The IPCC Assessment of Global Warming 2001

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Kevin E. Trenberth

National Center for Atmospheric Research[1]
P. O. Box 3000
Boulder, CO 80307

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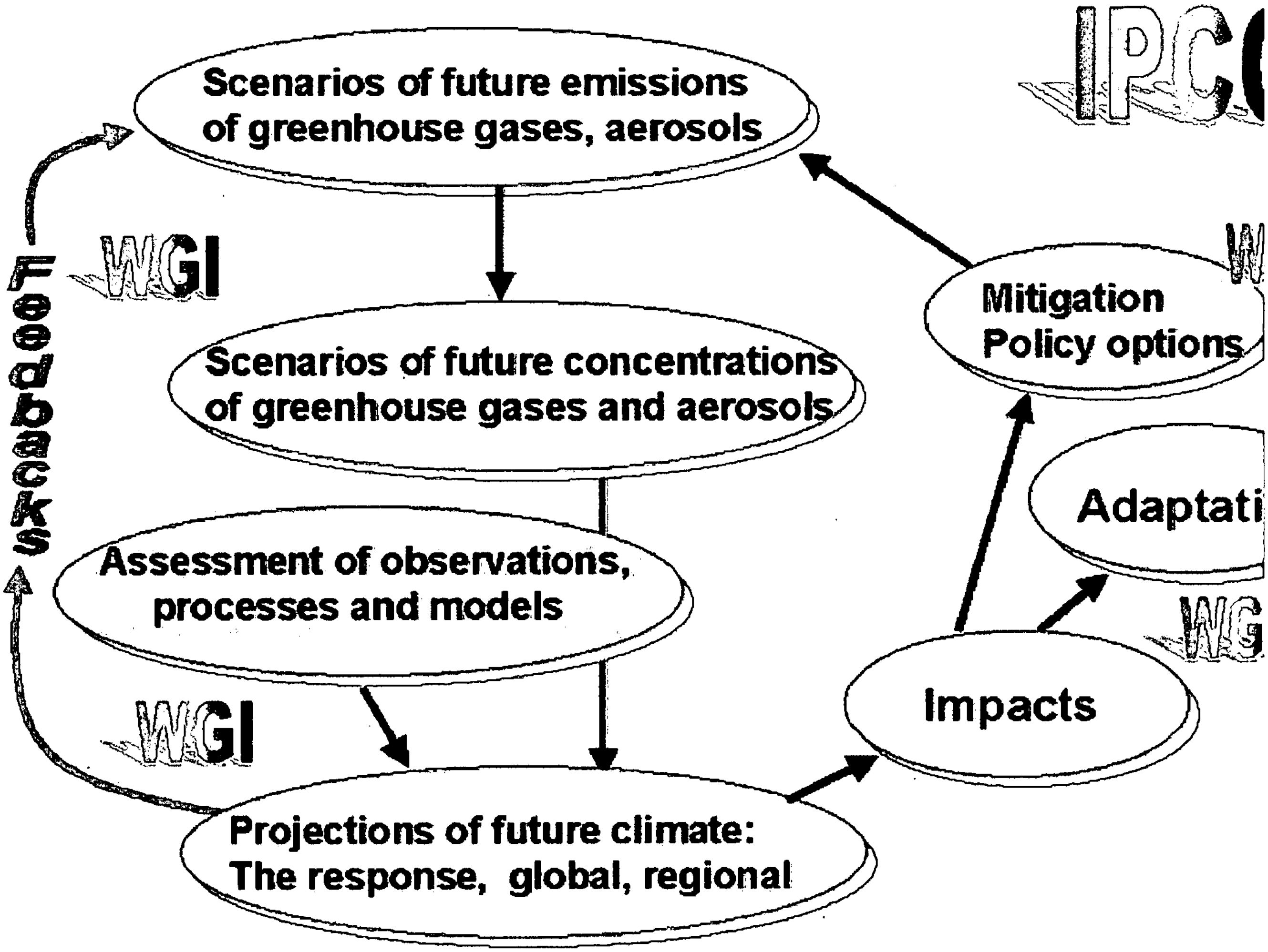
Summary
The latest 2001 Intergovernmental Panel on Climate Change (IPCC) report reaffirms in much stronger language that the climate is changing in ways that cannot be accounted for by natural variability and that "global warming" is happening. Global mean temperatures have risen and the last decade is the warmest on record. The major cause of warming in the last three decades is from human effects changing the composition of the atmosphere primarily through use of fossil fuels. While changes in particulate pollution mostly causes cooling, increases in long-lived greenhouse gases dominate and cause warming. The long lifetime of several greenhouse gases (carbon dioxide lasts for over a century) suggests that we can not stop the changes, although we can slow them down. Moreover, the slow response of the oceans to warming, means that we have not yet seen all of the climate change we are already committed to. Major climate changes are projected under all likely scenarios of the future and the rates of change are much greater than occur naturally, and so are likely to be disruptive.

Introduction
This report is a brief summary of the science of global climate change, and the effects of human activities on climate in particular, with some insights from the latest 2001 IPCC report, but also with my own biases included.

The IPCC is a United Nations body that was set up jointly under the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988. Its mandate is to provide policy makers with an objective assessment of the scientific, technical and socio-economic information available about climate change, its environmental and socio-economic impacts, and possible response options. In other words, the assessment should be policy relevant but not policy prescriptive.

The IPCC carries out major assessments of the state of knowledge and understanding about every five years, the first in 1990, the second in 1995, and the third was completed in early 2001. There are three major working groups under the IPCC. In the 2001 assessment, Working Group (WG) I deals with the science of climate change, WG II deals with impacts of climate change and options for adaptation to such changes, and WG III deals with options for mitigating and slowing the climate change, including possible policy options (Fig. 1).



Each WG is made up of participants from all the United Nations countries, and for the Third Assessment, WG I consisted of 123 lead authors, 516 contributors, 21 review editors, and over 700 reviewers. The resulting report (IPCC 2001) is about 1000 pages long and involves 14 chapters. There is a Technical Summary and a short Summary for Policy Makers (SPM). I participated as a lead author of a chapter, as well as a lead author of both the Technical Summary and the SPM.

The SPM was approved line by line by governments in a major meeting, which took place over four days in Shanghai, China, in January 2001. The argument here is that the scientists determine what can said, but the governments determine how it can best be said. Negotiations occur over wording to ensure accuracy, balance, clarity of message, and relevance to understanding and policy. In Shanghai, there were about 100 countries represented by delegations, perhaps 10 non-governmental organizations, and about 42 scientists. Simultaneous translation occurred throughout the meeting into English, French, Spanish, Russian, Chinese and Arabic. On the first evening, delegates were treated to a wonderful reception hosted by China.

The IPCC process is dependent on the good will of the participants in producing a balanced assessment. However, in Shanghai, it appeared that there were attempts to blunt, and perhaps obfuscate, the messages in the report, most notably by Saudi Arabia. This led to very protracted debates over wording on even bland and what should be uncontroversial text. For instance, the opening introductory paragraph of 5 lines took over an hour and half to deal with, and then with a small group spun off to recommend revised wording. The draft sentence "Many hundred of scientists contributed to its preparation and review" was the primary focus. The sentence is factual but was challenged on grounds that it implied that all of these scientists endorsed the report in every respect. Of course it does not say that, but dealing with many alternative proposed wordings took inordinate amounts of time and the final changes were trivial. The result was that the schedule of the meeting quickly became disrupted so that extra evening sessions were scheduled. During the limited breaks that did occur, authors of the report worked with delegates in side meetings to craft revised text for submission to the plenary. There were no coffee breaks at any time and I was amazed at the fortitude of the Chairman (Sir John Houghton) and others who helped run the meeting in their capacity to keep going without taking a break! On the second day, following a 1.5 hour break to quickly consume imported hot chicken sandwiches for the evening meal, the session ran until 10:45 p.m. The days began for most of us at 8:00 a.m. with side bar meetings. Adjournment on the third day was at 11:30 p.m. and the SPM was finally approved well after midnight at 12:45 a.m. on the final day. The meeting closed just after 1:00 a.m. In many ways the meeting became one of endurance. In spite of these trials and tribulations, the result is a reasonably balanced consensus summary. However, the SPM did grow to about double the initial draft length during the course of the meeting.

Each new IPCC report reviews all the published literature over the previous 5 years or so, and assesses the state of knowledge, while trying to reconcile disparate claims and resolve discrepancies, and highlight uncertainties. The IPCC process is very open. Two major reviews were carried out in producing the report, and skeptics can and do participate, some as authors. The strength is that result is a consensus report. It is not necessarily the latest or greatest, it is too long for readability, but because it does sort out what can be reliably stated, it is a useful reference. The greatest weakness is that all chapters are written in parallel, and also the working groups operate in parallel. Several plenary sessions of all authors helps to cut down on conflicts, gaps, and duplication, but some of those problems are almost inevitable. The summaries provide more digestible material for most readers and are available over the internet. See http://www.ipcc.ch.

The Basic Problem

Climate changes have occurred in the past naturally, over decades to millennia for various reasons. However, humankind is performing a great geophysical experiment (Revelle and Suess, 1957). By modifying the Earth's environment in various ways, we are changing the climate. Legitimate debates go on about the extent and rate of these changes, and what, if anything, to do about them, but that the experiment is underway is not in doubt. The human-induced environmental changes of most relevance are in land use (e.g., farming, building cities), storage and use of water (dams, reservoirs, irrigation), generation of heat, and combustion of fossil fuels. The latter, in particular, pollutes the atmosphere and alters the balance of radiation on Earth through both visible particulate pollution (called aerosols) and gases that change the composition of the atmosphere. The latter are referred to as greenhouse gases (GHGs) because they are relatively transparent to incoming solar radiation, while they absorb and reemit outgoing infrared radiation, thus creating a blanketing effect, which results in warming. Global warming and associated climate change are expected as a result.

The problem with this experiment is that if it turns out badly - however that is defined - we cannot undo it. We cannot even abruptly turn it off. Too many of the things we are doing now have long-term ramifications for centuries into the future. For instance, carbon dioxide has an atmospheric lifetime of greater than a century and simply stopping increases in emissions would still result in increases in emissions to well below current levels. Even fully implementing the Kyoto protocol would merely slow the time of doubling of carbon dioxide concentrations in the atmosphere from pre-industrial values by perhaps 15 years (for instance from 2060 to 2075) unless substantial further emissions reductions were to take place at some time in the future (Wigley 1998). Moreover, changes underway in the oceans would endure.

Observed Climate Change

Analysis of observations of surface temperature show that there has been a global mean warming of about 0.7°C over the past one hundred years. The IPCC states this as 0.6±0.2°C, but this is a linear fit to what is obviously not a linear trend; see Fig. 2 for the instrumental record of global mean temperatures. The warming became noticeable from the 1920s to the 1940s, leveled off from the 1950s to the 1970s and took off again in the late 1970s. The calendar year 1998 is by far the warmest on record, exceeding the previous record held by 1997. Global temperatures in the latest year, 2000, were overall about the same as 1999. The last ten years are the warmest decade on record. Synthesis of information from tree rings, corals, ice cores and historical data further indicates that these years are the warmest in at least the past 1000 years, which is as far back as a hemispheric estimate of temperatures can be made (Mann et al. 1998, 1999). The melting of glaciers over most of the world and rising sea levels confirm the reality of the global temperature increases. There is good evidence for decadal changes in the atmospheric circulation and some evidence for ocean changes. These mean that increases in temperature are not uniform or monotonic; some places warm more than the average and some places cool. Changes in precipitation and other components of the hydrological cycle vary considerably geographically. It is likely that precipitation has increased by perhaps 1%/decade in the 20th Century over most mid and high latitude continents of the Northern Hemisphere. Changes in climate variability and extremes are beginning to emerge. Perhaps of greatest note are the observed increase in the heat index (that incorporates humidity and temperature information on comfort), and precipitation events tend to be more intense.

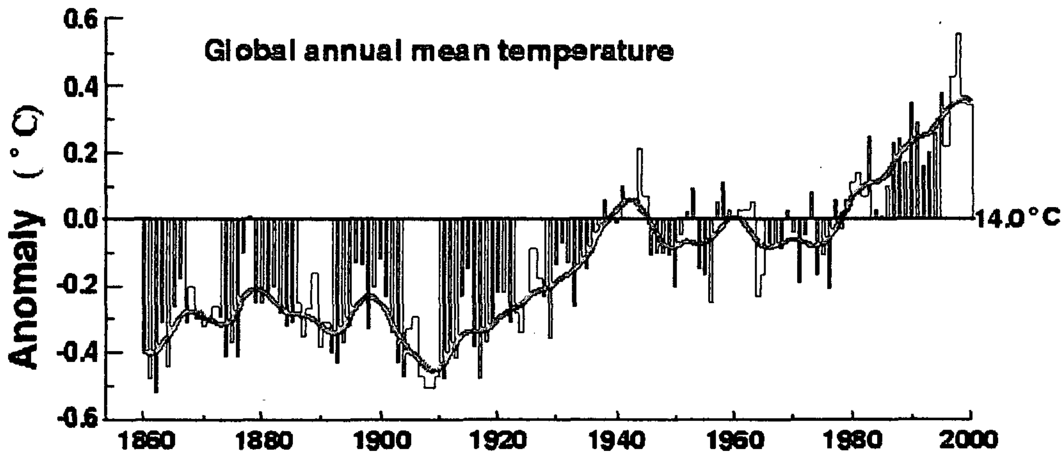


Fig 2: Global annual mean temperatures from 1860 to 1999 as departures from the 1961 to 1990 means. (From data provided by Hadley Center, UKMO, and Climate Research Unit, Univ. East Anglia.)

One persistent issue has been the discrepancy in trends from the so-called satellite temperature record and that at the surface. The satellite record begins in 1979 and measures radiation from the Earth in the microwave coming from about the lowest 8 km of the atmosphere in the troposphere. Consequently it does not measure the same thing as the surface temperature. Models run with increasing greenhouse gases suggest that warming in the troposphere should be larger than that at the surface whereas the observed record shows a significantly less warming (1979-1999) and this has been highlighted by skeptics. However, when observed stratospheric ozone depletion is included in models they suggest that the surface and tropospheric temperatures should increase at about the same rate. In fact this is what has happened from about 1960 to the present based on balloon observations that replicate the satellite record after 1979. The shorter satellite record is influenced by El Niño events (which warm the troposphere more) and effects of volcanic eruptions (which have a much greater cooling on the troposphere), and thus the Pinatubo eruption in 1991 leads to a relative downward trend in the troposphere. Other effects from aerosols, cloudiness changes, and so on, have not been quantified but also influence the two records differently. Accordingly, the small trend in the satellite record is not inconsistent with the observed larger trend in surface temperatures.

The Climate System and its Driving Forces

Because humans live in and breathe the atmosphere it is natural to focus on the atmospheric changes. Climate involves variations in which the atmosphere is influenced by and interacts with other parts of the climate system, and "external" forcings. The internal interactive components in the climate system include the atmosphere, the oceans, sea ice, the land and its features (including the vegetation, albedo, biomass, and ecosystems), snow cover, land ice, and hydrology (including rivers, lakes and surface and subsurface water). The components normally regarded as external to the system include the sun and its output, the Earth's rotation, sun-Earth geometry and the slowly changing orbit, the physical components of the Earth system such as the distribution of land and ocean, the geographic features on the land, the ocean bottom topography and basin configurations, and the mass and basic composition of the atmosphere and ocean. These components determine the mean climate, which may vary from natural causes. A change in the average net radiation at the top of the atmosphere due to perturbations in the incident solar radiation or the emergent infrared radiation leads to what is known as radiative forcing of the system. Changes in the incident radiation energy from the sun or changes in atmospheric composition due to natural events like volcanoes are possible examples. Other external forcings may occur as a result of human activities.

The source of energy that drives the climate is the radiation from the sun. About 31% is scattered or reflected back to space by molecules, tiny airborne particles (known as aerosols) and clouds in the atmosphere, or by the Earth's surface. To balance the incoming energy, the Earth itself must radiate on average the same amount of energy back to space. It does this by emitting thermal "long-wave" radiation in the infrared part of the spectrum. The radiation emitted by the Earth to space corresponds to a temperature of about -19°C, much colder the annual average global mean temperature of about 14°C.

The reason is because the bulk of the Earth's radiation to space is intercepted by the atmosphere and re-emitted both up and down. The emissions to space occur either from the tops of clouds at different atmospheric levels (which are almost always colder than the surface), or by gases present in the atmosphere which absorb and emit infrared radiation. Water vapor, carbon dioxide and some other minor gases present in the atmosphere absorb some of the thermal radiation leaving the surface and emit radiation from much higher and colder levels out to space. The blanketing is known as the natural greenhouse effect. Water vapor gives rise to about 60% of the current greenhouse while CO2 accounts for about 26% (Kiehl and Trenberth 1997). Clouds also absorb and emit thermal radiation and have a blanketing effect similar to that of the greenhouse gases. But clouds are also bright reflectors of solar radiation and thus also act to cool the surface. While on average there is strong cancellation between the two opposing effects, the net global effect of clouds in our current climate, as determined by space-based measurements, is a small cooling of the surface.

Human Influences

The amount of carbon dioxide in the atmosphere has increased by about 31% since the beginning of the industrial revolution, from 280 parts per million by volume (ppm) to 367 ppm, owing mainly to combustion of fossil fuels and the removal of forests. In the absence of controls, future projections are that the rate of increase in carbon dioxide amount may accelerate and concentrations could double from pre-industrial values within the next 50 to 100 years. Several other greenhouse gases are also increasing in concentration in the atmosphere from human activities (especially biomass burning, agriculture, animal husbandry, fossil fuel use and industry, and through creation of landfills and rice paddies). These include methane, nitrous oxide, the chlorofluorocarbons (CFCs) and tropospheric ozone, and they tend to reinforce the changes from increased carbon dioxide. However, the observed decreases in lower stratospheric ozone since the 1970s, caused principally by human-introduced CFCs and halons, contribute to a small negative radiative forcing.

Human activities also affect the amount of aerosol in the atmosphere, which influences climate in other ways. A direct effect of some aerosols is the scattering of a fraction of solar radiation back to space, which tends to cool the Earth's surface. Other aerosols (like soot) directly absorb solar radiation leading to local heating of the atmosphere and some absorb and emit thermal radiation. A further influence of aerosols is that many act as nuclei on which cloud droplets condense, affecting the number and size of droplets in a cloud and hence altering the reflection and the absorption of solar radiation by the cloud. Recent evidence highlights the possible importance of this effect, although the magnitude is very uncertain (Hansen et al. 1997).

Aerosols occur in the atmosphere from natural causes; for instance, they are blown off the surface of deserts or dry regions. The eruption of Mt. Pinatubo in the Philippines in June 1991 added considerable amounts of aerosol to the stratosphere which, for about two years, scattered solar radiation leading to a loss of radiation at the surface and a cooling. Human activities contribute to aerosol particle formation mainly through injection of sulfur dioxide into the atmosphere (which contributes to acid rain) particularly from power stations and through biomass burning. Because man-made aerosols are mostly introduced near the Earth's surface where they can be washed out of the atmosphere by rain, they typically remain in the atmosphere for only a few days and they tend to be concentrated near their sources such as industrial regions. The radiative forcing therefore possesses a very strong regional pattern, and the presence of aerosols can only help mask temporarily any global warming arising from increased greenhouse gases.

The increases in greenhouse gases in the atmosphere and changes in aerosol content produce a change in the radiative forcing. The determination of the climatic response to this change in forcing is complicated by feedbacks. Some of these can amplify the original warming (positive feedback) while others serve to reduce it (negative feedback).

If, for instance, the amount of carbon dioxide in the atmosphere were suddenly doubled, but with other things remaining the same, the outgoing long-wave radiation would be reduced and instead trapped in the atmosphere. To restore the radiative balance, the atmosphere must warm up and, in the absence of other changes, the warming at the surface and throughout the troposphere would be about 1.2°C. In reality, many other factors will change, and various feedbacks come into play, so that the best estimate of the average global warming for doubled carbon dioxide is 2.5°C (IPCC, 1996). In other words the net effect of the feedbacks is positive and roughly doubles the response otherwise expected. The main positive feedback comes from water vapor increases with warming, as discussed further below.

Modeling of Climate Change

To quantify the response of the climate system to changes in forcing it is essential to account for all the complex interactions and feedbacks among the climate system components and this is done using numerical models of the climate system based upon sound well-established physical principles. With comprehensive climate models, experiments can be run with and without increases in greenhouse gases and also other influences, such as changes in aerosols. The best models encapsulate the current understanding of the physical processes involved in the climate system, the interactions, and the performance of the system as a whole. They have been extensively tested and evaluated using observations. They are exceedingly useful tools for carrying out numerical climate experiments, but they are not perfect, and so have to be used carefully (see Trenberth 1997). The latest models have increasingly been able to reproduce the climate of the past century or so (see Fig. 3 and Stott et al. 2000).

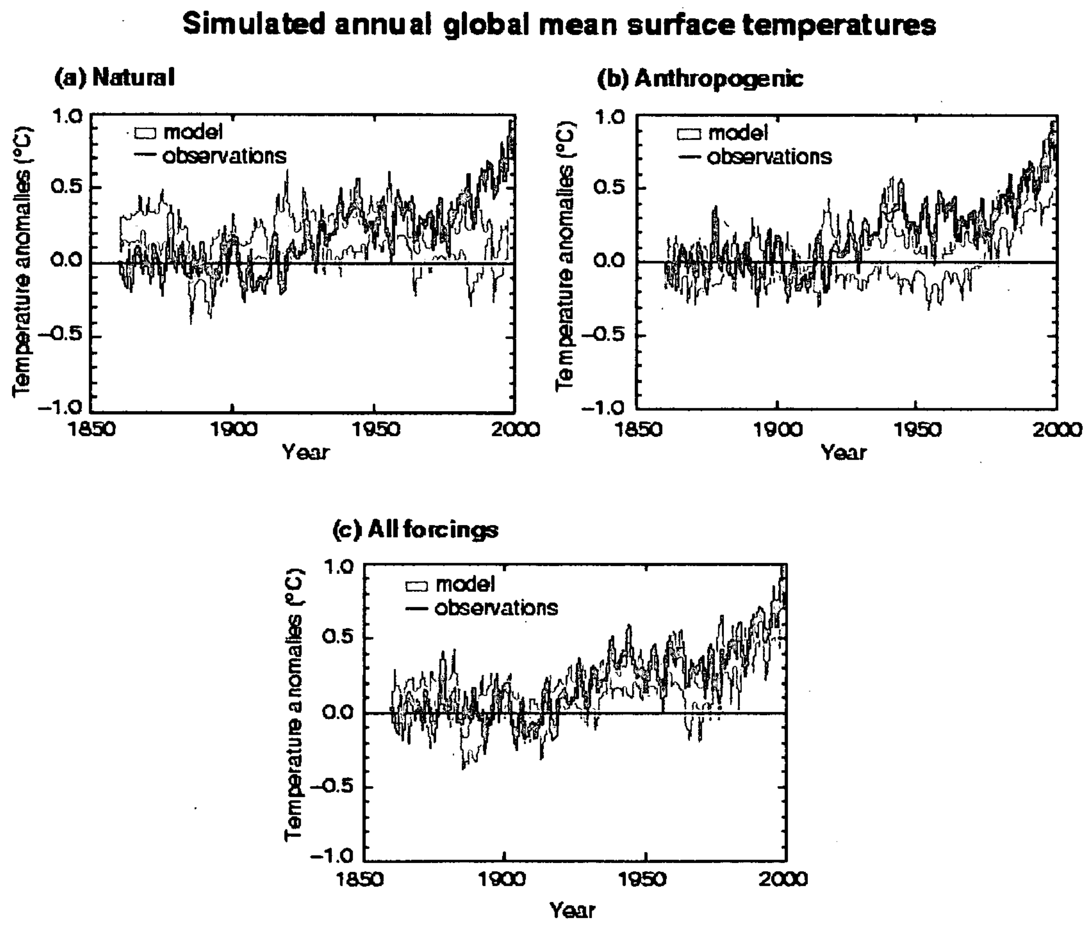


Figure 3: Simulating the Earth's temperature variations, and comparing the results to measured changes, can provide clues to the underlying causes of the major changes. A climate model can be used to simulate the temperature changes that occur from natural causes and from anthropogenic

causes. The simulations represented by the band in Figure 3 (a) were done with only natural forcings: solar variation and volcanic activity. Those encompassed by the band in Figure 3 (b) were done with anthropogenic forcings: greenhouse gases and aerosols and the those encompassed by the band in Figure 3 (c) were done with a both natural and anthropogenic forcings included. From Figure 3 (b) it can be seen that inclusion of anthropogenic forcings provides a plausible explanation for a substantial part of the observed temperature changes over the past century, but the best match with observations is obtained in Figure 3 (c) when both natural and anthropogenic factors are included. The band of model results presented here are for four runs from the same model. From IPCC (2001).

Detection and Attribution.

Key issues in global climate change remain those of firstly detecting whether the recent climate is different than should be expected from natural variability, and secondly attributing the climate changes to various causes, including the human influences. Several key points emerge from the recent IPCC assessment, which address these issues. The following is my interpretation of the IPCC report and other recent findings.

1. The magnitude and rate of change of global, or at least Northern Hemisphere, mean surface temperature over past few decades is outside the range of anything deduced from paleo-climate records for the previous 950 years; data are inadequate before that.
2. Model estimated internal climate variability is reasonably consistent with the deduced paleo-climate pre-industrial variability; and together these provide more reliable estimates of the natural variability, enabling the above statement to be made with greater confidence.
3. Even doubling the model-estimated climate variability cannot account for the rate and magnitude of temperature increase of the last few decades.
4. Consequently, detection of climate change is now much clearer than 5 years ago, and it is very unlikely that recent climate change is natural in origin.
5. The net effects of the natural forcing agents (solar and volcanoes) over the last 2-4 decades is likely to be negative and, thus, cannot be a cause of the recent increase in temperature.
6. A combination of internal climate variability, natural forcing and perhaps small anthropogenic forcing can account for the observed globally averaged surface temperature increase up until about 1970. The warming between about 1920 and 1940 likely has a significant contribution from increases in solar radiation, even though this is poorly known, which is estimated to account for 0.15 to 0.2°C of warming (Fig. 3). However, it also probably has a natural component related to changes in North Atlantic Ocean circulation.
7. The rate and magnitude of the warming over the last few decades cannot be explained unless the net anthropogenic forcing is positive over about the last 30 years. Uncertainties in aerosol forcing (especially the so-called indirect effect on clouds) are therefore constrained to be less than otherwise estimated simply from knowledge of the processes and observations.
8. The nearer the "balance" or offset between positive anthropogenic GHG forcing and negative anthropogenic aerosol forcing over the last 50 years, the larger the climate sensitivity needs to be to explain warming over the last few decades.

The most contentious paragraph in the IPCC (2001) SPM was the concluding one on attribution. After much debate the following was carefully crafted: "In the light of new evidence, and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations."

Consequently, it is concluded that the positive radiative forcing from increases in GHGs is responsible for the warming in recent years. Moreover, although not highlighted by the IPCC, increasing evidence suggests that the signal of human influence on climate emerged from the noise of natural variability

The line of argument given above is open to criticism that there is some circular reasoning involved. The objective is to account for the change in temperature, but the temperature change itself is invoked as part of the argument. Climate modelers attempt to avoid such a trap by basing their models on sound physical principles. However, many parameters have to be chosen in the models. Although the choices are based on knowledge of the processes, and the parameters are physically based, there is ample scope for unintentional tuning. Inevitably, running a model with two different choices of parameters gives different answers and the one that brings the model into best agreement with observations is chosen. It is important, therefore, to recognize the limitations of the objective approach to attribution of climate change, and uncertainties remain. Nevertheless, there are direct implications in these findings for the near future, which is strongly constrained to show further temperature increases of probably 0.1 to 0.2° over the next decade, and so time will tell whether the assessment is correct or not, and quite quickly (within a decade).

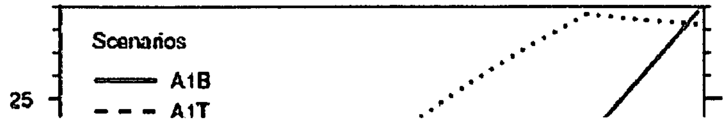
Prediction of climate change

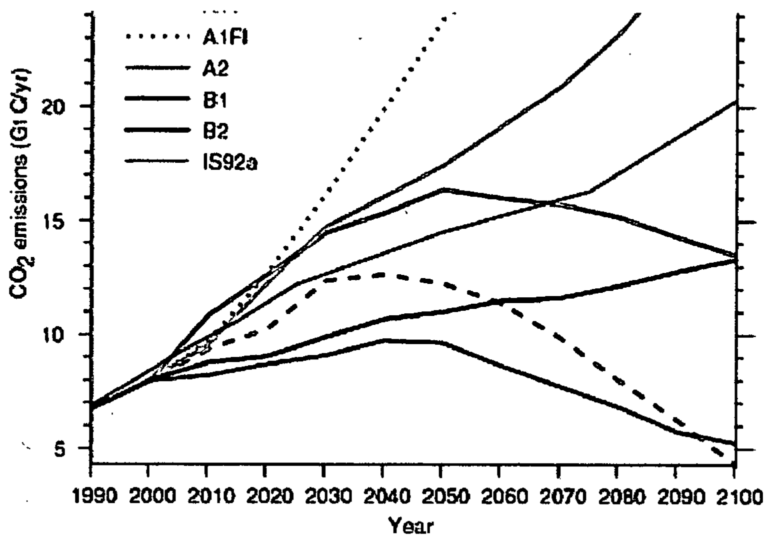
Projections have been made of future global warming effects based upon model results to the year 2100. As the actions of humans are not predictable in any deterministic sense, "predictions" necessarily contain a "what if" emissions scenario. It is presumed that these predictions are used for planning purposes including taking actions to prevent undesirable outcomes, consistent with the Framework Convention on Climate Change, and so the prediction would not come true. Accordingly, they are not truly predictions but rather projections that are tied to particular emissions scenarios. In addition, for a given scenario, the rate of temperature increase depends on the model and how features such as clouds are depicted, so that a range of possible outcomes exists.

In 2001, the basis for future emissions scenarios was set up by the Special Report on Emissions Scenarios (SRES), see box. The emissions for several illustrative scenarios are given from IPCC (2001) in the figure at right for carbon dioxide. The IPCC converts these emissions into concentrations expected and in 2100, the values range from about 550 ppm to almost 1000 ppm, compared with 367 ppm at present. The projections for 2100 across all 35 SRES scenarios, also factoring in the range of uncertainties from models, gives increases of global mean temperatures of 1.4 to 5.8°C; see panel b of the figure (next page). Most values fall within about 2 to 4°C. These numbers are higher than in IPCC (1996) which ranged from about 1 to 3.5°C mainly because the new emissions scenarios contain less sulfur emissions (because they are likely to be controlled for air quality reasons). The 35 SRES scenarios also expand the range of possibilities. Changes in models (both in models going from emissions to concentrations, and climate models) account for less than 20% of the change from IPCC (1996) to IPCC (2001).

The figure (panel c) also shows the corresponding sea level rise, which is only realized with considerable delay as heat slowly penetrates into the ocean. Thus sea level rises continue unabated long into the future. Note that while these projections include crude estimates of the effects of sulfate aerosol they deliberately omit other possible human influences such as changes in land use. A major concern is that the rates of climate change as projected exceed anything seen in nature in the past 10,000 years.

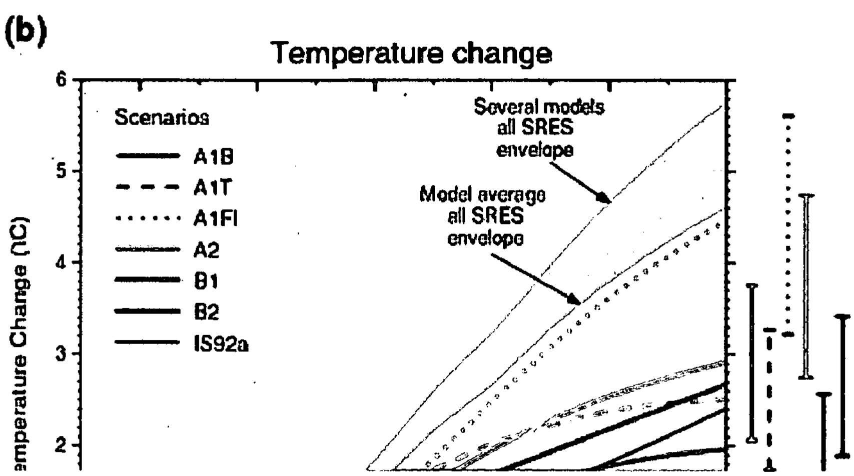
(a) CO_2 emissions

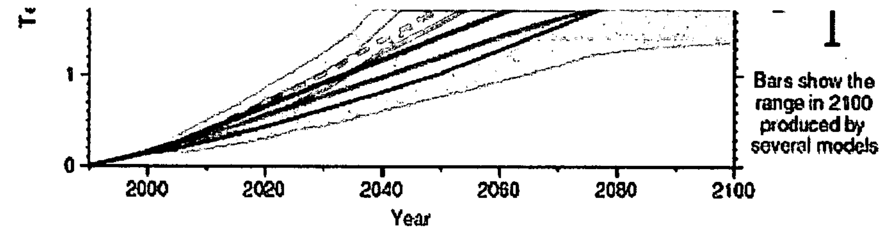


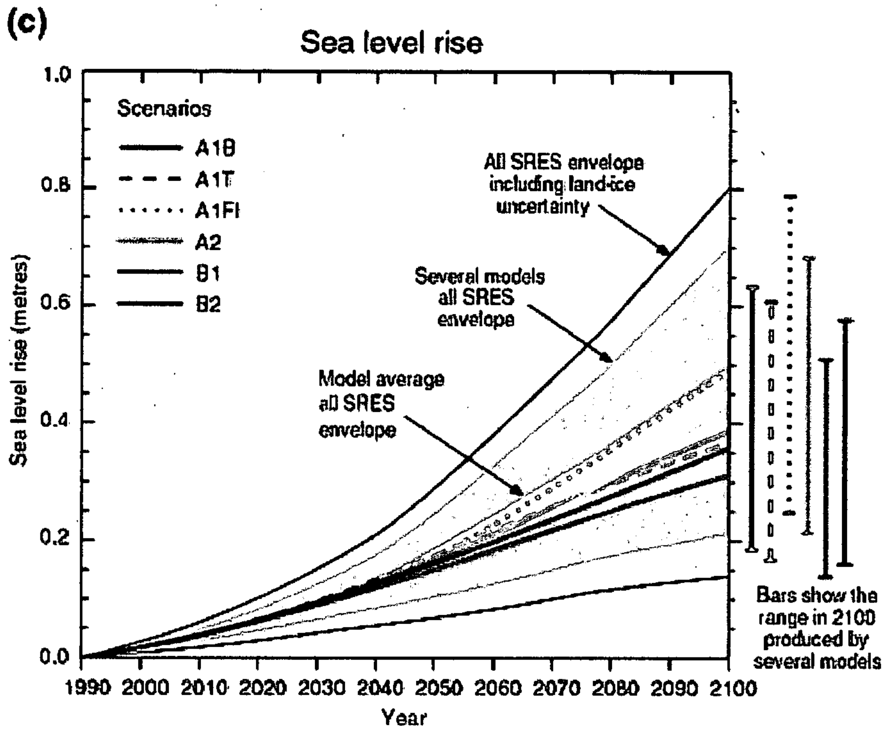


Increased heating leads naturally to expectations for increases in global mean temperatures (often mistakenly thought of as "global warming"), but other changes in weather are also important. Increases in greenhouse gases in the atmosphere produce global warming through an increase in downwelling infrared radiation, and thus not only increase surface temperatures but also enhance the hydrological cycle as much of the heating at the surface goes into evaporating surface moisture. Global temperature increases signify that the water-holding capacity of the atmosphere increases and, together with enhanced evaporation, this means that the actual atmospheric moisture should increase. Because water vapor is a powerful GHG, this provides a positive feedback. It also follows that naturally-occurring droughts are likely to be exacerbated by enhanced drying. Thus droughts, such as those set up by El Niño, are likely to set in quicker, plants will wilt sooner, and the droughts may become more extensive and last longer with global warming. Once the land is dry then all the solar radiation goes into raising temperature, bringing on the sweltering heat waves.

Further, globally there must be an increase in precipitation to balance the enhanced evaporation. Most (perhaps 75%) of the moisture in an extratropical storm comes from moisture stored in the atmosphere when it began. Thus the presence of increased moisture in the atmosphere implies stronger moisture flow converging into all precipitating weather systems, whether they are thunderstorms, or extratropical rain or snow storms. This leads to the expectation of enhanced rainfall or snowfall events and the result is that when it rains it pours harder than it would have under similar circumstances just a couple of decades ago (Trenberth 1998)!







Other even more important changes may be in the offing. The 1997-98 El Niño is the biggest recorded event by several measures. The last two decades have been marked by unusual El Niño activity following the apparent climate "shift" in the tropical Pacific at around 1976 (Trenberth and Hoar 1996, 1997). A key question is how is global warming influencing El Niño? Because El Niño is involved with movement of heat in the tropical Pacific Ocean, it is conceptually easy to see how increased heating from the build up of greenhouse gases can interfere. Climate models certainly show changes with global warming, but none simulate El Niño with sufficient fidelity to have confidence in the results. So the question of how El Niño may change with global warming is very much a research topic.

For any change in mean climate, there is likely to be an amplified change in extremes. The wide range of natural variability associated with day-to-day weather means that we are unlikely to notice most small climate changes except for the extremes. Extremes are exceedingly important to both natural systems and human systems and infrastructure, as we are adapted to a range of natural weather variations, and it is these extremes that exceed tolerances and cause nonlinear effects: the so-called "straw that breaks the camel's back". For instance, floods that used to have an expected return period of 100 years may now recur in 50 or 30 years. In practice, this effect may be experienced in floods through dams or levees that break, inundating the surrounding countryside and urban areas, resulting in drownings, water damage, and more subtle effects such as polluted drinking waters.

It is only recently that changes in extremes of weather and climate observed to date have been compared to changes projected by models and many projected changes are in the same direction as recent observed trends.. Higher maximum temperatures, more hot days and heat waves are very likely.

Increases of daily minimum temperature are projected to occur, especially over most land areas, and are generally larger where snow and ice retreat. Frost days and cold waves are very likely to become fewer. The changes in surface air temperature and surface humidity are projected to result in increases in the heat index. The increases in surface air temperature are also projected to result in an increase of the "cooling degree days" (which is a measure of the amount of cooling required on a given day once the temperature exceeds a given threshold) and a decrease of "heating degree days". Precipitation extremes are projected to increase more than the mean. The frequency of extreme precipitation events is projected to increase almost everywhere. There is projected to be a general drying of the mid-continental areas during summer. This is ascribed to a combination of increased temperature and drying that is not balanced by increases of precipitation. There is little agreement yet among models concerning future changes in mid-latitude storm intensity, frequency and variability. There is little consistent evidence that shows changes in the projected frequency of tropical cyclones and areas of formation, derived from large-scale model variables related to tropical cyclone genesis. However, some measures of intensities show projected increases, and theoretical and modeling studies suggest that the upper limit of these intensities could increase. Mean and peak precipitation intensities from tropical cyclones are likely to increase appreciably.

Concluding remarks

In 1995 the IPCC assessment concluded that "the balance of evidence suggests that there is a discernible human influence on global climate". Since then the evidence has become much stronger --- from the recent record warmth, the improved paleo-record that provides context, improved modeling and simulation of the past climate, and improved statistical analysis. Thus the headline in IPCC (2001) is "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities". The best assessment of the global warming contribution is that the human climate signal emerged from the noise of background variability in the late 1970s. Biggest impact is likely to be making the extremes more extreme. While some changes arising from global warming are benign or even beneficial, the economic effects of the weather extremes are substantial and clearly warrant attention in policy debates.

Because of the long lifetime of carbon dioxide and the slow penetration and equilibration of the oceans, there is a substantial future commitment to further global climate change even in the absence of further emissions of greenhouse gases into the atmosphere. The IPCC considered various options for stabilizing carbon dioxide and greenhouse gas concentrations at levels up to about four time those of pre-industrial levels, and all show that substantial reductions in emissions, well below current levels, would be required sooner or later, in all cases. Moreover these projections emphasize that even stabilizing concentrations does not stop the climate changes owing to the slow response of the system, and so temperature, and especially sea level, continue to rise for many decades thereafter.

Consequently, there is a strong case for slowing down the projected rates of climate change from human influences. Any climate change scenario is fraught with uncertainties, and so slowing down provides time for researchers to provide better projections of how the climate may change and the impacts of those changes. Slowing down climate change therefore allows better planning for and adaptation to changes as they come along. Natural systems and human systems, many of which have long amortization lifetimes (e.g., power stations, dams, and buildings), are less likely to be dislocated and become obsolete. Increasing use of renewable resources, such as solar power, and increased energy efficiency are clearly key steps toward slowing the rate of climate change as well as a more sustainable world.

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/13