THE ENHANCED GREENHOUSE EFFECT

A review of the Scientific Aspects

Update : December 1994

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1. Introduction

The threat of climate change remains the environmental concern with by far the greatest significance for the fossil fuel industry, having major business implications. It has been the focus of continuing scientific and political attention since the late 1980s. The UN Framework Convention on Climate Change, which was the showpiece of the UN Conference on Environment and Development in Rio (UNCED) came into force in March 1994 having been ratified by the requisite 50 signatory nations. Implementation of the Convention will ensure that the momentum of action to address potential global warming is maintained.

The purpose of this paper is to review major developments in scientific understanding and the implications for policy formulation.

2. The Nature of the Issues

The features which make potential human-induced global warming such a problematic and controversial issue are recalled in Figure 1. Each element in this scheme, together with the crucial interactions between the elements is subject to substantial uncertainty. The consequences of global warming could be dramatic, as could the economic effects of ill-advised policy measures. Furthermore, the time scales (decades to hundreds of years) which must be addressed far exceed normal planning experience and the global dimension raises intractable questions of international relations such as equity, trade relationships and conflicting national priorities.

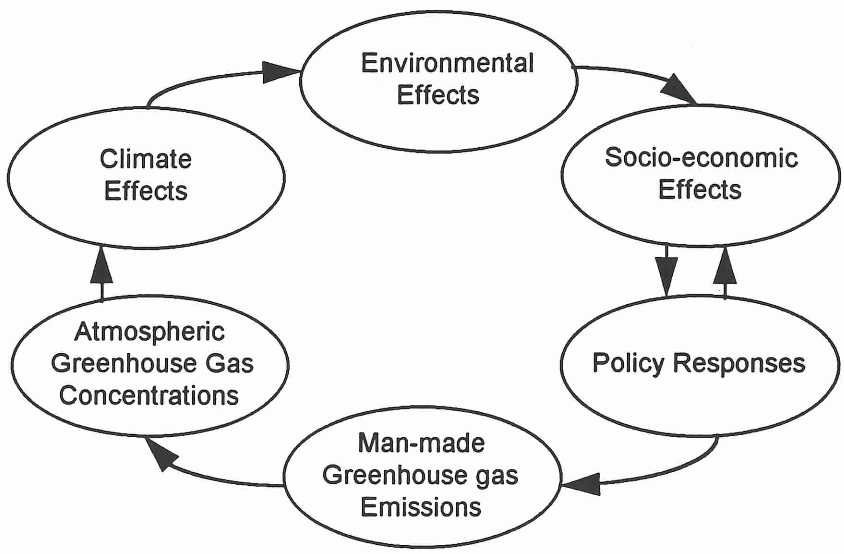

Figure 1: Global Warming, the Circle of Uncertainty

3. Expressions of Scientific Opinion

The Intergovernmental Panel on Climate Change (IPCC) represents the most coherent, authoritative and influential expression of scientific views on Climate Change. IPCC was established in 1988 under the auspices of the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) and comprises several hundred leading independent experts from numerous countries. It should be recognised that IPCC was established by governments and the summaries of its deliberations are the work of officials or official nominees. The conclusions of the IPCC (first reports completed in 1990) can be regarded as the mainstream view: they provided the essential underpinning for government positions at the Rio conference. Post-Rio the IPCC has been kept in existence.

There are three Working Groups.

WG1 is concerned with the "Science of Climate Change'. It produced a "Supplementary Report to the IPCC Scientific Assessment" in 1992 and was due to produce a Special Report in November 1994. WGs II and III are concerned with "Impacts and Response Strategies" and "Cross-cutting Issues" respectively. The latter includes economic impacts and scenarios for future emissions. All three WGs will produce major new reports in 1995.

Although the IPCC position is often referred to as the scientific consensus, there is a range of views among IPCC scientists about the magnitude of the threat from global warming and its causes. Furthermore, there is a significant minority outside IPCC (which includes distinguished scientists) who take a contrary view, generally believing the concerns over global warming to be exaggerated and misguided. The views of these "sceptics" have received increasing attention in recent months (although IPCC members point out that only some of them are actually conducting research in the relevant fields).

4. Agreed Scientific Fundamentals

Notwithstanding the controversy indicated above, there is complete agreement on the following well-known scientific fundamentals:

- Natural Atmospheric Greenhouse Gases affect the retention of energy in the global system by re-reflecting part of the outgoing infra-red radiation from the earth (so called "radiative forcing").

- This maintains the <u>average</u> global temperature approximately 33°C higher than it would be in the absence of atmospheric greenhouse gases and reduces diurnal variation (This is the natural "greenhouse effect").

- The major greenhouse gas is water vapour (this point is often left aside in discussions on global warming). Trace greenhouse gases include carbon dioxide, methane, nitrous oxide, ozone and more recently man-made chloroflurocarbons (CFCs). Calculations of relative contributions are extremely difficult because of differences in atmospheric lifetimes, indirect effects and overlapping radiative effects but roughly speaking water vapour accounts for three quarters of the natural greenhouse effect with all other greenhouse gases making up the remainder.

- The concentration of greenhouse gases (other than water vapour) have increased rapidly since the industrial revolution. Expressing all these gases in terms of their CO_2 equivalent Global Warming Potential (GWP - a subject itself of some controversy) the increase is around 40% over pre-industrial levels. This has led to an increase in radiative forcing of about 1% of the total incoming radiation. While this may appear small, it is important since living organisms can only tolerate a relatively small range of temperature.

- This increase in radiative forcing will have some effect on the processes which determine global climate.

- Human activities have contributed to the increase in atmospheric greenhouse gas concentrations (AGGCs).

- The rate of increase in the concentration of atmospheric greenhouse gases is faster than previously experienced during the history of human civilisation (although not unprecedented on a geological time scale).

- Natural factors other than those directly contributing to AGGCs (volcanic activity, solar orbit, patterns of ocean circulation etc.) and human activities other than fossil fuel consumption (deforestation, agricultural practices, atmospheric pollution, hydrological projects, urbanisation, etc.) can also significantly affect climate causing warming or cooling.

Starting from this broad area of agreement, the controversies arise mainly from differences of view about the potential consequences of the increase in AGGCs and the interpretation of past and present climate observations.

5. Conclusions of the IPCC

The most recent statement of IPCC conclusions concerning the science of global warming is given in the 1992 assessment which re-examined the position presented in the full 1990 report in the light of further research and comment. IPCC conclusions are based on a comprehensive review of climatological, palaeoclimatological and experimental observations together with heavy dependence on the output of elaborate computer models which simulate global climate (General Circulation Models - GCMs).

To model future climate, it is necessary to make some estimate of future emissions of greenhouse gases and the resulting concentrations in the atmosphere. The IPCC calculations are based on a series of projections representing a simple extrapolation of existing trends (the reference case, mistakenly called "business as usual" by some - see later) and various levels of mitigating action (Figure 2).

The reference case leads to an approximate doubling of pre-industrial carbon dioxide concentrations by the year 2030. Clearly the nature of these projections, called scenarios by IPCC, is critical for the outcome of the modelling and is a matter of lively debate.

The 1992 Assessment confirmed (in the view of IPCC) the principal conclusions reached in 1990:

- Greenhouse gas concentrations in the atmosphere are increasing substantially, due to human activities (but see later comments in section 6).

- Evidence from observations and more particularly from GCMs indicates that global mean surface temperature will increase by 1.5 to 4.5°C, depending on the model, with a doubling of the equivalent carbon dioxide concentration (which, as indicated, would occur in approximately 2030 if present trends were to continue unaltered).

- There are many uncertainties with regard to the timing, magnitude and regional patterns of climate change.

- Global mean surface air temperature has increased by 0.3 to 0.6°C over the last 100 years. This warming is consistent with model predictions but also is within natural climate variability (see Figures 3 and 7).

- Alternatively this variability and other human factors (see below) could have offset a still larger human induced greenhouse warming.

- The unequivocal detection of the enhanced greenhouse effect is not likely for a decade or more (there is no clear evidence yet of a "greenhouse signal").

The 1992 report also contained new conclusions, including:

* Depletion of ozone in the lower stratosphere (largely associated with CFCs) results in a decrease in radiative forcing comparable in magnitude to the contribution of CFCs.

* Cooling by sulphur dioxide aerosols (partly resulting from man-made pollution) may have offset a significant part of the greenhouse warming in the Northern Hemisphere.

* Rates of increase of methane and CFC concentrations in the atmosphere have decreased. The latter is largely attributable to international agreements to restrict CFCs, but the reason for the former is not known.

* The anomalously high global temperatures of the late 1980s continued into 1990-1991 which are the warmest years on record (subsequent years 1992 and 1993 have been more in line with the longer term means).

6. Additional Significant Recent Developments

The latest IPCC WG I Supplementary Report (available to us in draft form) covers only those factors which cause radiative forcing of climate change. Revision of Global Warming Potentials of the long lived greenhouse gases to include indirect as well as direct effects indicates an increased importance of methane over a shorter (20 years) time span than previously thought. Improved estimates are made of the cooling effect of atmospheric particles (sulphate aerosols, aerosols from biomass burning and dust from volcanic eruptions). The IPCC latest views on the radiative forcing by various factors is shown in Figure 4. It should be emphasised that the cooling effect of particles and aerosols represent temporary and regionally distributed masking of the radiative forcing due to the long lived greenhouse gases (CO_2 etc.) produced over many decades.

The major volcanic eruption at Mount Pinatubo in 1991 is considered to have caused significant interference with short term climate, notably by emitting substantial quantities of dust particles into the atmosphere which have a cooling effect that could mask global warming for a limited period.

A recent observation is that there has been a remarkable and unpredicted slowing in the rate of increase of atmospheric carbon dioxide concentrations over the last 18 months, thus deviating from the trend which gave rise to climate change concerns. It is too early to say whether or not this is simply a minor perturbation. Some leading scientists active in the field attribute it to indirect effects from the Mount Pinatubo eruption (temporary cooling due to dust particles affecting biosphere respiration more than photosynthesis; see footnote [1]) or to transient effects associated with the El Nino process; see footnote [2]). Similar unexplained variations in the rate of atmospheric CO_2 increase have occurred before (e.g. in 1982). Latest measurements show that in late 1993, the rate of increase has risen again. These observations emphasise the limited state of knowledge concerning the carbon cycle and its inherent feedback mechanisms.

Other important scientific developments include new information from Greenland ice cores which suggests that substantial changes in climate occurred more frequently and rapidly in the past than previously realised and increasing awareness of the key role of ocean circulation patterns in determining regional climate. These patterns appear to be relatively unstable and potentially subject to disturbance.

7. Areas of Controversy and Alternative Scientific Views

Scientific criticism of the IPCC view falls under the following headings:

a. Understanding of the carbon cycle and the relationship with anthropogenic carbon emissions.

b. Reliability and interpretation of temperature records.

c. Understanding of climate processes and particularly the way they are represented in GCMs.

d. Consequences of global warming.

e. Ecosystem responses to climate change.

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1 The terrestrial biosphere component of the carbon cycle is largely determined by the balance between respiration of biota (which emits carbon dioxide) and photosynthesis (which consumes atmospheric carbon dioxide). In general respiration is more sensitive to temperature than photosynthesis; hence it is argued that a rapid cooling effect would be expected to lead to a short term reduction in atmospheric carbon dioxide until the balance of the processes is restored.

2 The El Nino Southern Oscillation phenomenon is an irregular oscillation of the coupled ocean/atmosphere system in the tropical Pacific Ocean, occurring approximately every 3 to 5 years. During the peak of an El Nino, sea surface temperatures in the eastern tropical Pacific can be several degrees warmer than the climatological mean. El Nino events are associated with major climatological effects, such as failure of the Indian Monsoon. An opposite phase of cold events is referred to as La Nina. These phenomena are also associated with changes in the exchange of carbon dioxide between ocean and atmosphere.

The nature of the criticism under each heading is summarised below.

a. Understanding of the carbon cycle and the relationship with anthropogenic carbon emissions

Man-made carbon dioxide emissions are small compared with the amounts of carbon in the total carbon cycle (Figure 5). A small shift in the balance of processes governing this cycle could therefore account for changes in atmospheric carbon dioxide concentrations, or overwhelm any effects from human activity.

The carbon fluxes and sinks shown in Figure 5 represent the best estimates prepared by WG I (see Table 1). Of these, only the amount of carbon in the atmosphere and the amount of CO_2 released from fossil fuel combustion is known with any degree of accuracy. Even the uncertainty in the stated uncertainty ranges of the remaining figures is not known.

Table 1. Annual average anthropogenic carbon budget for 1980 to 1989

CO_2 sources		**GtC/yr.**
(1)	Emissions from fossil fuel and cement production	5.5 ± 0.5
(2)	Net emissions from changes in tropical land-use	1.6 ± 1.0
(3)	Total anthropogenic emissions = (1) + (2)	7.1 ± 1.1
Partitioning amongst reservoirs		
(4)	Storage in the atmosphere	3.2 ± 0.2
(5)	Ocean uptake	2.0 ± 0.8
(6)	Uptake by Northern Hemisphere forest re-growth	0.5 ± 0.5
(7)	Additional terrestrial sinks (CO_2 fertilisation, nitrogen fertilisation, climatic effects) - [(1) + (2)] - [(4) + (5) + (6)]	1.4 ± 1.5

The recent figures recognise that forest regrowth in temperate regions plus the "missing sink" (widely presumed to be net carbon storage in the rest of the biosphere) represent significant sinks. Moreover, the cold deep waters of the ocean are potentially capable of absorbing all the CO_2 that would be released if all known reserves of fossil fuel were to be burned (albeit over a timescale of hundreds of years).

What is clear is that currently, only about half of the anthropogenic CO_2 released accumulates in the atmosphere. How this relationship will change as CO_2 emissions and other global variables change is not clear.
Understanding of gases other than CO_2 such as methane and nitrous oxide and the complex role of water vapour is even less well developed.

b. Reliability and interpretation of temperature records

The best available surface temperature record indicates a rise of 0.45°C (±0.08°C) over the last century, but measuring global average temperatures is notoriously difficult. In general coverage of the earth's surface by reliable measuring stations is insufficient with the oceans in particular being under-represented and the coverage is even poorer when the earlier records are examined. The increase of 0.45°C is approximately half of the 1°C increase that has been predicted by various models based on the present rise in AGGCs.

Sceptics further argue that several other factors could have made a significant contribution to the observed temperature increase, including urbanisation, desertification and a decrease in stratospheric turbidity which has occurred over recent years (before the Mount Pinatubo eruption). They claim that when the effects of these factors are subtracted, the rise due to greenhouse gas effects is at most 0.3°C over the last century and could be negligible. Previous major eruptions (e.g. Mt. St. Helens) have also had noticeable effects on short term climate.

The rather imperfect surface temperature record described above does not agree well with more sophisticated temperature measurements made of the middle troposphere by satellite measurements. These allow true mean global temperature measurements to be made on a daily basis. Many models suggest that the global warming signal will be most evident in the middle troposphere , yet these satellite measurements suggest global cooling of -0.06°C /decade over the last 15 years versus ca. + 0.2°C /decade for the surface measurements. Even after empirical corrections for the El Nino Southern Oscillation and known major volcanic eruptions, the satellite data suggest warming of +0.09°C /decade, approximately half the uncorrected surface measurement. Unfortunately the time series for such measurements only goes back some 15 years.

The postulated link between any observed temperature rise and human activities has to be seen in relation to natural climate variability, which is still largely unpredictable. It is pointed out that the temperature variability over the last century is larger than the effect being sought and that the observed rise could be accounted for by a recovery from the Little Ice Age. Climate changes in the recent geological past, such as the relatively warm Roman period and the Little Ice Age, do not appear to have been associated with changes in CO_2 levels.

Other natural phenomena have been put forward as possible explanations for the observed warming. For example changes in solar activity show some correlation with temperature fluctuations and it has also been claimed that the temperature increased during the 1980s because the La Nina process failed to occur from 1975 to 1988. While none of these explanations has so far achieved widespread acceptance in the IPCC scientific community, they serve to emphasise again how incompletely the natural climate system is understood.

Figures 6 and 7 show graphically how temperature has fluctuated in the recent and distant past to provide a perspective against which to consider current anxieties.

c. Understanding of climate processes and particularly the way they are represented in GCMs

GCMs are massive, three dimensional climate models which attempt to describe and predict climate behaviour based on consideration of the input of solar energy and the resulting physical processes in the global system. These models generally describe climate in terms of temperature, precipitation and barometric pressure for grids covering the globe. They are impressive, but the task is formidable, given the need to take into account numerous climate processes and feedback effects that can either amplify or dampen the direct effects of increasing AGGCs. Climate modellers themselves recognise the following main limitations of the GCMs and go as far as to suggest that such models should not be used for making predictions, but merely to help increase our understanding of climate processes:

i. <u>There is insufficient understanding of major feedback mechanisms</u>

These mechanisms include the distribution of water vapour and heat, changes in cloud cover and albedo, exchange between atmosphere and ocean and changes in plant growth and area covered. A better understanding of the role of clouds is critically needed. Some of the complexities of the feedback processes can be illustrated here. Increased temperature will in principle lead to increased water vapour in the atmosphere. However, while water vapour is a greenhouse gas, water droplets in the form of clouds have a completely different effect, both reflecting and absorbing incoming radiation while also trapping outgoing radiation. Different approaches to the modelling of clouds provide estimates of equilibrium warming which vary by a factor of three. In general such feedback has been treated as positive in GCMs but the latest cloud research programme suggests on balance, a net cooling effect. Indeed, satellite measurements show that clouds may absorb 15-20% of incoming radiation, a figure much higher than previously estimated.

ii. <u>Models do not replicate global temperature history well</u> and they must be "tuned" to represent the current situation. Earlier climate models simulated either the atmosphere alone or the oceans alone and were reasonably good at representing today's climate. However, when "coupled" together as GCMs these models had to calculate their own values for the exchange of heat and moisture between ocean and atmosphere. Left to their own devices, the coupled models would "drift" even without changes to the input variables leading to very unrealistic climate representations. Accordingly the fluxes are "adjusted", sometimes by as much as 20-40% of the total incoming radiation. These adjustments are believed to disguise rather than to correct the underlying defects in the models.

When GCMs are used to "backcast", they indicate a pattern of accelerating warming over the past century: in fact the historical record (Figure 6) shows intermittent periods of warming (in the 1930s and 1980s) with long periods of little change and even cooling between the late 1930s and the late 1970s. Also regional predictions (e.g. effects at the poles) are not consistent with observations.

The introduction of factors to represent sulphate and other aerosols that may have masked global warming in recent years is reported to improve the "backcasting" capability of climate models. However, critics warn that the understanding of aerosols is poor (white particles reflect heat, while black particles absorb it) such that this may just be yet another 'tuning knob' to force models to give a better representation of the historical climate record.

iii. <u>GCMs have poor resolving power</u>

Limitations on computer speed and memory limit the resolution of GCM output to grid blocks whose cells are several hundred kilometers to a side. Such resolution is too coarse to reveal effects of certain processes (such as clouds and hydrology). Currently therefore it is not possible to predict how climate might change at the regional or local level and hence what the impact on ecosystems would be at these levels.

iv. <u>Chronology of carbon dioxide fluctuations and temperature</u>

While there is a remarkable correlation between past temperature (as deduced from ice isotopic composition) and the carbon dioxide profile, it is not clear that carbon dioxide changes ever significantly preceded the temperature signal. Clearly, factors such as changes in earth orbital patterns (external forcing) can produce temperature and other climate changes which in turn can lead to fluctuations in atmospheric carbon dioxide concentrations.

In summary there are serious limitations to the ability of models to predict climate change and these limitations are likely to remain for some time. The limitations are both inherent and practical. It is inherent that the climate system is chaotic in nature and therefore not amenable to deterministic prediction. At best climate could only be modelled in terms of probability. This can be observed in the natural variability of the present climate.

Practical limitations will also persist for some time. For example, while the Deep Ocean is critically important because of its ability to exchange both heat and CO_2, there are major uncertainties in our knowledge of its present state. The models themselves have errors in them, the magnitude of which is not known because of the limited availability of the computing power. Moreover, a number of important processes such as the carbon cycle and the impacts of clouds, continental glaciers, solar variability and volcanic activity, are either absent from climate models, or are poorly understood.

d. Consequences of global warming

GCMs and other projections predict various consequences from increased concentrations of greenhouse gases in addition to temperature rise, although different models do not always agree on the nature of these consequences. Climate features affected include increased precipitation and cloudiness, increased frequency and severity of storms and decreased diurnal temperature range. Secondary consequences include sea level rise, decrease of glaciers, disturbance of ecosystems.

The sceptics argue that there is no convincing, statistically significant evidence that climate features have been affected in the way predicted and that progressive refinement of the models has led to less alarming predictions. A good example is sea-level rise. In the 1980s some scientists predicted a 6m sea level rise due to break-up of Antarctic ice sheets. In 1990, the IPCC report suggested 66 cm by 2100 as a "best guess". By 1992, IPPC had reduced this estimate to 48 cm, while some scientists have predicted that sea level would actually fall due to increased snow cover on land.

e. Ecosystem Responses to Climate Change

Various models are available to examine the effect of climate and atmospheric changes on ecosystems, agriculture and the economy. As a general point the changes brought about by man's activities in the absence of climate change, are likely to be at least as important as those induced by climate change.

For terrestrial ecosystems there is widespread agreement that increased plant fertilisation due to raised CO_2 in the atmosphere plus increased nitrogen and other nutrients derived from atmospheric pollutants will increase plant growth. Estimates vary from 0% to 50%. The increase in net carbon storage will be less than this (possibly half) and insufficient to materially offset man-made emissions of CO_2. In the oceans, plant life is not thought to be limited by carbon and there is no CO_2 fertilisation effect.

Models of natural vegetation redistribution have been validated against historical records. Changes in higher latitudes, e.g. tundra ---> conifer forests, are reasonably well understood but in the tropics the changes will depend on moisture/rainfall rather than temperature. Climate models produce wide estimates of such changes and the impact on ecosystems is most uncertain.

Certain ecosystems transitions could be more problematic. For example, dieback of forests (with fire) could produce short term pulses of CO_2, offsetting the increased carbon storage potential of the overall ecosystem.

Agricultural systems are man-made and accordingly man can adapt them to changing climate. Whether this will produce an overall positive or negative effect on the agricultural economy will depend on societal choices, e.g. local self sufficiency versus changes in the patterns of world trade in (and prices for) agricultural products. On balance the effects in economic terms range from slightly positive to somewhat negative. At the regional level, different models can give quite contradictory results. The uncertainty in this part of the cycle (Figure 1) is no less than that in the other parts.

8. Conclusions concerning the Science of Climate Change

The array of arguments outlined in the last section may appear to represent a formidable case against the global warming hypothesis or at least to favour a healthy scepticism. However, many of them raise questions or point to uncertainties rather than offer convincing alternative positions. These arguments will have been familiar to IPCC scientists who have not materially changed their views. Those who conclude that global warming is likely would argue that uncertainty applies both ways - the effects could be larger then predicted.

A definitive, unequivocal position on the science of global warming would require an understanding of the immensely complex systems which determine the world's climate and biogeochemical cycles. This is quite simply beyond current capabilities. It is not surprising that there should be controversy and the only statements which can be made with confidence relate to the fundamentals stated in section 4 which may be summarised as follows:

- Human activities have contributed to an increase in atmospheric greenhouse gas concentrations which must have some effect on the radiation balance which ultimately determines global climate. However, it is not possible to quantify the consequences for global climate with respect to timing, magnitude or regional distribution nor to specify their significance in comparison with natural climate variation.

- It is thus not possible to dismiss the global warming hypothesis as scientifically unsound; on the other hand any policy measure should take into account explicitly the weaknesses in the scientific case.

9. **Current Shell Activities**

In addition to monitoring scientific and political developments, Shell specialists are involved in a range of national and international initiatives and activities targeted at the critical issues or organisations involved:

The overall objective is to promote an objective debate on the policy issues concerning possible climate change based on an understanding of the science. The Group position is that:

Scientific uncertainty and the evolution of energy systems indicate that policies to curb greenhouse gas emissions beyond 'no regrets' measures could be premature, divert resources from more pressing needs and further distort markets.

This objective is supported by a PA communications plan that will include a new Management Brief (further details from PAE). PL/12 have looked at the relationship between energy systems and CO_2 emissions through the work on evolution of energy systems. This shows that there is considerable potential for technological change on both the energy supply and energy use sides which would limit the increase in CO2. Market forces may drive such developments even in the absence of policy responses to limit CO_2 emissions. This work has been presented to a number of groups of government officials and at international fora such as the International Energy Agency and the World Bank (further details from PL/12).

Activities by Shell include:

- Scientific understanding

  As part of an industry consortium (IPIECA) support has been provided for research on key areas of scientific uncertainty (cloud processes at the UK Meteorological Office; ocean / atmospheric exchange processes at the Lamont Doherty Observatory, Columbia University, USA).

- Integrated Assessment of Science, Economics and Policy

  Shell is a part sponsor of the MIT Global Change Program which brings together a wide range of expertise in a fully integrated multi-disciplinary programme which addresses all of the processes shown in Figure 1.

- <u>IPCC Technical Assessments</u>
  Monitoring of and input to IPCC deliberations is conducted via IPIECA (International Petroleum Industry Environmental Conservation Association): HSE/3 is Vice-Chairman of the Global Warming Committee. Under the aegis of IPIECA, HSE/3, PL/12 and SMDF/7 have been officially accepted as members of the Peer Reviewers Panel for the next IPCC Technical Assessments. Industry viewpoints are also promoted via specialist workshops involving IPCC/COP participants together with industry experts and by liaison with the International Energy Agency (IEA), for example through the Coal Industry Advisory Board (CIAB).

- Direct input to the IPCC process has included participation in IPCC meetings and correspondence (by PL/12) challenging the OECD Economic model and the Scenarios adopted by IPCC and introducing ideas from the Long Term Energy Study. Contributions have also been made to a variety of seminars dealing with implementation of UNCED commitments.

- <u>UN Framework Convention on Climate Change (UNFCCC) / UNCSD</u>
  Shell (particularly Group PA) plays an active part in the International Chamber of Commerce which is the principal industry-wide vehicle for contributing to the UNFCCC process. Group PA also plays an active role in the World Business Council on Sustainable Development (WBCSD) (formed from a merger of WICE and BCSD) which, alongside the ICC, interacts with the UN Commission on Sustainable Development (UNCSD) and develops industry positions, for example on Agenda 21. Liaison with the Global Environment Facility (GEF) is being developed via IPIECA (HSE/4 is a member of the relevant IPIECA post-UNCED Working Group). There are also direct Shell contacts with GEF through involvement in the Brazil Biomass BIG project. Shell is also making an input to the OECD's work on climate change through the Business and Industry Advisory Committee (BIAC).

- <u>National / Regional Policies</u>
  Shell Staff interact with organisations developing national and regional plans to address climate change, either directly or via industry associations. For example in Europe, relevant bodies include EUROPIA, UNICE etc. The importance of making input at the national government level should not be underestimated.
  It is the national governments which determine the policy of UN bodies and which will

subsequently implement it nationally. OpCos needing guidance on making an input to the climate change debate in their country are advised to contact HSE/3, PAE or PL/12.

* * * * *

Glossary of Abbreviations

AGGCs	Atmospheric Greenhouse Gas Concentrations
BCSD	Business Council for Sustainable Development
BIAC	Business and Industry Advisory Committee
CFC	Chlorofluoro Carbon
CH4	Methane
CIAB	Coal Industry Advisory Board
CO2	Carbon Dioxide
EUROPIA	European Petroleum Industry Association
GCM	General Circulation Model
GEF	Global Environment Facility
GWP	Global Warming Potential
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPIECA	International Petroleum Industry Environmental Conservation Association
MIT	Massachusetts Institute of Technology
N2O	Nitrous Oxide
OECD	Organisation for Economic Cooperation and Development
UNCED	United Nations Conference on Environment and Development
UNCSD	United Nations Commission on Sustainable Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNICE	Union of Industrial and Employers' Confederations of Europe
WBCSD	World Business Council for Sustainable Development
WICE	World Industry Council for the Environment
WMO	World Meteorological Organisation

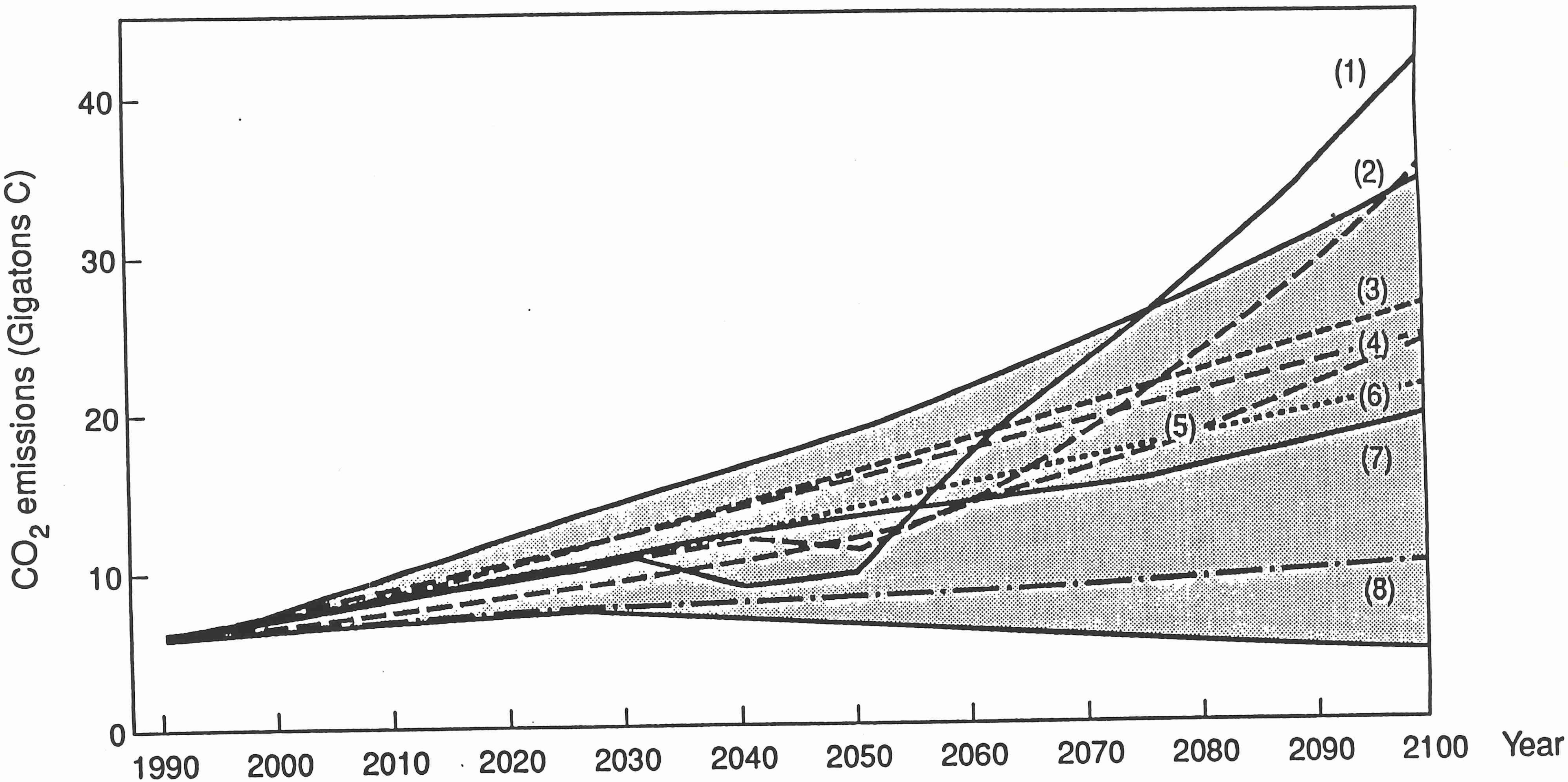


Figure 2
Representative published "emissions scenarios" based on various assumptions about population growth, industrial and economic activity. The shaded area indicates the range of the scenarios in the 1992 IPCC update and curve 7 represents the mid range IPCC scenario IS92a. The other curves are from different individual research groups or organisations.

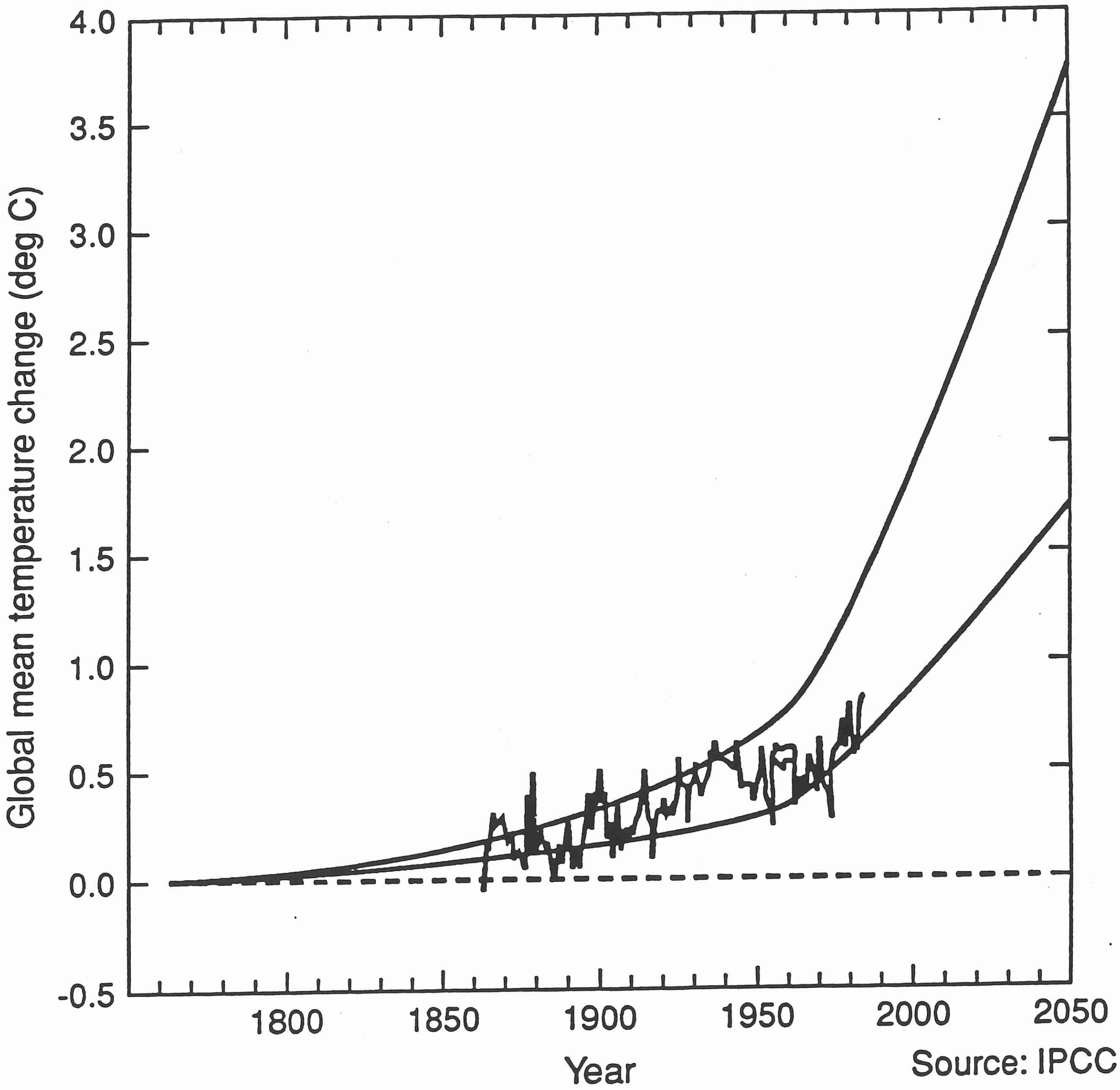
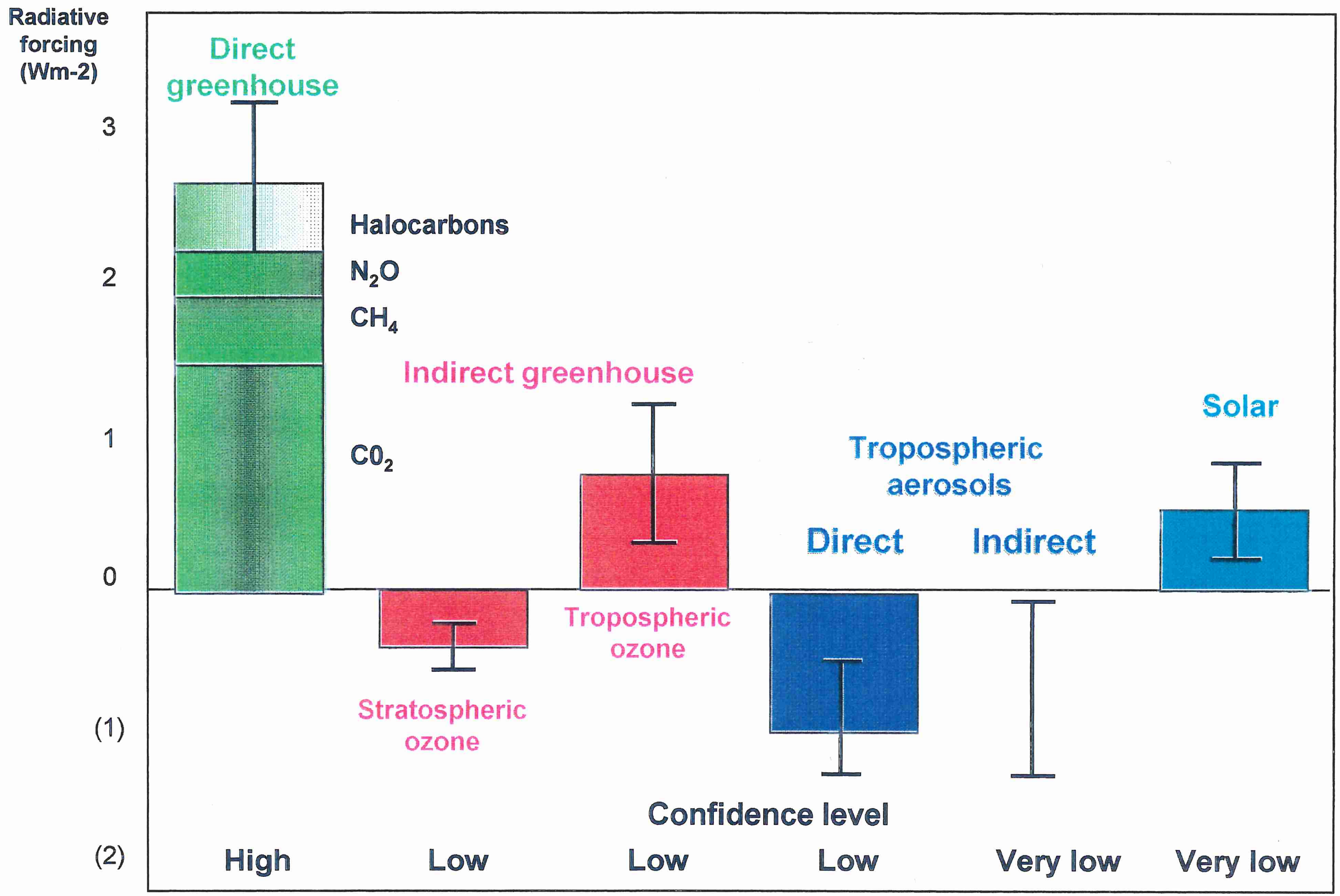


Figure 3
Observed versus predicted global warming. The smooth curves represent the upper and lower IPCC predictions for the warming which would occur with a doubling of pre-industrial CO_2 levels. The irregular curve represents the observed temperature pattern.

Figure 4. Radiative forcing by different factors



Explanation of Figure 4

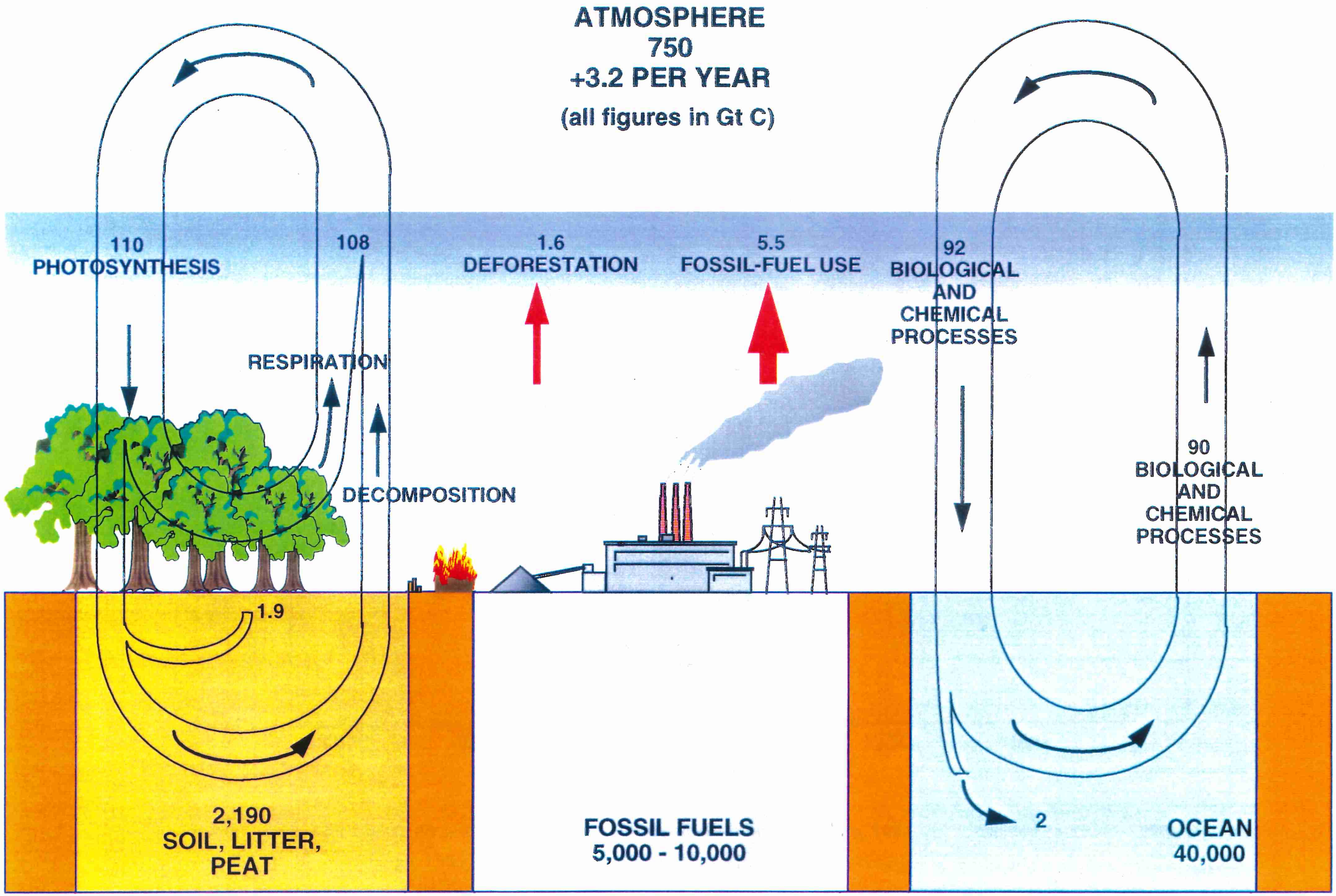
A number of factors contribute to radiative forcing (the enhanced greenhouse effect). Best known are the direct effects of the greenhouse gases themselves(CO_2, CH_4, N_2O, Halo carbons etc.). However, some of these gases, such as CH_4, may have indirect effects through chemical reactions in the atmosphere leading to changes in concentration of other radiatively active gases, especially ozone and water vapour. Tropospheric aerosols have direct effects through reflection of radiation back into space, as well as indirect effects, e.g. through promotion of cloud formation.

The figure shows estimates of the relative contributions to radiative forcing of the different factors. Measurements are made in Wm^{-2} and the bars show the confidence intervals. The total direct enhanced greenhouse gas radiative forcing of 2.5 Wm^{-2} is approximately 1% of incoming solar radiation. This is a small but nonetheless important figure.

Changes in solar radiation are also believed to have made a small contribution to the total radiative forcing.

The combined negative forcing of tropospheric aerosols and stratospheric ozone may have offset the positive direct effects of the greenhouse gases. However, the confidence level in such conclusions is low.

FIGURE 5


ATMOSPHERE
750
+3.2 PER YEAR
(all figures in Gt C)
110
PHOTOSYNTHESIS
108
RESPIRATION
DECOMPOSITION
1.6
DEFORESTATION
5.5
FOSSIL-FUEL USE
92
BIOLOGICAL AND CHEMICAL PROCESSES
90
BIOLOGICAL AND CHEMICAL PROCESSES
1.9
2
2,190
SOIL, LITTER, PEAT
FOSSIL FUELS
5,000 - 10,000
OCEAN
40,000

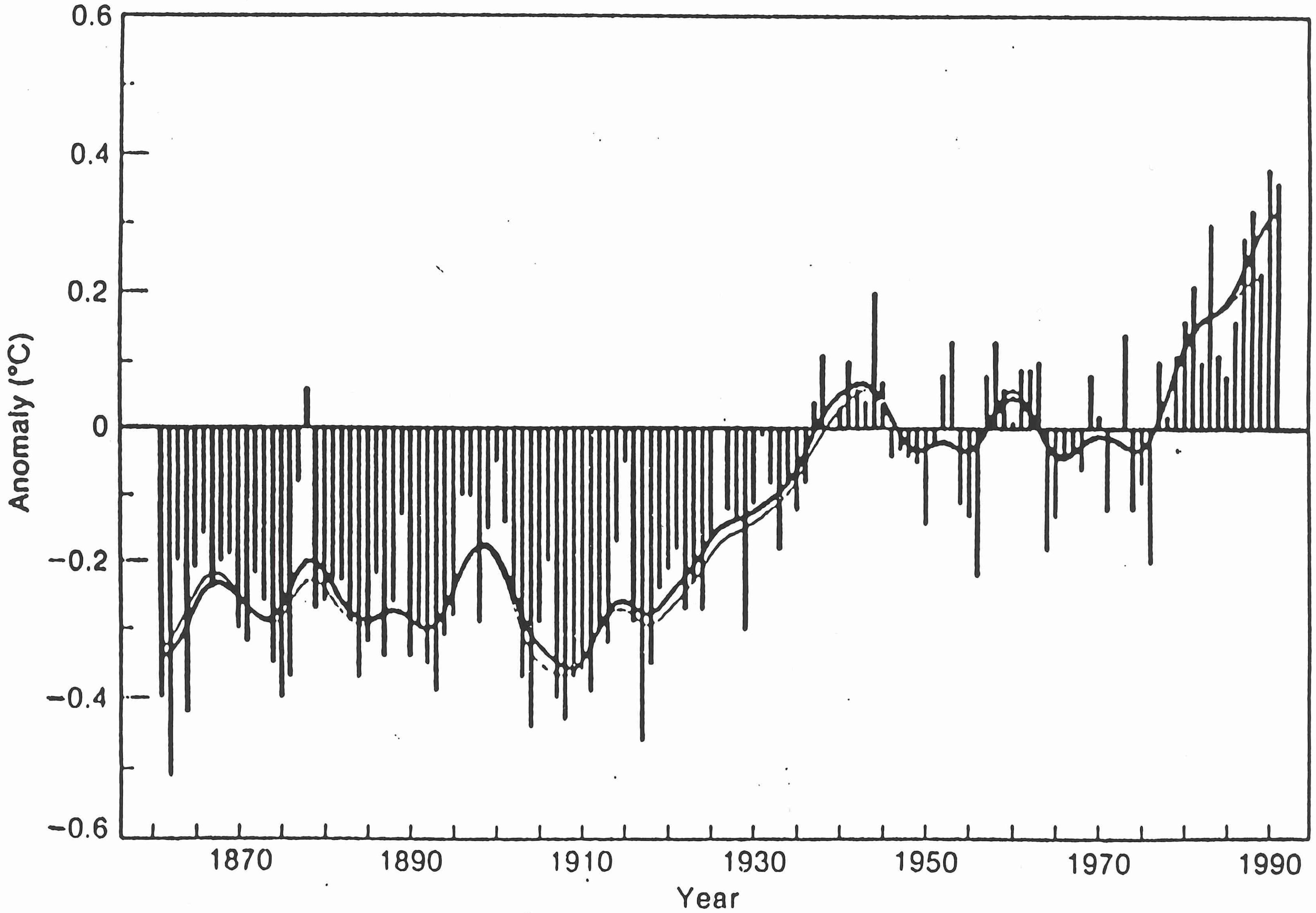


Figure 6. Combined land, air and sea surface global temperature anomalies, 1861-1991, relative to 1951 - 1980

SOURCE : Climate Change 1992. The Supplementary Report to The IPCC Scientific Assessment.

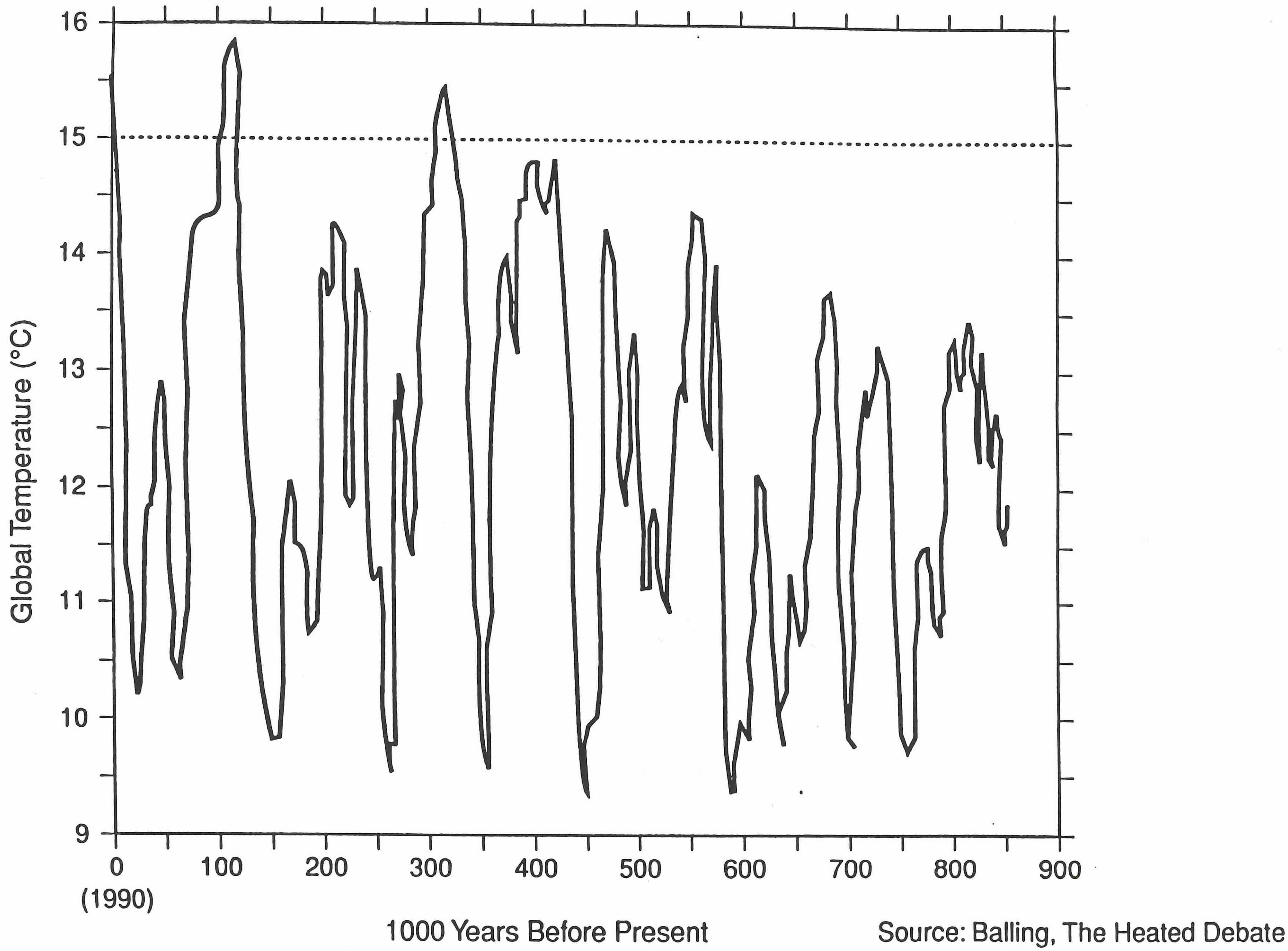


Figure 7
Long term fluctuation of global mean temperature

Production: Shell Reprographics (ODHC/13), The Hague ®