GLOBAL WARMING - THE STATE OF THE SCIENCE

- *Explaining past and current warming trends*
- *Latest climate predictions*
- *Is the Antarctic ice breaking up?*

POST note 61
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POSTnotes are intended to give Members an overview of issues arising from science and technology. Members can obtain further details from the PARLIAMENTARY OFFICE OF SCIENCE AND TECHNOLOGY (extension 2840).

There is increasing evidence for a human influence on the climate. At the recent Conference of the Framework Convention on Climate Change (FCCC) in Berlin, more countries than before (including the UK) accepted scientific evidence that human activities were warming the planet. Despite political differences with some countries continuing to challenge the evidence, the conference agreed to define by 1997, targets for reducing and limiting greenhouse gas emissions after 2000[1].

This briefing examines recent scientific findings on global warming and climate change, and the uncertainties remaining.

BACKGROUND

Previous POST briefings[2] described the basic scientific principles and uncertainties behind global warming and climate change. There is no doubt that the earth's climate is affected by a **natural** Greenhouse Effect; neither is there any doubt that human activities are increasing the amounts in the atmosphere of several gases known to contribute further to greenhouse warming. It is also known that average global temperatures have increased by around 0.5°C over the last century.

At the time of the last FCCC meeting in 1992, the key uncertainties were:-

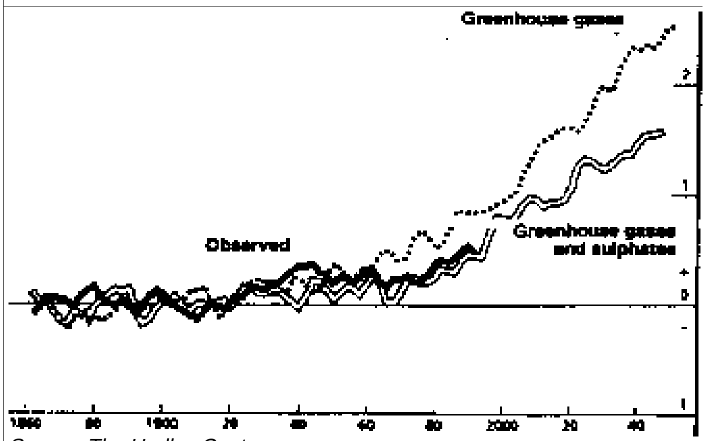
- some critics argued that measurements made in urban areas were influenced by the local warming ('heat island') effect of urban areas;
- even if the data on warming were accepted, some argued that this was not a result of human activities, but due to natural variability in the climate caused by a range of factors including changes in the energy output from the sun;
- predictions of the extent and nature of potential effects of global warming and other aspects of climate change were challenged on the grounds that the models used were of limited accuracy.

Much scientific work has been carried out since the 1992 meeting and has been brought together by the Intergovernmental Panel on Climate Change (IPCC), a body of over 350 of the world's experts in global warming and climate change. As a result, some of the uncertainties have narrowed, allowing greater confidence in the assessment of climate change.

1 A Library Research Briefing on global warming policy responses will be published later in May.

2 POST Notes 16 (July 1990) and 33 (March 1992).

FIGURE 1 OBSERVED AND MODELLED GLOBAL TEMPERATURES



Source: The Hadley Centre

RECENT TEMPERATURE TRENDS

Global average surface temperatures have increased by approx. 0.5°C from 1860 to the present day (shown as solid line in **Figure 1**), and recent increases have been particularly marked with the 8 warmest years on record occurring over the last 10 years. Following earlier criticisms of the possible distorting local effects of heat from industrial or urban sources, work has shown that the effect of such **'heat islands'** was small, and records have been adjusted to take this factor into account.

There is still some uncertainty over how far variations in the **heat output of the sun** can account for global temperature trends, with some scientists claiming that changes in sunspot activity indicate that the output from the sun has increased, thereby warming the globe. IPCC scientists continue to calculate, however, that available measurements show that the variations in solar output are simply not large enough to explain the observed temperature trend on their own. Very recently, this conclusion received support from an analysis at AT&T's Bell Laboratory which looked at the differences between summer and winter temperatures across the world since 1920. If the world was warming due to increased solar output, the effect would be more marked in the summer and the temperature difference would increase. On the other hand if the warming arose from the greenhouse effect, winters should warm more than the summers, so the difference would decrease. The study revealed that the winter/summer differences decreased, providing strong evidence that increased solar output cannot alone be responsible for the warming trend.

Other **natural variations** have been cited as causes of the warming trend. These include volcanic eruptions and the El Nino events in the Pacific Ocean, which transfer large amounts of heat between the ocean and the atmosphere every few years. These phenomena affect the climate over short time scales (2-3 years), and current understanding does not support the theory that they are responsible for the observed **global** temperature trend; IPCC scientists conclude that such events explain only part of the observed changes in climate.

But perhaps the greatest source of scepticism at the 1992 Convention was the poor apparent correlation between the irregular rate of warming in the record compared to the smoother trend predicted by the models (Figure 1). The world warmed from 1920 to 1950, but then stabilised between 1950 to 1970, only to warm more swiftly in the 1980s and 1990s. In addition, year-to-year variability was much greater than predicted in the models, which also forecast a larger warming than observed (dotted line in Figure 1).

Since 1992, climate models have improved in 3 ways:

- better understanding of the influence of the oceans;
- an improved ability to model climate changes as a result of gradual changes in greenhouse gases; and
- a greater understanding of the effects of fine particles (aerosols) - see **Box**.

As a result of these improvements, modellers at the Hadley Centre in Bracknell and at the Max Planck Institute in Hamburg are now able to reproduce past trends more accurately, and the predicted overall increase from 1860 now closely matches the observations (open line in Figure 1). In addition, models have benefited from recent validation from the 'free experiment' offered by the eruption of Mt Pinatubo which cooled the atmosphere for 2 years or so by an amount predicted accurately by climate models.

HOW WILL FUTURE CLIMATE CHANGE?

The improved models can be used to predict the likely climatic effects of increasing emissions of greenhouse gases and aerosols. The baseline assumptions for policy purposes is to assess the consequences of 'Business-as-Usual' - a scenario defined by IPCC where no specific measures are taken in future to curb emissions. This approximates to an increase in effective global carbon dioxide (CO_2) concentration of 1% per year (allowing for projected increases in other gases) and significant increases in emissions of sulphate aerosols from developing countries (especially China and southern Asia). Under this 'non-interventionist' scenario, models predict an increase in global average temperature of slightly more than 0.2°C per decade which would increase global average temperatures by 1.6°C (relative to those of 1900) by 2050 and 2.6°C by 2100.

Box - THE INFLUENCE OF SULPHATE AEROSOLS

Aerosols are fine particles produced both naturally (through volcanic eruptions, sea-spray and wind erosion) and from human activities such as burning fossil fuels and smelting. The most influential of these on the atmosphere are sulphate aerosols which are formed through chemical and physical changes to sulphur dioxide (SO_2), emitted from combustion of sulphur-containing fuels. Sulphate aerosols can act on global temperatures in two ways:-

- a direct cooling from reflection of sunlight;
- an indirect cooling through increasing the amount of sunlight reflected by clouds.

Sulphate aerosols are short-lived in the atmosphere, their influence complex, and difficult to model. Nevertheless, the climate models have started to incorporate the direct effects of aerosols, and this has improved the fit between the model results and actual observations.

As sulphate aerosols remain in the atmosphere for less than two weeks, any regional decreases in sulphur emissions arising from acid rain controls[3], would reduce the production of aerosols and consequently remove the regional cooling effect. A paradox arises, therefore, in that success in reducing SO_2 emissions may lead to a regionally significant increases in the rate of warming.

3 POST Note 47, Acid Rain Agreements, November 1993.

This is, of course, a global average and the effects of this warming on particular regions and their climate will depend on complex factors including the influence of sea-ice and oceans, the exact distributions of sulphate aerosols from industrial regions, and regional and local geographical factors (e.g. mountains, river basins, habitats and soil types). Model projections, while still broad-brush, give some insight into potential changes at both global and regional levels.

Global Climate Changes

Predictions of global temperature, precipitation and soil moisture changes are summarised in **Table 1**. The general conclusions are that:-

- temperature increases almost everywhere, with the greatest increase at high latitudes in the northern hemisphere;
- precipitation increases in many areas but decreases in many parts of the sub-tropics;
- soil moisture generally reflects changes in precipitation; increasing in much of North America, central Africa and northern Asia in winter. The summer picture is more complicated and very variable.

Regional Climate Changes

Predicting regional changes is more imprecise because of the limited ability of the global models to resolve small-scale features and an incomplete understanding of the patchy distribution and influence of sulphate aerosols. A European regional model has been developed by the Hadley Centre which nests within the

TABLE 1 ESTIMATES OF GLOBAL CLIMATE CHANGE BY 2050 (including aerosols)

PARAMETER	INCREASE	DECREASE
Temperature	General warming everywhere; greatest in high latitudes in northern hemisphere, central northern and southern Africa and northern South America.	Isolated regions in North Atlantic and North Pacific Oceans.
Precipitation	Modest increase in most places; greatest increases along the equator over the sea.	Slight decreases in low latitudes; greatest decreases in northern South America, southern Africa, Indian sub-continent and northern Australia.
Soil Moisture	Increases in North America, central Africa and Northern Asia.	Decreases in central and South America, southern Africa, Europe, Middle East, south Asia and Australasia.

TABLE 2 ESTIMATES OF CLIMATE CHANGE IN EUROPE BY 2050 (excluding aerosols)

PARAMETER	INCREASE	DECREASE
Temperature	Large increase in far east; moderate increase over most other areas; slight increase over much of UK & Atlantic coast.	None.
Precipitation	Slight increase in northern Europe.	Large to moderate decreases in southern Europe; little change over central Europe (including most of UK).
Soil Moisture	Moderate increases over Scandinavia and the Baltic states.	Large decreases over southeastern Europe and the Alps. Moderate decreases over most other areas.

Source: Hadley Centre

global model and has a resolution of 50 km (five times that of the global model), allowing more precise predictions of the changes in climate over a smaller area. In general (**Table 2**), temperatures increase everywhere with southern Europe becoming drier and northern Europe becoming wetter. In general, different models of regional climate tend to agree more on the temperature trends than on the precipitation changes which remain highly uncertain. An additional factor is that the European models have, until very recently, not been updated to take aerosols into account, and early indications from the Hadley Centre are that aerosols may well reverse some of the changes predicted with greenhouse gases alone.

ISSUES

Is Climate Change Occurring Now?

In recent years, a number of highly publicised events have raised questions whether the effects of climate change may be evident now. Recent examples are:-

- an apparent increase in the frequency of extreme events (e.g. storms, heat-waves, 'green winters');
- changes in the Antarctic ice shelves; and
- plant growth in polar regions.

Climate Extremes

Since a warmer world contains more heat energy, intuition might suggest that storms and other extreme events might become more intense or common and there is a tendency among the public to see such events as 'proof' of the onset of global warming. Such proof is currently lacking on two grounds.

Firstly, events such as the southern Spanish drought and Scandinavian green winters, while significant in living memory, have counterparts in historical records. As such, there is no firm evidence that the frequency of these events has actually increased. Even if they had, scientists from the European Climate Support Network (ECSN) consider it unlikely that a simple relationship exists between mean climate and extreme events - especially in Europe, where the climate is naturally highly variable. Thus, ECSN scientists attribute many of the recent extreme events in Europe to changes in circulation patterns bringing warmer air more frequently into Europe from the south and south-west, rather than to an overall warming.

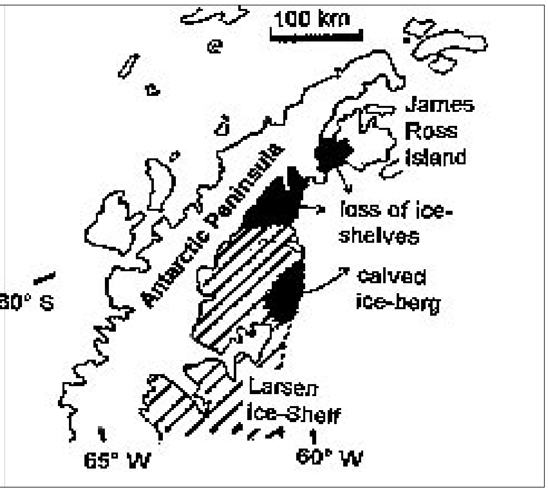
Nevertheless, results from the climate models do indicate that an enhanced greenhouse effect **could** lead to more extreme events, and the question thus remains open whether record floods etc. (northern Europe) and droughts (Southern Spain) are merely part of the naturally variable European climate, or regional changes influenced by wider global changes.

Changes in Antarctic Ice Shelves

In February 1995, British Antarctic Survey (BAS) scientists observed a huge iceberg the size of Oxfordshire breaking off (or "calving") from the Larsen Ice Shelf on the east side of the Antarctic Peninsula (**Figure 2**). Iceberg calving is not uncommon, but this calving was part of a more widespread pattern where all of the climatically sensitive ice shelves in the Antarctic Peninsula have now suffered major disintegration, which is unique in recorded history. For the first time, James Ross Island (Figure 2) is not connected to the mainland by an ice shelf. This trend is locally important, indicating that summer temperatures in the Peninsula region now regularly exceed 0°C, so that further ice shelves will disintegrate in the coming decades. Because the ice

Figure 2

ICE LOSS IN THE ANTARCTIC PENINSULA



shelves were already floating on water, however, their loss will have a minimal effect on sea level.

Shrinkage of the Antarctic ice-cover may be one consequence of global warming, but how far can events to date be taken as 'proof' that global warming is becoming significant? BAS has continuous temperature records in the Antarctic Peninsula since the 1940s, which show a warming of around 0.5°C per decade. However, this appears to be a **regional** effect and not matched elsewhere in Antarctica, so that the changes to the Peninsular ice sheet cannot be explained in terms of a **general** warming of Antarctica. At current rates of warming there should be no imminent collapse of the Antarctic Ice Sheet that would dramatically raise sea-level. However, the picture is not altogether clear, and BAS concludes that it will be some time before it can be established whether the observed trends are just a local phenomenon or a manifestation of some external force such as global warming.

Plant Growth in Polar Regions

There have also been reports of enhanced plant growth in high latitudes; with some trees and flowering plants that have been dormant for hundreds of years growing again, and a succession of winters in Scandinavia without snow on the ground (so-called 'green winters'). BAS considers that enhanced plant growth in Antarctica could be due to the observed regional warming, and ECSN scientists consider that the changes in northern high latitude regions are likely to be due to the highly variable climate, as already mentioned above.

Are Uncertainties Reducing?

The above discussion showed that models have improved to the extent that they can simulate past changes in global temperature more closely. Scientists at the Hadley Centre and the Climate Research Unit (CRU) recognise, however, that the ability to reproduce the past does not provide definitive proof of the cause of the warming. Instead, some more definitive ‘fingerprint’ is needed which will help differentiate the human influence on the climate from natural variability. One such approach (on the summer / winter temperature differences) was mentioned earlier. Scientists in the UK, USA and Germany have also developed a ‘fingerprint’ in terms of the pattern of temperature changes over the globe expected if an enhanced greenhouse effect was underway. For instance, there is a resonable match between modelled and observed temperature increases in northern high latitudes, and some similarity between observed and modelled cooling in southeast Europe and over northern mid-latitude oceans.

This study showed a good match between the observed pattern of global temperature changes with that predicted from models using CO_2 and sulphate aerosols and IPCC scientists see such studies offering the first hard evidence that human influences on climate are becoming distinguishable from natural variability.

Such findings are not conclusive however, and some still see global warming as no more than an uncorroborated theory. Overall however, uncertainties have narrowed and an increasingly widespread view within the IPCC is that the reality of a human influence on climate has been demonstrated (a position shared by the UK Government), and that the burden of proof is shifting more onto proponents of alternative theories to show how their explanations can better explain the observed trends in world climate. IPCC will publish its latest consensus in early 1996 and whether the changes underway can ever be attributed **entirely** to human activities will remain unanswered. However, this is to some extent a side-issue and the mainstream interest is shifting away from a detailed assignment of past causes to the significance of the likely consequences of continued future increases in greenhouse gas emissions.

On the impacts of the predicted changes (e.g. sea-level rise, changes in natural habitats and effects on crops), models in the past have tended to focus on the changes in 50-70 years time when CO_2 levels are expected to have doubled relative to pre-industrial levels. This has led to some observers inferring that significant impacts will not be felt until this time. IPCC scientists now warn, however, that it is the **rate** of the temperature rise itself that will be a more important factor than the actual temperature in 50-70 years’ time. As such, IPCC now predicts that manysignificant impacts of climate change are likely well before the levels of CO_2 double; perhaps in less than 30 years. For instance, sea levels have increased by 1-2mm per year for the past 100 years, and the best estimate predicts a further rise of 180mm by 2030; implying an increase nearly four times faster than over the last century. This is of concern to low-lying countries.

Finally, the Hadley Centre and other modelling centres recognise that uncertainties still remain:

- limitations in the models (from a lack of understanding of clouds, oceans, aerosols);
- limitations in the observations (from a lack of data and monitoring sites worldwide);
- model omissions (e.g. indirect effects of aerosols; low-atmosphere ozone; solar variability; volcanic activity; effects of vegetation, marine plankton);
- dependence on the accuracy of emission scenarios which require better estimates of future emissions.

In view of the international negotiations entering their most sensitive stages over the next two years, narrowing these uncertainties further is a high priority for international research programmes.