# GLOBAL CLIMATE AND HUMAN ACTIVITIES

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**Summary**

Comprehensive scientific study of the climate needs to include all components of the climate system, namely the atmosphere, oceans, land surface, cryosphere, and the land and marine biospheres. Physical, dynamical, chemical, and biological processes within these components interact in complex ways. The science of climate therefore involves many scientific disciplines. Of particular importance are the factors that might cause

climate to change. These factors may be of natural origin (e.g. volcanic activity or variations in radiation from the sun) or anthropogenic, i.e. due to human activities (e.g. emissions of gases such as carbon dioxide into the atmosphere). However, before addressing some of these factors it is important to understand something of the character of climate variability.

There is strong scientific evidence that the average temperature of the Earth's surface is rising because of the increased concentration of carbon dioxide and other "greenhouse" gases in the atmosphere due to human activities, especially the burning of fossil fuels such as coal, oil, and gas. This "global warming" will lead to substantial changes of climate, many of which will impact human communities in deleterious ways.

In terms of the likely global pattern of climate change in the twenty-first century, in the absence of any mitigating action, the global average temperature is likely to rise by about 2.5°C (range 1–3.5°C) and sea level by about 0.6 m (range 0.2–1 m). The hydrological cycle is likely to be more intense (leading in some places to more frequent and more intense floods and droughts) and the rate of climate change is likely to be substantially greater than the Earth has experienced over at least the last 10 000 years. Adapting to this rapid rate of change will be difficult for many ecosystems and for humans.

Action has been taken by the world's scientists through the Intergovernmental Panel on Climate Change (IPCC) to assess as thoroughly as possible knowledge regarding the basic science and the impacts including an assessment of the uncertainties. The world's governments have also taken action in setting up the Framework Convention on Climate Change (FCCC) at the Earth Summit in 1992 and at subsequent meetings of the Parties to that Convention, especially that at Kyoto in 1997.

In order to mitigate climate change the FCCC in its article 2 has set an Objective which is the stabilization of the concentration of greenhouse gases in the atmosphere at a level and on a timescale consistent with the needs both of the environment and of sustainable development. Such stabilization will eventually demand severe cuts in global emissions, for instance of carbon dioxide, to levels well below today's emissions by the second half of the twenty-first century. To achieve the required reductions in the emissions of carbon dioxide, three possibilities are available: to sequester carbon dioxide resulting from the burning of fossil fuels rather than releasing it to the atmosphere, to become much more efficient in the generation and use of energy, and to provide for energy supply from non-fossil fuel sources.

The article will summarize the science of climate change including the evidence for it, will describe the main impacts and the actions taken so far, and the further actions that are likely to be necessary to mitigate climate change.

## 1. The Science of Climate Change

### 1.1 The Variability of Climate

Variations in day-to-day weather occur all the time; they are very much part of our lives. The climate of a region is its average weather over a period that may be a few months, a season, or a few years. Variations in climate are also very familiar to us. We describe summers as wet or dry, winters as mild, cold or stormy, recognizing that in many parts of the world the seasons vary a great deal from year to year.

Most of the variations we take for granted. Those we particularly notice are the extreme situations and the climate disasters. During recent decades, different parts of the world have experienced extreme temperatures, record floods, droughts, and windstorms. Such extremes are an important manifestation of the large natural variability of the climate; their impact has served to emphasize the vulnerability of human communities to climate variation and extremes. This is well illustrated by the unparalleled losses experienced by the insurance industry during the later years of the 1980s and the 1990s. Although there is no strong evidence that these events are outside the range of the natural variability of climate experienced in historic times, their impact has served to add more relevance to the question as to whether human activities (such as fossil fuel burning) are likely to lead to substantial and damaging future climate change.

To obtain a perspective on climate change we shall first look at the climate of the last 100 000 years or so, which has been dominated by the last ice age, and then look at climate trends over the last century.

The climate record over many thousands of years can be built up by analyzing the composition of the ice and the air trapped in the ice obtained from different depths from cores drilled from the Antarctic or the Greenland ice-caps. Figure 1 is a record of the temperature at which the ice was laid down and of the atmospheric carbon dioxide content over the last 160 000 years from an Antarctic ice core. Currently the Earth's climate is in a warm phase which began when the last ice age came to an end about 20 000 years ago; the last warm period was about 120 000 years ago.

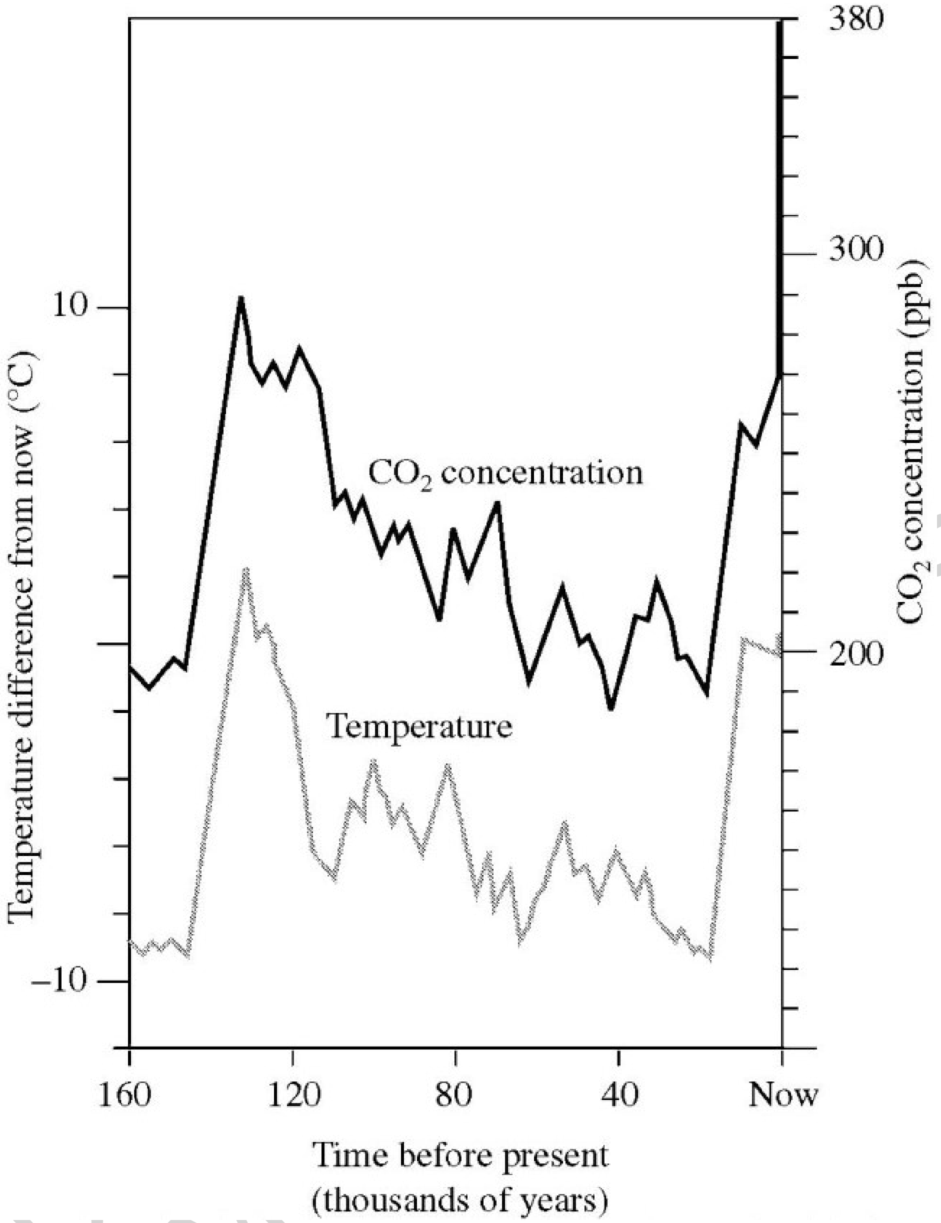


Figure 1: Observations from the Vostok ice core, showing for the last 160 000 years the variation of atmospheric temperature over Antarctica (it is estimated that the variation of global average temperature would be of the order of half that in the polar regions) and the atmospheric carbon dioxide concentration. Note the current value of carbon dioxide concentration of just over 360 parts per million (ppm).

The main triggers for the ice ages have been the small regular variations in the geometry of the Earth's orbit about the sun which affect the distribution of solar radiation at the Earth's surface. Of particular interest is the strong correlation between the atmospheric temperature and the carbon dioxide content. Part of this undoubtedly arises because the amount of carbon dioxide in the atmosphere is dependent on factors that are strongly related to the average surface temperature. But it is also true that it is not possible to understand the range of temperature variations of the past without allowing for the influence of carbon dioxide on atmospheric temperature through the greenhouse effect (see Section 1.2). Note also from Figure 1 the very rapid rise in atmospheric carbon dioxide concentration over the past two hundred years or so because of human activities, which has taken the concentration of this gas well outside the range of its natural variation during the last million years or more.

For the past century, the changes in the average air temperature near the Earth's surface as established from the instrumental record are shown in Figure 2. Over this period this temperature has increased by somewhat more than 0.5°C although the increase has not been uniform. There are strong indications that the increase since the 1970s is linked with the growth in the atmosphere of greenhouse gases such as carbon dioxide from anthropogenic sources. The 1990s have been particularly warm in terms of this global average temperature. Not only is 1998 the warmest year on record, the first eight months of 1998 were the warmest of those months on record. Note also the year-to-year variations, which are a further illustration of natural climate variability.

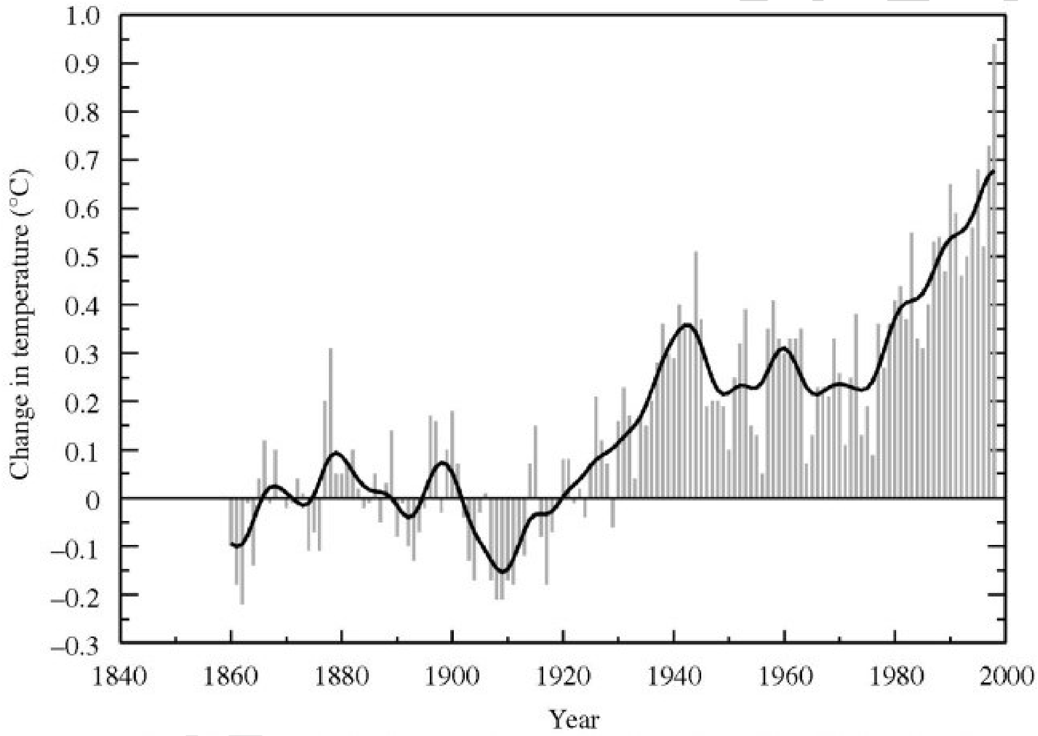


Figure 2: Changes in the global annual mean surface temperature, relative to that at the end of the nineteenth century, shown by the vertical bars. A smoothed curve has been added (From Hadley Centre, UK)

## 1.2 The Greenhouse Effect

That the Earth's surface is kept warm by the "greenhouse effect" has been known for nearly two centuries. But it was only about one hundred years ago, in 1896, that Svante Arrhenius, a Swedish chemist, made the first calculation of the average rise in temperature to be expected at the Earth's surface if the atmospheric carbon dioxide concentration should double. His estimate of 5 or 6°C was not far out, just a little larger than current estimates which fall in the range 1.5–4.5°C.

The Earth absorbs radiation from the sun, mainly at the surface. A balancing amount of energy is then radiated to space at longer, infrared, wavelengths. Some of the gases in the atmosphere, particularly water vapor, carbon dioxide and methane, and clouds, absorb some of the infrared radiation emitted by the surface and themselves emit radiation from higher altitudes at colder temperatures. The Earth's surface is thereby kept about 30°C warmer than it would otherwise be. This is known as the "greenhouse effect" because the glass in a greenhouse possesses similar optical properties to the atmosphere.

Increases in the concentration of the "greenhouse gases" will tend to lead to further warming of the surface and the lower atmosphere; this is the "enhanced greenhouse effect." Its approximate magnitude can be simply estimated from radiation energy balance calculations, but for detailed information about it, sophisticated computer models have to be used which take into account the influences of the atmospheric and oceanic circulations (see Section 1.6).

It was in the late 1960s that scientists began to realize that the rate of increase of the amount of atmospheric carbon dioxide, due to the increasing rate of burning of fossil fuels, was such that significant global warming would occur. Associated with the warming would be substantial changes in the Earth's climate. By the late 1980s, wide concern was being expressed about the likely impact of climate change and it became a subject firmly on the political agenda.

### 1.3 The Intergovernmental Panel on Climate Change (IPCC)

The IPCC was formed in 1988 jointly by two United Nations bodies, the World Meteorological Organization and the United Nations Environment Programme, to provide assessments of future climate change and its likely impact. Its first report published in 1990 provided the scientific basis for the Framework Convention on Climate Change (FCCC) agreed at the Earth Summit held at Rio de Janeiro in June 1992 and signed by about 160 nations. To assist in the Convention process, a new comprehensive report was produced by the IPCC at the end of 1995 and a further report is being prepared for the year 2001. The writing and review process of these reports has involved the leading scientists in the world in the field of climate change together with many hundred scientists from many countries—in fact, a large proportion of the world's scientists who are involved in this field of science. The policymakers' summaries of the reports have been agreed at meetings at which delegates from up to 100 countries have been present as well as representatives of nongovernmental organizations and of the scientific community. Their findings therefore have the support both of the scientific community and of governments.

The IPCC has assessed not only the basic science of climate change but also its likely impacts on human activities and the options for adaptation to those impacts. It has also addressed how climate change can be mitigated through the reduction of emissions of greenhouse gases into the atmosphere, for instance by changes in the generation and use of energy, by the sequestration of carbon dioxide or by reducing the emissions of methane from a variety of sources. The IPCC has also supported the work of the FCCC through its assessments of studies of the likely economic costs of the damage due to climate change and its assessments of adaptation and mitigation and of studies of the social and political implications of action or of inaction. The material in this article which summarizes all aspects of the issue of anthropogenic global climate change is substantially based on the Second Assessment Report of the IPCC published in 1996.

## 1.4 Greenhouse Gases

The main greenhouse gases that result from human activities are carbon dioxide and methane. Their atmospheric concentrations have risen by about 30% (Figure 3) and 145%, respectively, since preindustrial times, largely because of fossil fuel use, land-use change (e.g. deforestation), and agriculture. Carbon dioxide is responsible for about two-thirds of the enhanced greenhouse effect to date due to the increases in greenhouse gases. If no action is taken to mitigate emissions from carbon dioxide, the level of emissions and its atmospheric concentration will continue to rise throughout next century (Figure 3). Its concentration could reach 560 ppm or double its preindustrial concentration before the year 2100.

Other greenhouse gases of importance (see Figure 4) are nitrous oxide, which has contributed about 6% to the greenhouse effect to date, the chlorofluorocarbons (CFCs), and ozone. Emissions of chlorofluorocarbons into the atmosphere have led to some destruction of the ozone layer, most dramatically illustrated by the discovery of the “ozone hole” over Antarctica in 1985. Because ozone is also a greenhouse gas, this ozone destruction has partially compensated for the greenhouse effect of the chlorofluorocarbons.

An important consideration is the time taken for the anthropogenic emissions of greenhouse gases to be removed from the atmosphere. For methane, the removal process is governed by chemical reactions; the lifetime of methane in the atmosphere is about 10 years. On the timescales we are considering, carbon dioxide emitted into the atmosphere is not destroyed but redistributed among the carbon reservoirs, in the biosphere and in the oceans. The carbon reservoirs exchange carbon between themselves on a wide range of timescales which vary from less than a year to decades (for exchange with the top layers of the ocean and the land biosphere) or to millennia (for the deep ocean or long-lived soil pools). The large range of turnover times means that the time taken for a perturbation in the atmospheric carbon dioxide concentration to relax back to an equilibrium state cannot be described by a single time constant. Although a lifetime of about a hundred years is often quoted for atmospheric carbon dioxide so as to provide some guide, use of a single lifetime can be misleading.

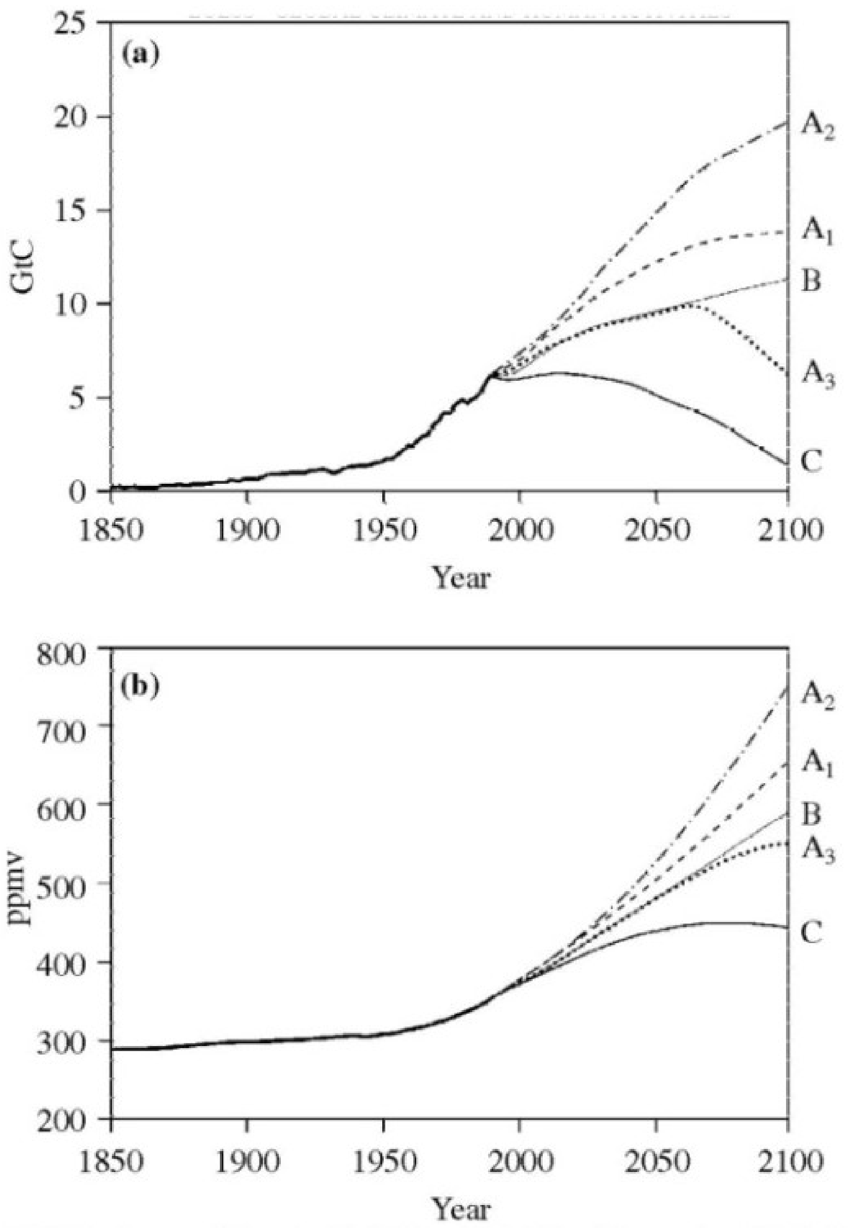


Figure 3: (a) Global carbon net emissions from fossil fuel use, 1850–1990 and for scenarios to 2100, in Gt C. The scenarios make different assumptions regarding economic growth, fuel availability and development of new renewable energy sources. Curves A and B assume “business as usual” (i.e. no strong pressure to reduce fossil fuel use for environmental reasons); A3 assumes rapid technical innovation to bring in non-fossil fuel sources and C is an “ecologically driven” scenario. (From World Energy Council Report *Global Energy Perspectives*, CUP, 1998.) (b) Atmospheric carbon dioxide concentration in ppm from 1850 to 1990 and for scenarios in (a) above to 2100. (From World Energy Council Report *Global Energy Perspectives*, CUP, 1998.)

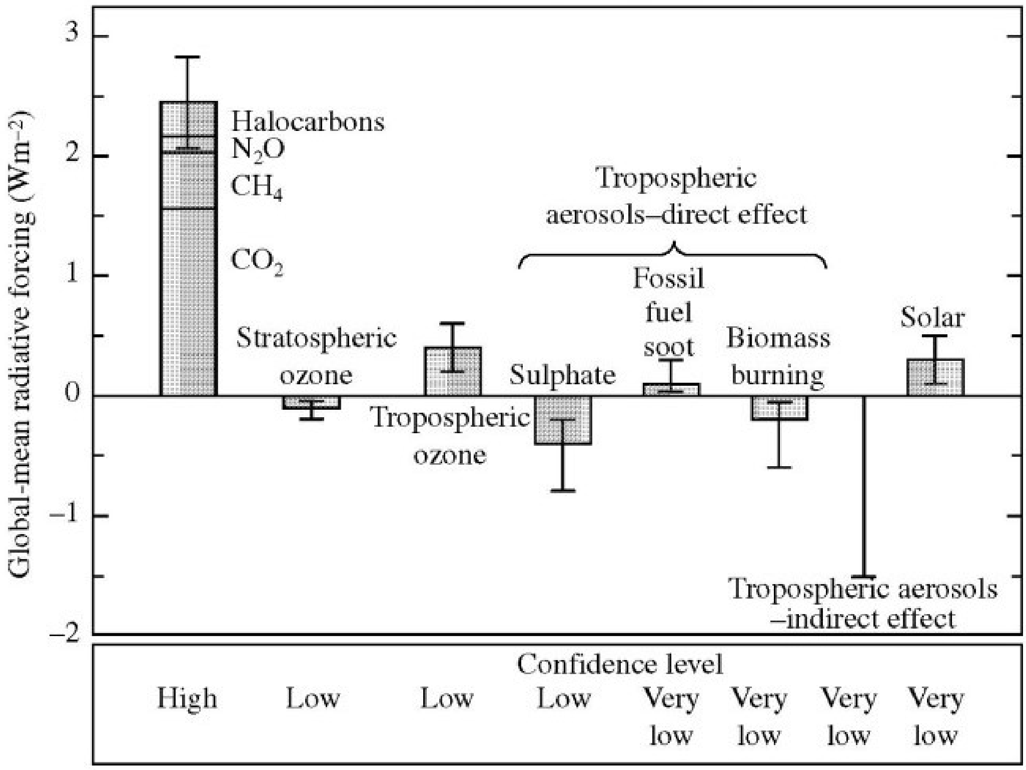


Figure 4: Estimates of the globally and annually averaged anthropogenic radiative forcing (in W $m^{-2}$) due to changes in concentrations of greenhouse gases and aerosols from preindustrial times to 1992 and to natural changes in solar output from 1850 to the present. Error bars indicate the range of uncertainty in the estimates; the "confidence level" provides an indication of the degree of scientific understanding for each component. The indirect aerosol effect arises from the induced change in cloud properties due to aerosols. (From IPCC Report 1995: Technical Summary)

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**Biographical Sketch**

For more than 40 years, **Sir John Houghton** CBE, DSc, FRS has exerted a strong and beneficial influence on the development of the science of meteorology and its applications to practical problems throughout the world. He is well known internationally for his outstanding research in remote sensing of the atmosphere from space. He developed radiometers for the Nimbus satellites in the 1970s. These instruments provided, for the first time, global information of the structure of the stratosphere and mesosphere. As chief executive of the United Kingdom Meteorological Office he was influential in developing the UK's strong international reputation in many areas of climate research. Sir John helped establish the Hadley Centre for Climate Prediction and Research which, since its inception, has sought to collaborate in, and contribute to, the growing international research effort on climate change. As Permanent Representative of the United Kingdom with WMO for 8 years and as a member of Executive Council (and third vice president 1987–1991), he exerted a valuable influence on the development of WMO policy. In 1981 and 1984 Sir John was chairman of the Joint Scientific Committee for the World Climate Research Program and in 1992 was appointed chairman of the Joint Scientific Committee for the Global Climate Observing System. In 1993 he chaired the Intergovernmental Meeting on the World Climate Program—"The Climate Agenda." In 1988, he was appointed chairman of the Scientific Assessment Working Group of the Intergovernmental Panel on Climate Change (and is currently cochairman). This Working Group has produced four major reports under his leadership. To achieve this has required great sensitivity to the political aspects of climate change, combined with firmness where necessary to ensure that the reports remained faithful to the underlying science. Since 1994 he has been one of the five members of the British Government Panel on Sustainable Development. He became a member of the Royal Commission on Environment in 1991 and since 1992 has been its chairman.