alone as estimated by current models". [9.1.3]
- It is implicitly assumed in these studies that the surface observational record is not affected by nonclimatic trends such as land use change [3.2.2.2].
- There are now a greater number of attribution studies than were available for the TAR, and these have used more recent climate data than previous studies and a greater variety of model simulations. Increased confidence in detection of an anthropogenic signal in the instrumental record refers to this proliferation of work [9.4.1.4]

[6.3b] On average, models used for attributing recent climate change to human interference assume that natural forcings alone would have yielded virtually no change over the 20th century, and global cooling since 1979.

- Climate models that include only natural forcings estimate that over the 20th century say there would have been no climate change on Earth. [Figure 9.4.2].
- The same models run over the post-1979 interval say that natural forcings alone would have yielded cooling everywhere except for a small portion of the Bering Strait and a few other locations. [Figure 9.4.2]

[6.3c] Attribution studies to date do not take into account all known sources of possible influence on the climate.

- Studies have concentrated on what are believed to be the most important forcings with most analyses excluding some forcings that could potentially have significant effects, particularly on regional scales but possibly on global scales also. [9.4.18]
- Observational campaigns have demonstrated the importance of black carbon in the South Asia region and modelling studies have shown that the global forcing from black carbon could be large, yet few detection studies have explicitly included the temperature response to black carbon aerosols because there are few transient coupled model simulations including this forcing due to large modelling uncertainties. [9.4.18]
- Land use changes are another forcing that could be potentially important, particularly on regional scale. [9.4.18]
- Attribution analyses that use recent model simulations which include carbonaceous aerosols and land use changes continue to detect a significant anthropogenic influence on 20th century temperature changes. [9.4.18]

[6.3d] Due to the uncertainties involved, attribution of climate change to human cause is ultimately a judgment call.

- The approaches used in detection and attribution research described above can not fully account for all uncertainties. [9.1.2]
- Ultimately expert judgment is used to estimate the likelihood that a specific cause is responsible for a given climate change. [9.1.2]

7. OVERALL CONCLUSIONS

The following concluding statement is not in the IPCC Report, but was agreed upon by the ISPM writers based on their review of the current evidence.

The Earth's climate is an extremely complex system and we must not understate the difficulties involved in analyzing it. Of particular concern is the limited data available on processes known to have significant climatic influence, such as time-varying ocean circulations. Despite the many data limitations and uncertainties, knowledge of the climate system continues to advance based on improved and expanding data sets and improved understanding of meteorological and oceanographic mechanisms.

The climate in most places has undergone minor changes over the past 200 years, and the land-based surface temperature record of the past 100 years exhibits warming trends in many places. Measurement problems, including uneven sampling, missing data and local land-use changes, make interpretation of these trends difficult. Other, more stable data sets, such as satellite, radiosonde and ocean temperatures yield smaller warming trends. The actual climate change in many locations has been relatively small and within the range of known natural variability. There is no compelling evidence that dangerous or unprecedented changes are underway.

The available data over the past century can be interpreted within the framework of a variety of hypotheses as to cause and mechanisms for the measured changes. The hypothesis that greenhouse gas emissions have produced or are capable of producing a significant warming of the Earth's climate since the start of the industrial era is credible, and merits continued attention. However, the hypothesis cannot be proven by formal theoretical arguments, and the available data allow the hypothesis to be credibly disputed.

Arguments for the hypothesis rely on computer simulations, which can never be decisive as supporting evidence. The computer models rely upon approximations for many of the smaller scale processes of the oceans and atmosphere and these approximations are tuned to produce a credible simulation of global climate statistics. However there are too many degrees of freedom in tunable models for them to serve as supporting evidence for any one tuning scheme, such as that associated with a strong effect from greenhouse gases.

There is no evidence provided by the IPCC in its Fourth Assessment Report that the uncertainty can be formally resolved from first principles, statistical hypothesis testing or modeling exercises. Consequently, there will remain an unavoidable element of uncertainty as to the extent that humans are contributing to future climate change, and indeed whether or not such change is a good or bad thing.

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List of Reviewers/Tabulation of Responses

- To be added