Observations of climate change: The 2007 IPCC Assessment

Testimony of

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before

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Summary

Following a detailed diagnosis of the vital signs of the planet Earth, it has become evident that the planet is running a "fever" and the prognosis is that it is apt to get much worse. **"Warming of the climate system is unequivocal" and it is "very likely" due to human activities**. This is the verdict of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), known as AR4. In the following I provide a brief introduction to the IPCC and its processes. A summary is then given of the main findings from the AR4 for Chapter 3 "Observations: Surface and Atmospheric Climate Change" and its links to other observational chapters. Warming of the climate system is unequivocal as is now clear from an increasing body of evidence showing discernible physically consistent changes. These include increases in global average air temperature; atmospheric temperatures above the surface, surface and sub-surface ocean water temperature; widespread melting of snow; decreases in Arctic sea-ice extent and thickness; decreases in glacier and small ice cap extent and mass; and rising global mean sea level. The observed surface warming at global and continental scales is also consistent with reduced duration of freeze seasons; increased heat waves; increased atmospheric water vapor content and heavier precipitation events; changes in patterns of precipitation; increased drought; increases in intensity of hurricane activity, and changes in atmospheric winds. That is, the IPCC Fourth Assessment finds that the Earth is warming, and that major components of the Earth's climate system are already responding to that warming. This wide variety of observations gives a very high degree of confidence to the overall findings. Moreover these changes are now simulated in climate models for the past 100 years to a reasonable degree, adding confidence to future projections. The summary is followed by a few personal remarks about the meaning of these findings.

Introduction

My name is Kevin Trenberth. I am a senior scientist and the Head of the Climate Analysis Section at NCAR, the National Center for Atmospheric Research. I have authored over 400 publications in the area of climate, and given hundreds of talks on the subject. I am among the most highly cited researchers in all of geophysics. I am especially interested in global-scale climate dynamics; the observations, processes and modeling of climate changes from interannual to centennial time scales. I have particular expertise in El Niño, the hydrological and energy cycles, and hurricanes and climate change. I have served on many national and international committees including National Research Council/National Academy of Science committees, panels and/or boards. I co-chaired the international Climate Variability and Predictability (CLIVAR) Scientific Steering Group of the World Climate Research Programme (WCRP) from 1996 to 1999 and I have served as a member and officer of the Joint Scientific Committee that oversees the WCRP as a whole from 1998 to 2006. I chair the WCRP Observations and Assimilation Panel. I have been involved in global warming science and I have been extensively involved in the Intergovernmental Panel on Climate Change (IPCC) scientific assessment activity as a lead author of individual chapters, the Technical Summary, and Summary for Policy Makers (SPM) of Working Group (WG) I for both the Second and Third Assessment Reports (SAR and TAR; IPCC 1996, 2001). I am a Coordinating Lead Author of Chapter 3 of the Fourth IPCC Assessment (AR4) that deals with observations of the surface and atmospheric climate change.

The IPCC is a body of scientists from around the world convened by the United Nations jointly under the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) and initiated in 1988. Its mandate is to provide policy makers with an objective assessment of the scientific and technical information available about climate change, its environmental and socio-economic impacts, and possible response options. The IPCC reports on the science of global climate and the effects of human activities on climate in particular. Major assessments were made in 1990, 1995, 2001, and now 2007. Each new IPCC report reviews all the published literature over the previous 5 to 7 years, and assesses the state of knowledge, while trying to reconcile disparate claims and resolve discrepancies, and document uncertainties.

WG I deals with how the climate has changed and the possible causes. It considers how the climate system responds to various agents of change and our ability to model the processes involved as well as the performance of the whole system. It further seeks to attribute recent changes to the possible various causes, including the human influences, and thus it goes on to make projections for the future. WG II deals with impacts of climate change, vulnerability, and options for adaptation to such changes, and WG III deals with options for mitigating and slowing the climate change, including possible policy options. Each WG is made up of participants from the United Nations countries, and for the 2007 assessment there are over 450 lead authors, 800 contributing authors, and over 2,500 reviewers from over 130 countries. In my chapter, as well as the two Coordinating Lead Authors, we have 10 lead authors, 66 contributing authors, about 100 pages of text, 126 figure panels in 47 figures, and 863 references. The IPCC process is very open. Two major reviews were carried out in producing the report, and climate "skeptics" can and do participate, some as authors. For our chapter we received over 2230 comments on the expert review and 1270 on the governmental review, all of which were responded to in writing and by changing the report. The process is overseen by two Review Editors. The strength is that it is a consensus report. The SPM was approved line by line by governments in a major meeting in Paris from 29 January to 1 February, 2007. The rationale is that the scientists determine what can be said, but the governments help determine how it can best be said. Negotiations occur over wording to ensure accuracy, balance, clarity of message, and relevance to understanding and policy. The latest report (IPCC 2007) reaffirms in much stronger language that the climate is changing in ways that cannot be accounted for by natural variability and that "global warming" is happening.

Observed Climate Change

The iconic summary statement of the observations section of the IPCC (2007) report is "**Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.**" The language here is carefully chosen to reinforce the view that

1) There are multiple lines of evidence from many variables
2) There is a wide body of evidence and multiple analyses of each variable
3) The variables and evidence are physically consistent with warming
4) The human signal has clearly emerged from noise of natural variability, i.e., it is large.

Since the TAR, progress in understanding how the current climate is changing in space and in time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. Increasingly comprehensive observations are available for glaciers and snow cover since the 1960s, and for sea level and ice sheets since about the past decade. Numerous changes in climate have been observed at the scales of continents or ocean basins. These include wind patterns, precipitation, ocean salinity, sea ice, ice sheets, and aspects of extreme weather.

a. Temperature and related

Instrumental observations over the past 157 years show that temperatures at the surface (Fig. 1) have risen globally, with important regional variations. For the global average, warming in the last century has occurred in two phases, from the 1910s to the 1940s (0.35°C or 0.63ºF), and more strongly from the 1970s to the present (0.55°C or 1.0ºF) at a rate of about 0.16ºC (0.3ºF) per decade. An increasing rate of warming has taken place over the last 25 years, and 11 of the 12 warmest years on record have occurred in the past 12 years. Indeed, the 6 years since the TAR are among the 7 warmest years on record. The total warming since the 1800s is about 0.76ºC (1.4ºF). Globally, 2006 ranks 6th and it was the warmest on record in the United States. Sea surface temperatures (SSTs) are also increasing, however land areas are warming much faster than the oceans since 1970.

Two possible issues with the surface temperature record – urban heat island effects, and discrepancies with balloon-based and satellite measurements – have been extensively studied in the 2007 IPCC report. The urban heat island effects are real but local, and have been found to have a negligible influence on the overall surface temperature record. New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates that are similar to the surface temperature record and consistent within their respective uncertainties, largely reconciling a discrepancy noted in the TAR. The 2007 IPCC report essentially removes these two issues as serious sources of uncertainty for the global surface temperature record.

saxdRegional temperature observations do not always track the global average warming because of atmospheric wave patterns, as well as increased natural variability at smaller geographic scales. For example, the eastern half of the United States has not warmed as much as other areas, especially during the daytime, owing to increases in cloud and precipitation associated with changes in atmospheric circulation as the climate changes. On the other hand, average Arctic temperatures increased at almost twice the global average rate in the past 100 years and also since 1960. However, Arctic temperatures have high decadal variability and a warm period was observed from 1925 to 1945, but that was focused in the North Atlantic and not global as in the recent warming.

Since 1950, the number of heat waves globally has increased and widespread increases have occurred in the numbers of warm nights. Cold days, cold nights and frost have generally become rarer.

Decreases are found in the length of the freeze season of river and lake ice. Temperature at the top of the permafrost layer has increased by up to 3°C since the 1980s in the Arctic. The maximum area covered by seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900 and this value is up to 15% in spring.

The average temperature of global ocean water from the surface to a depth of 700 m increased significantly from 1961 to 2003, indicating that the ocean is absorbing most of the heat being added to the climate system. This causes seawater to expand and is estimated to have contributed 0.42 mm per yr to the average sea level rise from 1961 to 2003, and 1.8 mm per yr from 1993 to 2003.

Sea-ice extents have decreased in the Arctic since 1978, particularly in spring and summer (7.4% per decade), and patterns of the changes are consistent with regions showing a temperature increase, although changes in winds are also a major factor. Sea-ice extents were at record low values in 2005, which was also the warmest year since records began in 1850 for the Arctic north of 65°N. There have also been decreases in sea-ice thickness. In contrast to the Arctic, Antarctic sea ice does not exhibit any significant trend since the end of the 1970s, which is consistent with the lack of trend in surface temperature south of 65°S over that period. However, along the Antarctic Peninsula, where significant warming has occurred, progressive break up of ice shelves has occurred beginning in the late 1980s, culminating in the break up of the Larsen-B ice shelf in 2002.

The observed surface temperature increases are consistent with the observed nearly worldwide reduction in glacier and small ice cap mass and extent in the 20th century. In addition, flow speed has recently increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior, and melting of Greenland has increased after about 2000. Glaciers and ice caps respond not only to temperatures but also to changes in precipitation, and both winter accumulation and summer melting have increased over the last half century in association with temperature increases. In some regions moderately increased accumulation observed in recent decades is consistent with changes in atmospheric circulation and associated increases in winter precipitation (e.g., southwestern Norway, parts of coastal Alaska, Patagonia, and the South Island of New Zealand) even though increased ablation has led to marked declines in mass balances in Alaska and Patagonia. Tropical glacier changes are synchronous with higher latitude ones and all have shown declines in recent decades. Decreases in glaciers and ice caps contributed to sea level rise by 0.5 mm per yr from 1961 to 2003 and 0.8 mm per yr from 1993 to 2003. Taken together, shrinkage of the ice sheets of Greenland and Antarctica has contributed 0.4 mm per yr to sea level rise over 1993 to 2003.

Global average sea level rose at an average rate of 1.8 mm per over 1961 to 2003. The rate was faster during 1993-2003, when truly global values have been measured from altimeters in space, at about 3.1 mm per yr. Hence about 60% of this is from ocean warming and expansion, and 40% is from melting land ice, adding to the ocean volume. The observation of consistent sea level rise over several decades, and also an increasing rate of sea level rise in the last decade or so, is probably the single best metric of the cumulative global warming that we have experienced to date. There is really no explanation other than global warming for the observed sea level rise.

The average atmospheric water vapor content has increased over land and ocean as well as in the upper troposphere, and over the global oceans this is estimated to be 4% since 1970. The increase is broadly consistent with the extra water that warmer air can hold and amounts to a fairly constant relative humidity.

The added water vapor also adds to the greenhouse effect and roughly doubles that due to carbon dioxide, providing a powerful positive feedback to climate change.

The observed surface warming at global and continental scales is consistent with observed changes in sub-surface ocean water temperature; decreases in sea-ice extent and thickness; decreases in glacier and small ice cap extent and mass; sea-level rise; reduced duration of freeze seasons, increased heat waves; and increased atmospheric water vapor content. That is, the IPCC Fourth Assessment finds that the Earth is warming, and that major components of the Earth's climate system are already responding to that warming. This wide variety of observations gives a very high degree of confidence to the overall findings.

b. Precipitation and related

The 2007 IPCC report finds that changes are occurring in the amount, intensity, frequency, and type of precipitation in ways that are also consistent with a warming planet. These aspects of precipitation generally exhibit large natural variability (compared to temperature trends), and El Niño and changes in atmospheric circulation patterns have a substantial influence, making it harder to detect trends in the observational record.

A key ingredient in changes in character of precipitation is the observed increase in water vapor and thus the supply of atmospheric moisture to all storms, increasing the intensity of precipitation events. Indeed, widespread increases in heavy precipitation events and risk of flooding have been observed, even in places where total amounts have decreased. Hence the frequency of heavy rain events has increased in most places but so too has episodic heavy snowfall events that are thus associated with warming. Snow cover has decreased in many Northern Hemisphere regions, particularly in spring, and more precipitation is falling as rain instead of snow. These changes are consistent with changes in permafrost, noted above.

Long-term trends from 1900 to 2005 have been observed in total precipitation amounts over many large regions. Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Precipitation is highly variable spatially and temporally. Robust long term trends have not been observed for other large regions. The pattern of precipitation change is one of increases generally at higher northern latitudes (because as the atmosphere warms it holds more moisture) and drying in the tropics and subtropics over land. Basin-scale changes in ocean salinity provide further evidence of changes in the Earth's water cycle, with freshening at high latitudes and increased salinity in the subtropics.

More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. Increased drying due to higher temperatures and decreased precipitation have contributed to these changes, with the latter the dominant factor. The regions where droughts have occurred are determined largely by changes in sea surface temperature (SST), especially in the tropics (such as during El Niño), through changes in the atmospheric circulation and precipitation. In the western United States, diminishing snow pack and subsequent summer soil moisture reductions have also been a factor. In Australia and Europe, direct links to warming have been inferred through the extreme nature of high temperatures and heat waves accompanying drought.

Satellite records suggest a global trend towards more intense and longer lasting tropical cyclones (including hurricanes and typhoons) since about 1970, correlated with observed warming of tropical SSTs. There is no clear trend in the annual number of tropical cyclones globally although a substantial increase has occurred in the North Atlantic after 1994. There are concerns about the quality of tropical cyclone data, particularly before the satellite era. Further, strong multidecadal variability is observed and complicates detection of long term trends in tropical cyclone activity.

c Synthesis across variables

In summary, global mean temperatures have increased since the 19th century, especially since the mid-1970s. Temperatures have increased nearly everywhere over land, and SSTs have also increased, reinforcing the evidence from land. However, global warming does not mean that temperatures increase steadily or uniformly, indeed temperatures have increased neither monotonically, nor in a spatially uniform manner, especially over shorter time intervals. The atmospheric circulation has also changed: in particular increasing westerly wind flow is observed in most seasons in both hemispheres. In the Northern Hemisphere this brought milder maritime air into Europe and much of high-latitude Asia from the North Atlantic in winter, enhancing warming there. In the Southern Hemisphere, where the ozone hole has played a role, it has resulted in cooling over 1971-2000 for parts of the interior of Antarctica but large warming in the Antarctic Peninsula region and Patagonia. Temperatures generally have risen more than average where flow has become more poleward, and less than average or even cooled where flow has become more equatorward, reflecting atmospheric patterns of variability.

Over land in low latitudes and in summer more generally, there is a strong tendency for either hot and dry or cool and wet. Hence areas that have become wetter, such as the eastern United States and Argentina, have not warmed as much as other land areas. Increased precipitation is associated with increases in cloud and surface wetness. Thus more heat goes into increased evapotranspiration and less into raising temperature at the surface in wetter conditions.

The three main ocean basins are unique and contain very different wind systems, SST patterns and ocean currents, leading to vastly different variability associated, for instance, with El Niño in the Pacific, and the ocean currents including the Gulf Stream in the Atlantic. Consequently the oceans have not warmed uniformly, especially at depth. SSTs in the tropics have warmed at different rates and help drive, through coupling with tropical convection and winds, distinctive wave patterns known as teleconnections around the world. This has changed the atmospheric circulation and the monsoons. Changes in precipitation and storm tracks are not as well documented but clearly respond to these changes on interannual and decadal timescales. When precipitation increases over the ocean, as it has in recent years in the tropics, it decreases over land, although it has increased over land at higher latitudes. Droughts have increased over many tropical and mid-latitude land areas, in part because of decreased precipitation over land since the 1970s but also from increased drying arising from increased atmospheric demand associated with warming.

Many of these observed changes are now simulated in climate models run for the past 100 years, adding confidence to understanding of the relationship with the agents that alter the climate, and human-induced changes in atmospheric composition, in particular, as is documented in other IPCC chapters.

Some implications

The scientific understanding of climate change is now sufficiently clear to show that specific global and regional changes resulting from global warming are already upon us. Uncertainties remain, and new efforts at reprocessing past satellite records for phenomena such as hurricanes are required, but the 2007 IPCC report definitively shows that the climate is changing. "Warming is unequivocal" and it is "very likely" caused by human activities.

In my personal opinion as a climate scientist, the IPCC report strongly implies the need for a three pronged approach of mitigation, adaptation, and maintaining and improving climate observing and information systems.

While there are uncertainties (although these cut both ways) and some changes arising from global warming may be benign or even beneficial, at least in some places and in the short run, the IPCC report shows that the rate of change as projected exceeds anything seen in nature in the past 10,000 years. Moreover, the inertia of the climate system and the long life of carbon dioxide in the atmosphere mean that we are already committed to a significant level of climate change. I believe that mitigation actions are certainly needed to significantly reduce the build-up of greenhouse gases in the atmosphere and lessen the magnitude and rate of climate change.

At the same time, the 2007 IPCC report makes clear that even aggressive mitigation would yield benefits many decades in the future, and that no amount of mitigation can avoid significant climate change. I believe it is apt to be disruptive in many ways. Hence it is also vital to plan to cope with the changes, such as enhanced droughts, heat waves and wild fires, and stronger downpours and risk of flooding. Managing water resources will be a major challenge in the future. Adapting to climate change and reducing vulnerability is essential. This means that we should adapt to climate change by planning for it and making better predictions of likely outcomes on several time horizons.

Finally, although not reported by the IPCC, my experience in working with observations of climate change has led me to urge the Committee to address the considerable shortcomings in our observing systems. Weather observing systems are continually used for climate purposes for which they were not designed. Moreover, weather stations come and go and changes are made without regard to the effect on the climate record. Changes in observing systems, especially from satellites, as new satellites and instruments are launched, create artifacts in the climate record. Loss of Earth observing satellites is also of concern, as documented in the recent National Research Council (2007) decadal survey. Ground based observations are not being adequately kept up in many countries. Calibration of climate records is critical. Small changes over long times are characteristic of climate change but they occur in the midst of large variations associated with weather and natural climate variations such as El Niño. Yet the climate is changing and an imperative is to track the changes and the causes as they occur. We need to build a system based on these observations to inform decision makers on what is happening, and why, and what the predictions are for the future on several time horizons.

I appreciate the opportunity to address the Committee concerning the science of global climate change, and look forward to answering any questions you may have today or in the future.

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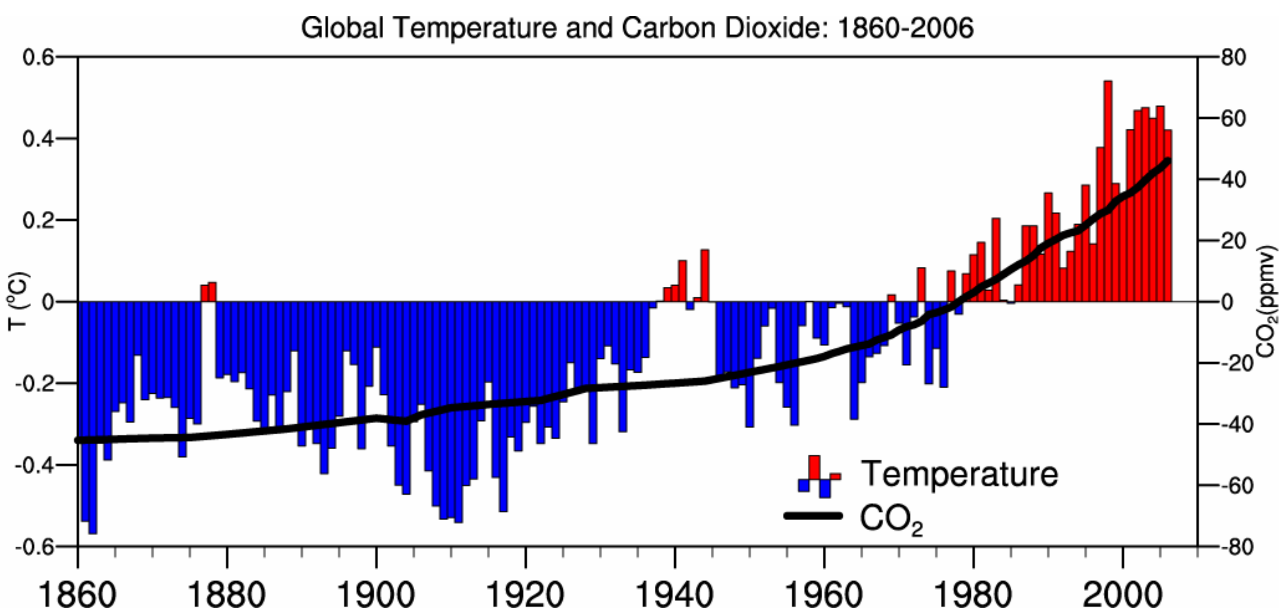

Figure 1. Time series of annual global mean temperature departures for 1861-2006 from a 1961-90 mean (bars), left scale, and the annual mean carbon dioxide from Mauna Loa after 1957 linked to values from bubbles of air in ice cores prior to then. The zero value for 1961-90 for temperature corresponds to 14ºC and for carbon dioxide 334 parts per million by volume (ppmv). Updated from Karl and Trenberth (2003).