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CLIMATE CHANGE SCIENCE

In February 2007 the United Nations Intergovernmental Panel on Climate Change (IPCC) concluded that most of the observed increase in global average temperatures since the mid-20th century is *very likely* (see Box 1) to result from the observed increase in human caused greenhouse gases. This POSTnote examines the uncertainties of climate science, and the attribution of recent climate change.

Background

The earth is habitable only because of the greenhouse effect. Without it, its average temperature would be around minus 18°C. The major greenhouse gases are water vapour, carbon dioxide (CO_2), and to a lesser extent methane.[1]

Climate scientists are certain that adding more of a greenhouse gas intensifies the greenhouse effect, thus warming earth's climate. There is some uncertainty about how much warming will occur.

The IPCC was established by the World Meteorological Organisation and the United Nations Environment Program, and is recognised as the definitive source of information on climate change. It publishes scientific assessments every six years or so on the physical science basis of climate change; impacts, adaptation and vulnerability; and mitigation. The most recent assessments were released in 2007.[2]

Widely accepted facts

Greenhouse gas concentrations

Carbon dioxide is the most important human caused greenhouse gas. The global mean atmospheric concentration of CO_2 has increased from a pre-industrial concentration of about 280 parts per million (ppm) to 379 ppm in 2005.

Box 1: The IPCC language of certainty
The IPCC uses the following italicised terms:

Virtually certain >99% probability of occurrence; *Extremely likely* >95%; *Very likely* >90%; *Likely* >66%; *More likely than not* >50%; *Unlikely* <33%; *Very unlikely* <10%; *Extremely unlikely* <5%; *Exceptionally unlikely <1%.*

From 1990 to 1999, the human originating CO_2 emission growth rate was about 0.7% a year. However, from 1999 to 2006 this increased to about 3.0% a year.

In 2005 the global average concentration of methane was 1,774 parts per billion (ppb), up from the pre-industrial (1750) concentration of 715 ppb.

It is *very likely* that the current atmospheric concentrations of CO_2 and methane exceed by far the natural range of the past 650 000 years. Data indicates that CO_2 varied within a range of 180 to 300 ppm and methane within 320 to 790 ppb over this period.

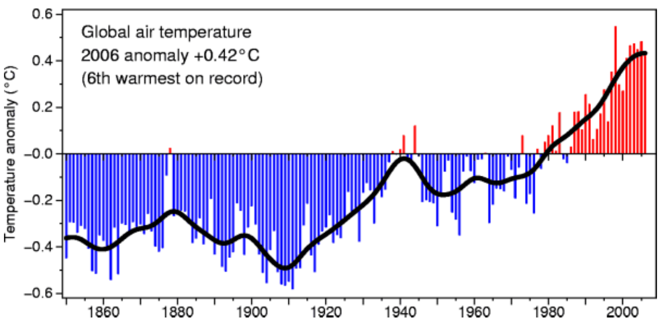
Global temperature trends since 1850

- Over the last 100 years the global mean surface temperature has warmed 0.74°C ±0.18 °C, although there is significant regional variability.
- Global mean temperature has not increased smoothly since 1900 as natural variability and other causes have also had a role (see Figure 1). For instance, it is widely accepted that a period of cooling from 1940 to 1970 was the result of the cooling effect of small atmospheric pollution particles (aerosols), from both human and natural sources. With the

installation of pollution control equipment by the 1970s in the major economies, and the move to cleaner sources of energy such as gas, the warming trend due to greenhouse gases has since dominated the cooling effect of aerosols.

- The atmosphere up to about 10 km (troposphere) has warmed at a similar rate to the earth's surface, while the atmosphere from about 10–30 km (stratosphere) has cooled markedly since 1979. This is in accord with physical expectations of the greenhouse effect.
- Northern hemisphere average temperatures since 1950 were *very likely* warmer than any other 50 year period during the past 500 years, and *likely* the highest in at least the past 1,300 years.
- There has been unequivocal warming of the world ocean since 1955, accounting for more than 80% of the changes in the earth's climate system. As a consequence, sea levels have also risen.

Figure 1: Global temperature trend since 1850.



The drivers of climate

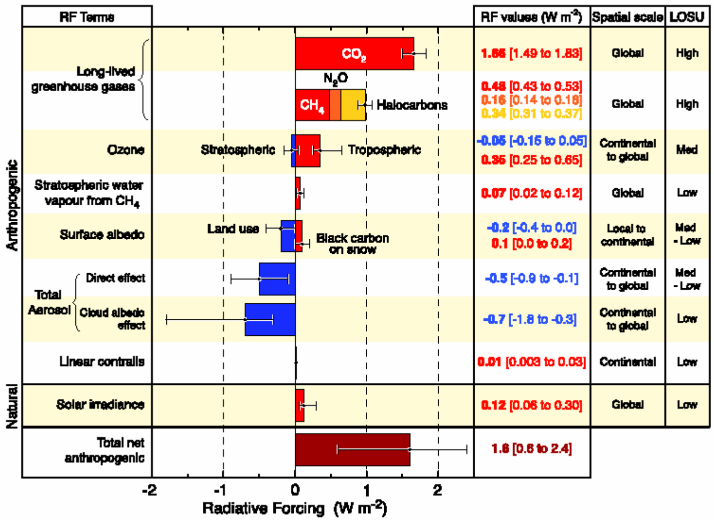
Factors that drive climate are separated into:

- Forcings: for example, a change in solar energy output, or human caused or natural changes in the concentration of greenhouse gases. Scientists can quantify and compare the contributions of different agents that affect surface temperatures by measuring their 'radiative forcing'. Radiative forcing is measured in Watts per square metre (Wm^{-2}), and may be positive or negative (see Figure 2).
- Feedbacks: these are internal climate processes that amplify or reduce the climate's response depending on how responsive the climate is to various forcing processes. For example, a warmer atmosphere can hold more moisture, which itself acts as a greenhouse gas, causing further warming. This is a positive feedback.

The attribution of climate change

Scientists have detected a human originating signal in surface temperature changes since 1950 over continental and sub-continental scale land areas. Climate models can simulate many aspects of the temperature evolution at these scales, and the detection of significant human caused effects on each of six continents provides strong evidence of human influence on the global climate. However, difficulties remain in attributing temperature changes at smaller than continental scales and over time periods less than 50 years.[3]

Figure 2: Radiative forcing components



The combined human caused radiative forcing is estimated to be +1.6 Wm^{-2}, indicating that since 1750 it is *extremely likely* that humans have exerted a substantial warming influence on climate. This radiative forcing is *likely* to be at least five times greater than that due to solar changes. For the period 1950 to 2005, it is *exceptionally unlikely* that the combined natural radiative forcing (solar plus volcanic sources of aerosols) has had a warming influence comparable with that of the combined human made radiative forcing.

Human caused forcings are necessary to reproduce observed temperature changes over the 20th century in climate models. This is considered strong evidence for the influence of humans on climate.

All analyses indicate a large human caused component of the warming trend in global ocean heat content. Climate models demonstrate that the observed trend cannot be explained by natural internal variability.

The observed surface temperature warming is highly significant relative to estimates of climate variability. The natural variability can be deduced from models, historical temperature records and reconstructions of prehistoric temperatures obtained from ice cores and tree rings. The IPCC concluded that it is *extremely unlikely* that recent global warming is due to internal variability alone.

The IPCC concluded that it is *very likely* that greenhouse gas forcing has been the dominant cause of the observed global warming over the last 50 years. Increases in greenhouse gas concentrations alone probably would have caused more warming than observed because volcanic and human caused aerosols have offset some warming that would otherwise have taken place.

Uncertainties in climate science

It is the uncertainty in the magnitude of climate forcings and feedbacks which creates uncertainty in the predictions of future climate states. For instance, the IPCC classed the level of scientific understanding (LOSU in Figure 2) as low for the following climate forcings:

- Solar irradiance;
- Contrails from aircraft;
- Cloud reflectivity;
- Water vapour from methane in the upper atmosphere (stratosphere).

Scientists use climate models to help quantify these forcings and feedbacks to predict future climate states.

Modelling the earth's climate

In a climate model, mathematical equations of climate are fed into a three dimensional grid of points that cover the earth's atmosphere and oceans. The spacing between these grid points, the model's resolution, is limited by the computer power used by the research group, and is generally less than 150km in the horizontal direction and 1 km in the vertical, with finer vertical resolution near the earth's surface. For example, the UK Hadley Centre global climate model has a horizontal resolution of 135km, and the Japanese Earth Simulator has a resolution of 90 km, soon to be reduced to 60km. The accuracy of models is determined by the accuracy of the physical approximations and numerical techniques used.

Limitations of climate models

Climate scientists are confident that climate models provide credible estimates of the most important aspects of future climate change, at least at continental and larger scales. This confidence arises from:

- their design is based on established physical laws that are also well established in weather forecasting models;
- their reproduction of important aspects of the current climate, including large scale distributions of atmospheric temperature, precipitation, radiation and wind;
- their reproduction of features of past climates and climate changes.

However, some physical processes, such as cloud formation, occur on space and time scales too small for climate models to resolve. Climate modellers deal with this problem by representing small scale processes with average values over one grid box. These assumptions are often a big source of climate model uncertainty. Climate modellers run lots of different models and by averaging the results, hope to remove or reduce the effects of natural variability, leaving only the human caused trends. The output of climate models is influenced by their climate sensitivity and feedbacks.

Climate sensitivity and feedbacks

Climate sensitivity is the term used to describe the response of the global climate system to CO_2 forcing and subsequent feedbacks. It is broadly defined as the temperature change following a doubling of atmospheric CO_2. Climate sensitivity is largely determined by feedback processes that amplify or dampen the forcing. The estimate of climate sensitivity reported by the IPCC ranges from 2.1 ºC to 4.4 ºC, with a mean value of 3.2ºC. There are several key physical processes involved that determine the magnitude of climate sensitivity, including water vapour, clouds and surface reflectivity.

Water vapour

Water vapour provides a positive feedback, without which predicted warming would be almost halved. There is good agreement between climate models and observations with this feedback.

The role of clouds in earth's climate

Clouds both cool and warm the earth. In the current climate, the cooling effect is larger. As the earth's atmosphere warms, the net cooling by clouds might be enhanced or weakened. The role of clouds remains the largest source of uncertainty in climate sensitivity estimates. All global climate models predict a positive cloud feedback, but strongly disagree on its magnitude. Realistic representations of cloud processes in climate models are a prerequisite for reliable current and future climate simulation. The IPCC concluded that recent studies re-emphasise the large degree of uncertainty associated with model cloud feedbacks, and that it is not yet possible to assess which of the model estimates of cloud feedbacks is the most reliable.

Climate projections

Despite uncertainties, all climate models predict substantial climate warming under greenhouse gas increases.

Global climate projections are developed by running the climate models with different amounts of greenhouse gases and under various scenarios. The IPCC uses these scenarios and model experiments to project future global climate, compared with the period 1980 - 1999. For example, for the low greenhouse gas emissions scenario, the best estimate of temperature change at 2090-2099 is 1.8^{0}C, with a *likely* range from 1.1 to 2.9^{0}C. For the high emissions scenario, the best estimate is 4^{0}C, with a *likely* range from 2.4 to 6.4^{0}C.

Other key uncertainties

Other important areas of uncertainty in climate science include:

- climate change and the carbon cycle. Currently the oceans and plants absorb about half of the human caused CO_2 emissions each year. The IPCC concluded that carbon uptake by plants and soils is likely to peak before mid-century, and then weaken or even reverse, thus amplifying climate change. There are large uncertainties concerning the effect of climate change on the carbon cycle.
- how much of the early 20th century warming was due to internal climate variability, or due to natural forcings such as solar activity.
- the spatial distribution of the impacts of climate change.
- future greenhouse gas emission rates from developed and developing countries. The economies of developing countries are growing rapidly, and their total greenhouse gas emissions could surpass those of developed countries over the next generation or so.

Box 2: Contrasting Views

A small minority of scientists claim that recent climate change is due to factors other than increased CO_2 levels, such as the impact of solar activity. Others argue that climate models are not reliable enough to predict future climate accurately. This box reviews some of these contrasting views.

Cosmic Rays

The Danish scientist Svensmark has put forward the theory that climate is controlled by cosmic rays. Cosmic rays are energetic particles arising from deep space that impinge on the earth's atmosphere. When solar activity is high, the greater magnetic output of the sun reduces the number of galactic cosmic rays reaching the earth's atmosphere. Svensmark proposes that when solar magnetic output is low, a greater number of galactic cosmic rays enter the earth's atmosphere. These cosmic rays may then promote the formation of aerosols, producing clouds and cooling the earth. During times of high solar activity, the earth is shielded from these galactic cosmic rays, less low level cloud is formed and the earth warms.

The IPCC notes that these claims are controversial, because of uncertainties about the data and a demonstrable physical process. In particular, the cosmic ray measurements do not tally with global total cloud cover after 1991 or with global low level cloud cover after 1994. The IPCC notes that there appears to be a small but statistically significant link between cloud cover in the UK and galactic cosmic ray flux during 1951 to 2000, but this is not true for the United States.

Solar geomagnetism

Sunspots, which appear as dark spots on the sun, are places where very intense magnetic forces break through the sun's surface. The monthly average number of sunspots increases and decreases on an approximately 11 year cycle. The magnetic field of the sun reverses with each cycle, so the magnetic poles of the sun revert back to their original position after two cycles (the Hale 22 year cycle).

Some research groups have found a correlation between solar geomagnetic activity with global temperatures.[4] Another research group has found that long term variations in global terrestrial temperature are highly correlated to the long term variations in a component of geomagnetic activity. The study concluded that using the sunspot number as a measure of solar activity (the traditional method) underestimates the role of the sun in global change.[5] Other research has concluded that: 'geomagnetic activity plays an important role in recent climate change, but that the mechanism behind this relationship needs further clarification.'[6]

Whilst observations of connections between climate and magnetic field variations have been suggested, no physical mechanism by which a reversal in the solar magnetic field direction could influence climate is apparent.[7] However, the 22 year cycle has been identified in regional climatic and temperature records all over the world.[8]

The methodologies used in the above studies have been questioned as they only examine one variable (for example solar activity), ignoring other climatic factors.[9]

Since its previous report in 2001, the IPCC has reduced its estimate of the impact of the sun on global climate since 1750. It has argued that if an increase in solar output were responsible for recent warming, then both the troposphere and stratosphere should have warmed. Observations show that the stratosphere has cooled – an indicator of the greenhouse effect due to greenhouse gas emissions.

Policy response

Research priorities of the Natural Environment Research Council and scientific bodies investigating or monitoring climate are aimed at reducing some of the key uncertainties in projecting future climate states. In particular, work is focusing on making climate projections more policy relevant for a regional area, rather than on global or continental scales. This work will inform government on two main levels: the level of reduction of greenhouse gas emissions required to avoid dangerous interference with the climate; and what are the regional effects of climate change.

Overview

- The science behind the greenhouse effect has been described since 1827;
- Climate scientists have no doubt that the earth's climate will warm in response to further CO_2 added to the atmosphere, but there are uncertainties about how much and what the regional details of this will be;
- A range of contrasting views has been put forward to explain recent warming;
- The IPCC considers that it is the addition of CO_2 to the atmosphere and other human causes that is *very likely* causing most of the recent climate change.

Endnotes

1 See: IPCC, 'Summary for Policy Makers' In *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group 1 to the Fourth Assessment Report of the IPCC. Cambridge University Press, 2007.

2 *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group 1 to the Fourth Assessment Report of the IPCC. Cambridge University Press, 2007.

3 Hegerl,G.C. *et al*, 'Understanding and Attributing Climate Change.' In *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group 1 to the Fourth Assessment Report of the IPCC. Cambridge University Press, 2007, at 704.

4 See for example: El-Broie, M.A. and Al-Thoyaib,S.S. 'Can we use the aa geomagnetic activity index to predict partially the variability in global mean temperatures?' in *International Journal of Physical Sciences*,Vol 1 (2) pp 67-74, October 2006.

5 Georgieva,L *et al*, 'Once again about global warming and solar activity.' In *Mem.S.A.It*., Vol 76, at 969, 2005.

6 Palamara, D.R. and Bryant, E.A. 'Geomagnetic activity forcing of the Northern Annular Mode via the stratosphere.' In *Annales Geophysicae*, Vol 22, pp 725-731, 2004.

7 Courtillot,V. *et al,* 'Are there connections between the Earth's magnetic field and climate?' in *Earth and Planetary Science Letters*, Vol 253, Issues 3-4, 30 January 2007.

8 As reported by: Kasatkina,E.A. *et al*, 'On periodicities in long term climatic variations near 68^0 N, 30^0 E.' in *Advances in Geosciences*,Vol 13, 2007,pp 25-29.

9 Ingram, W. J., 'Detection and attribution of climate change, and understanding solar influence on climate'. *Space Sci. Rev*., 2006, 125, 199-211.

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