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Climate change

Scientific background and process

Report 2000:1

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Abstract

The paper gives a brief description of natural and man-made forces behind climate change and outlines climate variations in the past together with a brief synopsis likely future impacts of anthropogenic emissions of greenhouse gases. The paper also gives a briefing on the background, organisation and functioning of the Inter-govern-mental Panel on Climate Change (IPCC).

Contents

1 Introduction

In its Second Assessment Report (SAR) from 1995 the Intergovernmental Panel on Climate Change (IPCC) concluded that

> «The balance of evidence, from changes in global mean surface air temperature and from changes in geographical, seasonal and vertical patterns of atmospheric temperature, suggests a discernible human influence on global climate. There are uncertainties in key factors, including the magnitude and patterns of long-term natural variability.»

Although carefully worded, the statement has created a rather heated debate, also among climate scientist. Some well-known and respected scientists disagree that we at this moment in time are able to discern a human influence on the global climate (Pearce, 1997). Also in connection with the production of the last Assessment report, some procedural errors were introduced in the final editing of the summaries of the report. These errors were used extensively by interest groups opposed to climate change policy to discredit the whole report and the organisation producing the report (IPCC). On this background it is perhaps understandable that many may have come to see IPCC and its reports as mainly *political manifestations*, to be discussed within the political arena on par with other political topics. Thus, a basic misconception of IPCC has to some degree been spreading, and this in turn has fed scepticism to the whole issue of climate change. Coupled with the notion that climate change is synonymous with global warming, and that some warming may seem desirable at least at Norwegian latitudes, this has resulted in an attitude in certain (mainly political) quarters that climate change is just one more doomsday prophesy from environmental groups.

In this paper we will give some background on the climate change problem by discussing some well understood and some less well understood mechanisms behind changes in the global climate. The likely human impact on climate change is further compared to natural climate change in the past, and we close this first part of the paper with a review of the main outstanding scientific problems in this field. This will hopefully clarify the nature of the problem of climate change. Then, in the second part of the paper, we will try to convey what IPCC is and what it is not and the role of IPCC in the debate on climate change, before we conclude with some comments on the nature of the problem of climate change.

2 On climate change

2.1 Basics

The system governing the climate on Earth consists of many sub-systems coupled together in a non-linear fashion. As such, the system is able to distort and amplify external signals affecting the various sub-systems. This is the basic reason why the climate is such a complex issue to study. Although we may have a good deal of knowledge about individual sub-systems, the many interlinkages with other systems make it very hard to predict the overall behaviour of the global climate in response to for instance emissions of the so called greenhouse gases.

An important sub-system is of course the atmosphere itself. However, the state of the atmosphere (temperature, humidity, clouds, distribution of high and low pressure areas, etc.) is affected by and influences the state of other sub-systems such as the oceans, the cryosphere (snow and ice), the biosphere and even the lithosphere (soil, rock, etc.). Despite these interactions it can be useful to list the main causes of global climate change as follows:

- Variations in solar radiation (the solar ‘constant’)
- Variations in the Earth’s orbit
- The shape and position of the continents
- Volcanic activity
- Variations in the reflections from the Earth’s surface and atmosphere (albedo)
- Changes in the composition of the Earth’s atmosphere due to weathering, volcanic activity and human activities:
  - gases
  - aerosols
  - cloud cover

These driving forces operate on a number of time scales, from the very long geological time scale to a more ‘human’ and politically relevant much shorter time scale. Below, we will briefly comment on most of these driving forces.

2.1.1 Solar radiation and the carbon-silicate cycle

The solar radiation varies both on short and long time scales. In broad terms the solar intensity has, as a consequence of the natural evolution of a star the size of our sun, increased by approximately 30 percent since the creation of the Earth some 4.6 billion years ago.

The ‘virgin’ atmosphere of the Earth contained much more CO_2 (and probably CH_4) than the present atmosphere. Extreme volcanic activity was an important source of CO_2 in these early ages. The greenhouse effect of these gases helped to keep the Earth warm, although the solar radiation was considerably less intense than today.

The carbon in the atmosphere also helped in stabilising the climate through what is known as the carbon-silicate cycle (see Box 1). When rock erodes, silicate binds to carbon dioxide in the atmosphere and is then transported to the seas where the carbon in the form of calcium carbonate settles in solid form at the bottom of the oceans. Over million of years plate tectonics and other processes brings the carbon to the surface where volcanic activity once more release it to the atmosphere. High CO_2 concentration in the atmosphere leads to a warm and more humid climate, and increased precipitation in turn leads to more erosion and consequently a stronger sink for atmospheric CO_2. Oppositely, a low CO_2 concentration leads to a colder climate with possible glaciation as a result, which protects the rock from erosion and weaken this sink for atmospheric CO_2. These feedbacks thus tend to stabilise the global temperature (and also the CO_2 concentration in the atmosphere) in the long run. Other feedback mechanisms work in the opposite direction (see sections below).

Box 1. The carbon-silicate cycle

On the multimillion year scale the carbon cycle is dominated by the following processes:

- uptake of atmospheric CO_2 by the chemical weathering of calcium and magnesium silicate minerals
- weathering of ancient sedimentary organic matter on the continents and the burial of new organic material in marine sediments
- thermal breakdown of carbonate minerals and organic matter via metamorphism, diagnesis and magmatism with transfer of CO_2 back to the earth surface.

The processes may be represented by the following reactions:

$$CO_2 + CaSiO_3 \leftrightarrow CaCO_3 + SiO_2 \qquad (1)$$
$$CH_2O + O_2 \leftrightarrow CO_2 + H_2O \qquad (2)$$

The first equation, read from left to right, represents weathering of silicates. (Ca may, completely or partly, be replaced by Mg.) We note that CO_2 is consumed. Read from right to left the equation represents breakdown of carbonate.

Equation (2) from right to left represents burial of organic material (CH_2O); this may also be denoted net photosynthesis. Read from left to right, it may be denoted “georespiration”, i. e. oxidation of organic matter after deep burial or uplift of previously sedimented organic matter.

A better understanding of the role of silicates and carbonates in affecting the atmospheric CO_2 levels, is obtained if we look more closely at weathering and breakdown reactions:

Weathering of carbonates may be written as
$$CO_2 + H_2O + CaCO_3 \rightarrow Ca^{2+} + 2HCO_3^- \qquad (3)$$

Similarly for silicates
$$2CO_2 + H_2O + CaSiO_3 \rightarrow Ca^{2+} + 2HCO_3^- + SiO_2 \qquad (4)$$

The bicarbonate will react with calcium to form solid $CaCO_3$
$$2HCO_3^- + Ca^{2+} \rightarrow CaCO_3 + CO_2 + H_2O \qquad (5)$$

Note that (5) is (3) read from right to left. This implies that carbonate weathering does not affect the atmospheric CO_2 concentration in a long-term perspective. Combing (4) and (5) gives the result of silicate weathering and carbonate formation, i.e. equation (1) (from left to right).

The carbon-silicia cycle is at the heart of a model of long term development in CO_2 concentration developed by Berner and co-workers (see Berner, 1998, for an overview). They stress that on a scale of some million years, uptake and release of CO_2 must be in close balance. Otherwise the CO_2 concentration will rise to very high values or decrease to values so low that life cannot exist. Results of the developed model are depicted in figure 1.

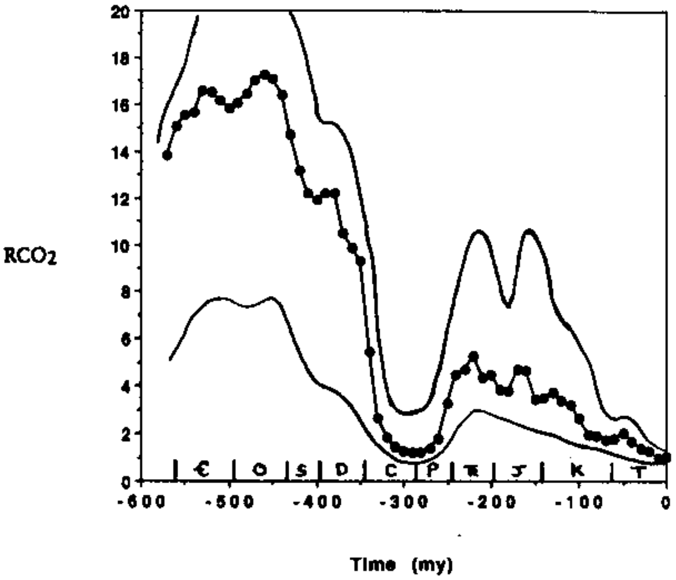

Figure 1. Model results of the ratio of CO_2 in the atmosphere at a given time divided by that at present (RCO-2). The line with filled circles represents the most likely values; the other lines indicate crude error limits. The rapid decrease between ca 380 and 350 million years before present (myBP) is largely due to the spread of vascular plants. The increase starting around 250 myBP is largely due to mountain uplift. Note that the sun's radiation has increased substantially during the period. If this is not taken into account, the modelled RCO-2 values would have been lower; in the period before about 400myBP less than half the values shown in the figure. From Berner 1994, fig. 19.

We can conclude that on a geological time scale, CO_2 concentrations have been far larger than present values. The results are in reasonable agreement with estimates of CO_2 levels by other methods.
The rapid decline in the CO_2 concentration between 380 and 350 million years before present (myBP) is especially interesting. Berner argues that during that period vascular plants spread to upland areas. This would greatly increase the weathering rate; he suggests by a factor of 5 – 10. Since weathering of silicate rocks represents a sink for atmospheric CO_2, there must be a feedback mechanism preventing the concentration from becoming too low. According to Berner, the main feedback is that as the CO_2 concentration decreases, the temperature goes down and the weathering decreases.

An important conclusion from the work by Berner et al. is that the atmospheric CO_2 level has been a key element in the complex of factors that has determined the climate on the earth through millions of years. Decreases in CO_2 levels have counteracted increased weathering due to the evolution of vascular plants and compensated for increasing solar radiation.

There are also more rapid cycles involving the transfer of carbon between reservoirs, see figure 2. The shortest-term cycle is mainly related to the photosynthesis and respiration of plants, while a medium-term cycle typically involves fossil fuels.

Also on a relatively short time scale, the solar output varies over the so-called solar sunspot cycle lasting for approximately 11 years. Although the total intensity of the solar radiation does not vary much with solar activity measured by number of sun spots or length of the sun spot cycle, it is still possible to observe a good correlation between the length of the sun spot cycle and mean temperature over land in the northern hemisphere (Friis-Christensen and Lassen, 1991). The correlation deteriorates, however, if the period is extended beyond the mid 1990s. We also lack a convincing explanation of how such small variations in solar output can cause observable effects on the global temperature.

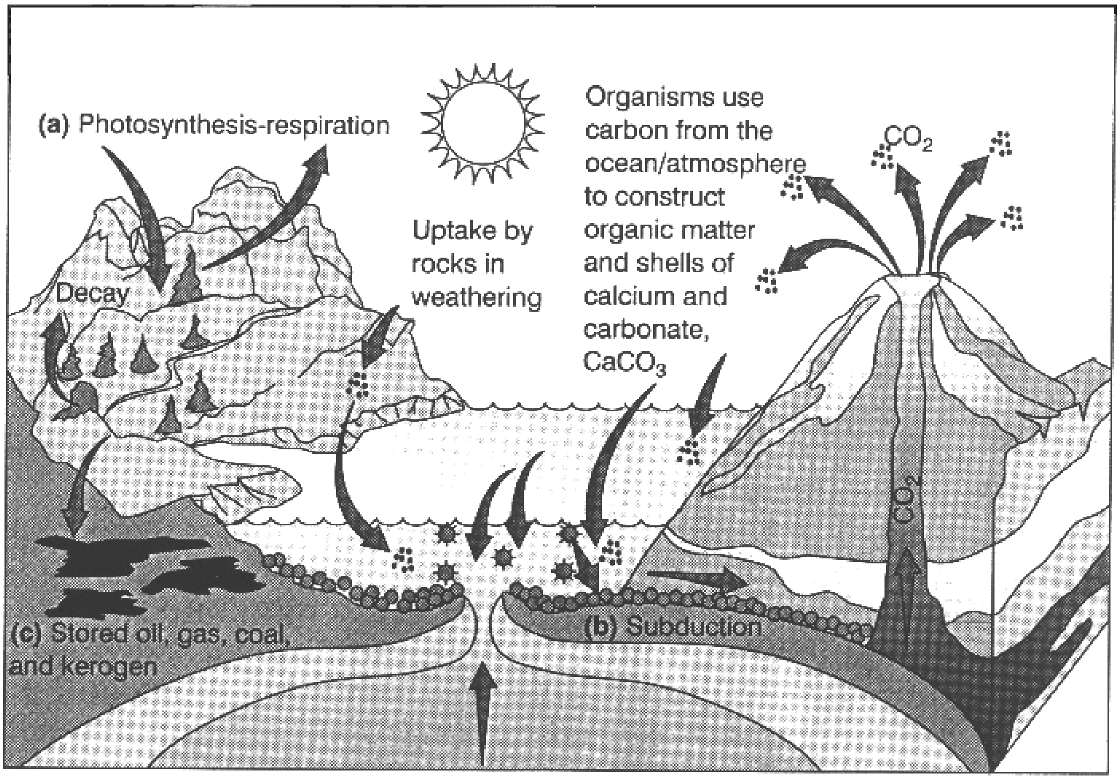

Figure 2. The biogeochemical carbon cycle prior to human inference. One may distinguish between a short-term cycle (a), a long-term cycle involving accumulation of $CaCO_3$ and organic carbon in marine sediments, their subduction, alteration and return of CO_2 to the atmosphere (b), and a medium-term cycle involving storage of carbon in organic materials in sedimentary rocks (c). Source: Fig. 5.2 in Mackenzie and Mackenzie 1995.

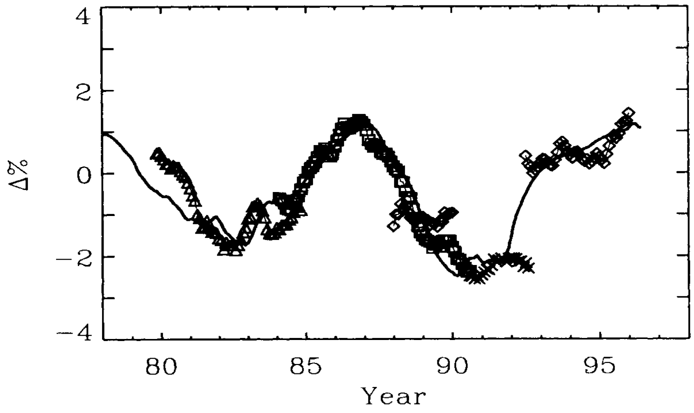

Figure 3. Variations in cosmic radiation (full line) and cloud cover (symbols); from Svensmark og Friis-Christensen (1997).

Svensmark and Friis-Christensen (1997) have suggested a mechanism to explain the correlation. They point out that the cosmic radiation hitting the Earth decreases with increasing sunspot activity since the solar wind deflects the cosmic radiation. Since increase in cosmic radiation increases the cloud cover, the cloud cover tends to be largest near sunspot minimum (see figure 3).

They estimate the increase in cloud cover to be about 3 % from sunspot maximum to minimum and state that this corresponds to a radiative forcing of – (1 – 1.5) Wm^{-2}. Other studies indicate that the effect is much smaller. Thus Ringer & Shine (1997) found the radiative forcing for one per cent change in cloud cover to be -0.165 Wm^{-2} using data from one satellite and in fact a positive value for other satellite data. In addition, Kuang et al. (1998) point out that the optical properties of clouds seems to more or less cancel out the effect of changes in cloud cover due to changes in cosmic radiation.

2.1.2 Variations in the Earth's orbit

The evidence for amplifying feedback mechanisms in the climate system is a recurrent theme in almost all studies of climate change. Thus, the correlation between global glaciations over the last few million years and small changes in the incoming solar radiation due to changes in the Earth's orbit around the sun is another example. There is relatively clear evidence for long term climate cycles with the same periods changes as the Earth's eccentricity (100 000 years), obliquity (41 000 years) and precession (19-23 000 years) in the records of past ice ages. The orbital changes (see figure 4) somehow seem to trigger global climate change. However, it is not well understood how these so called Milankovich cycles leads to the observed large scale synchronicity between the northern and southern hemisphere. Also the relation to the recorded changes in greenhouse gas concentration (CO_2 and CH_4) is less than fully understood.

Berger and co-workers have modelled variations during the past 200 thousand years (ka) of the Northern Hemisphere ice volume forced by insolation and reconstructed CO_2 levels (see figures 5 and 6). The agreement with other estimates of the ice volume variations is reasonably good. According to their model calculations, the variations in the Earth's insolation, although small, induce feedbacks that are sufficient to generate large climatic changes. The change in albedo is being particularly important. This supports the suggestion by Hays et al. (1976) that the orbital forcing acts as a pacemaker of the ice ages.

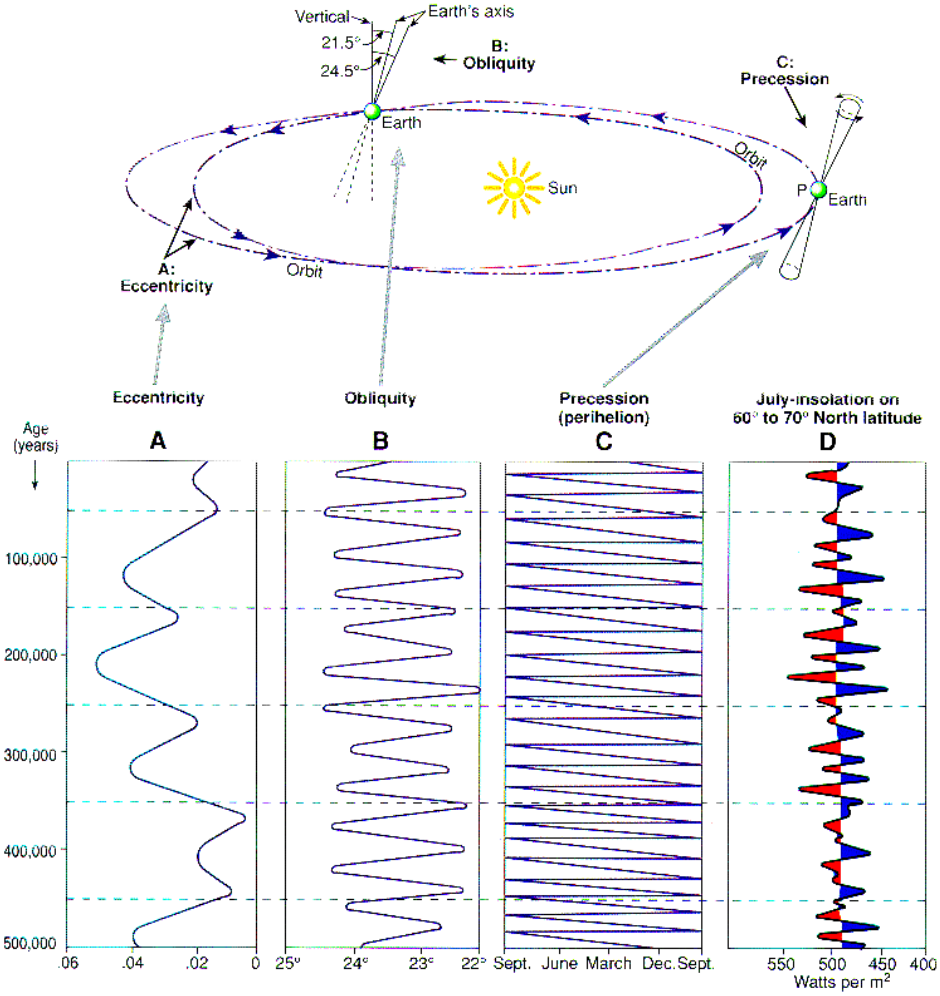

Fig. 1–26A.
The astronomic factors, also called Milankovitch factors, which are believed to determine the main climatic pattern during the late Cenozoic.

A: The eccentricity of the earth's orbit varies in 100 000 year cycles.

B: The obliquity: The tilt of the earth's axis relative to the orbital plain fluctuates in 41 000 year cycles.

C: The precession fluctuates in 23 000/19 000 year cycles, resulting from the wobbling of the earth's axis. P: Perihelion is the point on the earth's orbit which is closest to the sun.

Fig. 1–26B.
Calculated fluctuations of the Milankovitch factors during the last 500 000 years, and the resulting fluctuations of insolation to the earth on the 60° to 70° North latitudes.

A: Eccentricity. B: Obliquity. C: Precession (when Perihelion is closest to the sun). D: The fluctuation of insolation to the earth on the 60° to 70° North latitudes, as a result of the fluctuations of all Milankovitch factors combined. Red: warm. Blue: cold periods. (Modified from C. Covey, 1984.)

Figure 4. Variations in the Earth's orbit. From: Andersen og Borns (1997) fig. 1-26.

They also ran the model for the coming 130 ka with a CO_2 scenario based on the reconstructed values for the past. An important result is that the ice volume will remain almost as today up to 50 ka AP (after present). This conclusion was a robust feature of the model studies.

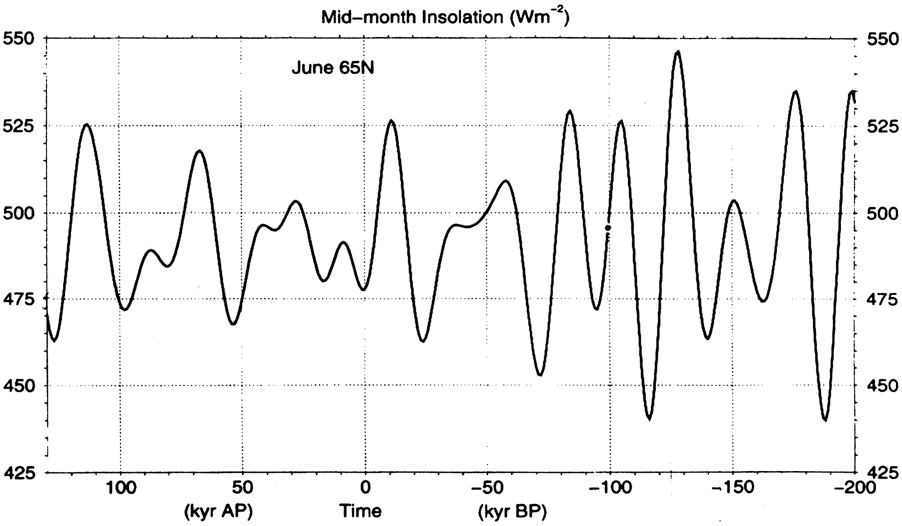

Figure 5. Northern hemisphere insolation during the past 200 000 and the next 150 000 years. Source: Berger and Loutre (1998).

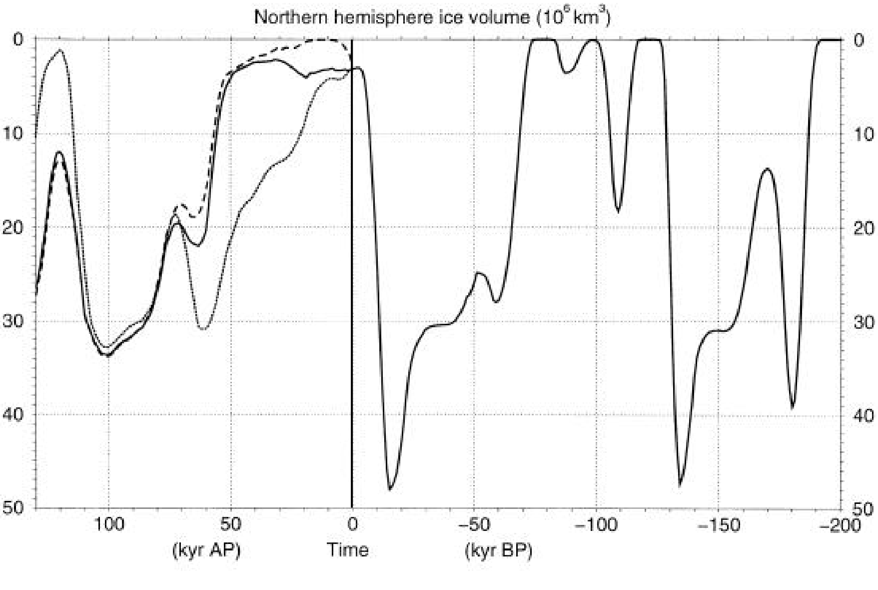

Figure 6. Estimates of northern hemisphere ice volumes during the last 200 000 years and the next 150 000 years. The forecasts are made based on three different assumptions about future CO_2 content in the atmosphere. The lower curve is based on a CO_2 concentration equal to 200 ppmv, i.e. close to conditions under the last ice age. The middle curve assumes a concentration level of approximately 280 ppmv, corresponding to the level just before the industrial revolution. Finally, the upper curve assumes continued growth in the CO_2 concentration towards a level of 750 ppmv over the next 200 years, before the concentration declines to 300 ppmv over the following 450 years. Source: Berger and Loutre (1998).

2.1.3 The shape and positions of continents

Over geological time scales continents and oceans have changes position and shape. For instance, 500 million years ago Norway was close to the South pole. During the journey to the present position all continents became assembled into a super-continent called Pangaea, which lasted until approximately 200 million years ago. This wandering of the continents has had great impact on the global climate, foremost through the increased likelihood for glaciation that appears when the polar regions are covered by continents, but also through changes in the heat transport carried out by ocean currents. Thus, it is a current hypothesis that the onset of the last ‘ice house’ period with cycles between glacial and inter-glacial periods some 2 million years ago, was caused by the closing of the gap between the South and North American continents.

2.1.4 Albedo

The glaciation in itself creates a positive feedback mechanism for climate change since the high albedo of ice leads to high reflection of sunlight, thus cooling the Earth further. To escape from this feedback loop, other factors affecting the climate must change. Thus, it is now hypothesised that the Earth in a period several hundred million years ago actually froze over and became a snowball. Only intense volcanic activity with huge releases of CO_2 causing warming and particles darkening the ice cover, thus increasing the absorption of solar radiation, eventually lead to a melting of the ice and snow (Hoffman, 1998).

Table 1. Some examples on albedo values (in per cent) in the visible part of the spectrum.

Sand	18-28
Grass	16-20
Green plants	15-25
Forests	14-20
Dense forests	5-10
New snow	75-95
Old snow	40-60
Cities	14-18

Source: Houghton (1985).

The cloud cover also affects the albedo or reflectivity of the Earth. The amount and position of clouds are in turn determined by the temperature, the humidity and the concentration of aerosols of the atmosphere, as well as local topographic features like mountains. Thus, the creation of Rocky Mountain 100 million years ago, the Alps between 10 and 60 million years ago and the Himalayas 10 million years ago all affected the cloud cover of the Earth.

On a much shorter time scale, land use change by humans, for instance in the form of deforestation, has affected the albedo of substantial parts of the Earth’s surface.

Table 1 shows some typical values of the albedo expressed as percentages. The average albedo of the Earth above the atmosphere is rougly 30%.

2.1.5 Atmospheric composition

Finally, the chemical composition of the atmosphere is a key factor in determining the global climate. Chemical constituents control the radiative balance of the Earth/ atmosphere system due to interactions with both shortwave and longwave radiation, see figure 7. By absorption of terrestrial (longwave) radiation and re-emission at lower temperatures, the atmosphere is trapping radiative energy and thereby heating the surface-troposphere system. This mechanism keeps the surface about 33 °C warmer than it would otherwise be. The trapping of radiative energy, often referred to as "the greenhouse effect", is mainly due to the presence of water vapour, clouds and carbon dioxide (CO_2) in the atmosphere. Water vapour and clouds are the dominating factors in what can be called the natural greenhouse effect. Other gases such as methane (CH_4), nitrous oxide (N_2O) and ozone (O_3) also absorb and re-emit longwave radiation and contribute to the natural greenhouse effect. In addition to being radiatively active in the longwave region of the spectrum, ozone also absorbs solar (shortwave) radiation.

While CO_2 is the most important gas for the man-made *enhancement* of the greenhouse effect (responsible for approximately 60% of the warming effect since pre-industrial times), there are also significant contributions from methane (CH_4), nitrous oxide (N_2O), and halocarbons, see figure 8 and table 2.

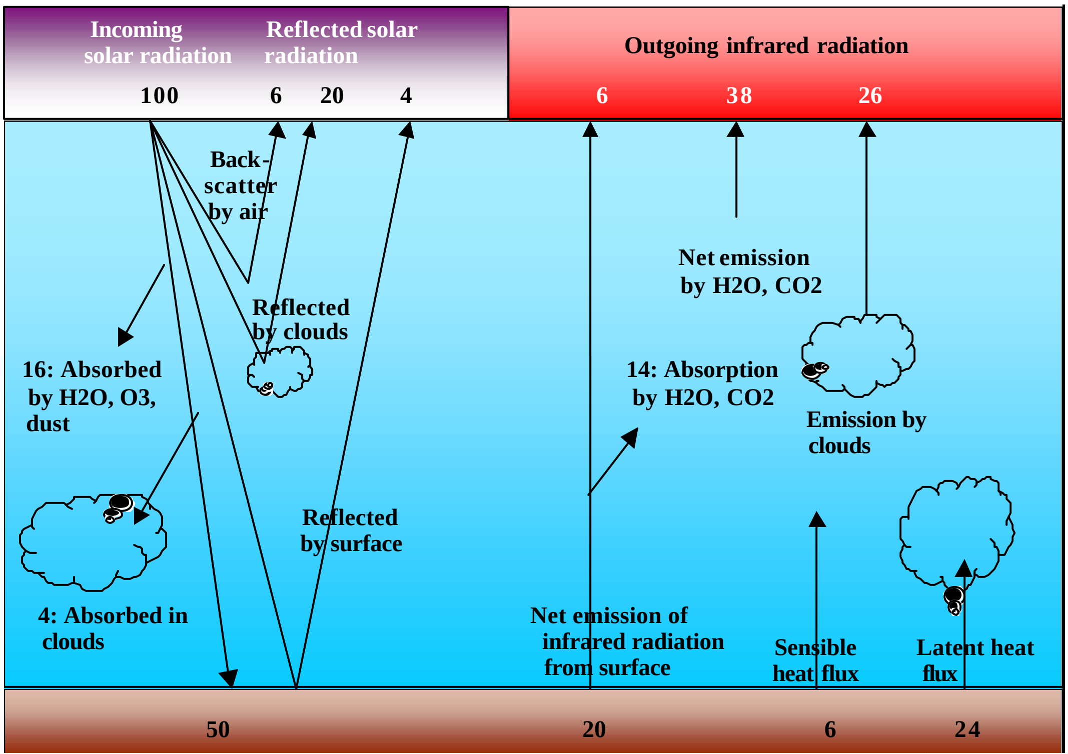

Figure 7. The Earth's radiation balance. Incoming radiation (342 W/m^2) set equal to 100.

Table 2. Summary of properties of important greenhouse gasses (IPCC, 1996, WMO, 1999).

	CO_2	*CH_4*	*CFC-11*	*N_2O*
Concentration unit	ppmv	ppmv	pptv	ppbv
Pre-industrial concentration	~280	~0.7	0	~275
Concentration 1994	358	1,72	268	312
Recent increase per year	1.5 (0.4%)	0.010 (0.6%)	0 (0%)	0.8 (0.25%)
Lifetime in the atmosphere (year)	(50-200)[1]	12[3]	50	120
GWP (100 years horizon)[2]	1	24	500-2000	360

1. One value cannot be given since different uptake processes have different rates.
2. GWPs (Global Warming Potentials) are estimated to be able to compare the different greenhouse gasses. CO_2 is used as reference and given the value 1. GWPs for other gasses depend on the time horizon used.

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[3] This has been defined as an adjustment time which takes into account the indirect effect of CH_4 on its own lifetime.

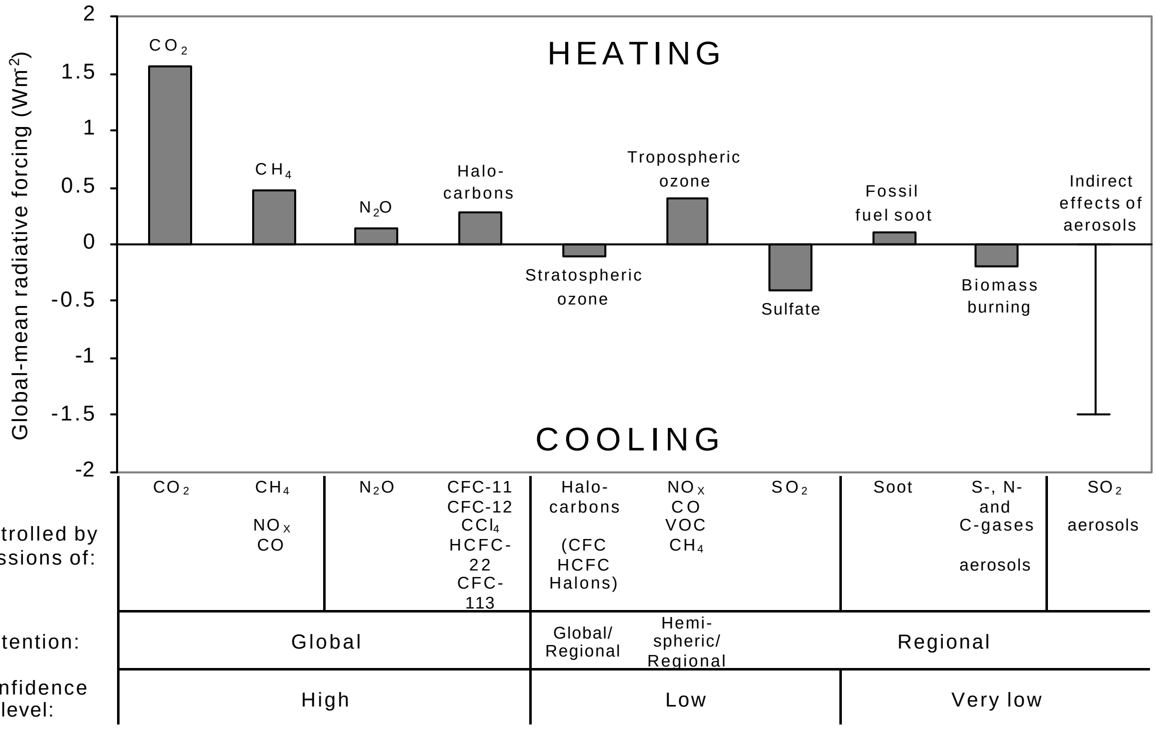

Figure 8. Change in the radiative balance at the top of the troposphere – called radiative forcing – since the beginning of the industrial area due to changes in concentration of various constituencies.

Source: Skodvin and Fuglestvedt (1997)

The depletion of the stratospheric ozone layer has caused a cooling effect, while the ozone increase in the underlying troposphere has probably given a warming that is of similar magnitude as the effect of methane. Sulphate particles formed from SO_2 and particles from biomass burning give a cooling effect due to scattering of solar radiation, while soot has a small warming effect through absorption of long wave radiation. Finally, there may be a large cooling effect from changes in the distribution and properties of clouds due to aerosols. This mechanism is, however, very poorly quantified at present.

We do not have the space here to go through the details, but note that due to the complexity of the chemical and other reactions taking place in the atmosphere, the uncertainties are quite large. We note for instance that water vapour (H_2O) is a potent greenhouse gas. The concentration of water in the atmosphere is, however, governed by the state of the atmosphere (temperature etc.) which in turn is influenced by the presence of the gases mentioned above. Thus, the effect of water vapour on the climate is properly classified as a feedback effect in the climate system, rather than as a direct greenhouse gas effect. Furthermore, the translation of changes in radiative forcing to estimates of changes in temperature is also very difficult, and the uncertainty is of course amplified further when additional feedback mechanisms, for instance involving the oceans or the biosphere, are taken into account.

In summary, we may conclude that there are a wide variety of mechanisms at work that affect the global climate on many time scales. Some of them are well understood, while others are less so. However, the often non-linear coupling between them creates the largest obstacle to our understanding of the climate system. On the short time scale that is of importance to our human society, we note that the composition of the atmosphere together with the interactions between atmosphere, the oceans and the biosphere are of most relevance.

2.2 Remembrance of things past

Since its creation 4.6 billion years ago, the Earth has gone through enormous changes. Continents have been born and reformed, the solar output has increased some 30 percent, and the oceans and the atmosphere have been created and changed. Given these fundamental changes, it is a near miracle that life has evolved and managed to stay alive over much of Earth's history.

Box 2: Some highlights from the history of the Earth

Time (Million years ago)	
4	The creation
600	
3 300	First life
680	First animal
470	First fish
412	First plant
330	First tropical forest
215	First dinosaur
140	First bird
65	Dinosaurs die out
2.3	First homo
.100	First homo sapiens sapiens
.040	Eurasia invaded by homo saphiens
.015	Cave paintings in France and Spain
.010	The end of the last ice age
.008	First civilization
.004	First cities

Adapted from C. Boyle (ed.)(1991): The Human Dawn, Time-Life Books B.V., Amsterdam.

Time scales of billions of years are difficult to grasp. In order to make it more 'digestible', some memorable moments in the Earth's history are listed in box 2[1].

The relatively slow start is noteworthy. It took more than a billion years before the first sign of life appeared in the ocean in the form of single cell bacteria, and almost three billion more years before the first animals were established, also in the ocean. One possible reason for this delay is that the Earth during the period from 750 to 550 million years ago may have frozen completely over (Hoffman et al., 1998). Only after melting of the snowball did land get occupied, first by plants and then gradually by animals migrating from the ocean. At this stage oxygen had become an important constituent of the atmosphere, which at earlier stages had been dominated by CO_2. Volcanic activity and geological processes like weathering and erosion had kept the CO_2 concentration in balance at a high level during the first period. With the invasion of land, these processes were modified and a new balance between the lithosphere, the oceans and the atmosphere was created. The balances were not perfect, however, and severe climate changes in the form of extensive glaciations took place in this early part of the history of the Earth.

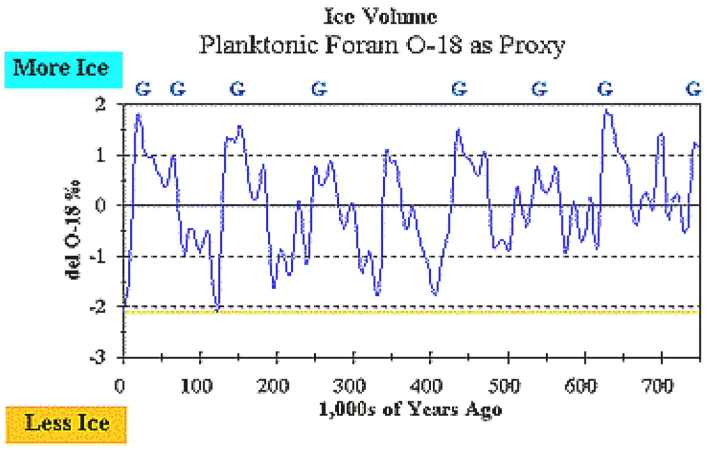

Figure 9. Ice ages over the last 750 000 years

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[1] See also Fortey, 1997.

The first human like animal is some 2 million years old, i.e. very recent in a geological perspective. *Homo sapiens* are thought to have first appeared about 400,000 years ago, certainly in Africa and perhaps in parts of Asia as well. Anatomically modern humans appeared in Africa and possibly in Asia perhaps 100,000 years ago and eventually arrived in Europe. Among these European peoples, the best known is the Cro-Magnons. Their populations expanded rapidly throughout Europe, and their level of material culture became increasingly more complex and sophisticated. The emergence of fully modern humans in other parts of the world is less understood, though it seems to have occurred 30,000-15,000 years ago and involved various migrations and the intermingling of different populations (see "human evolution" in *Britannica Online*[2]). Agriculture and stationary settlements seems to have appeared ca. 7 000 years ago, while the oldest remains of cities are some 4 000 years.

During this evolution towards civilisation, the Earth has gone in and out of so called *ice houses*, i.e. periods where more or less regular and extensive glaciation has take place. Currently we are in such an ‘ice house’ which started some 1.6 million years ago and we have so far experienced 10 major and 40 minor periods of glacial and interglacial conditions, see figure 9 for a record of ice ages over the last 750 000 years. The most recent ice age ended some 10 000 years ago and the present interglacial is expected to persist over an unusually long period. The ice sheets are not expected to appear for some 50 000 years.

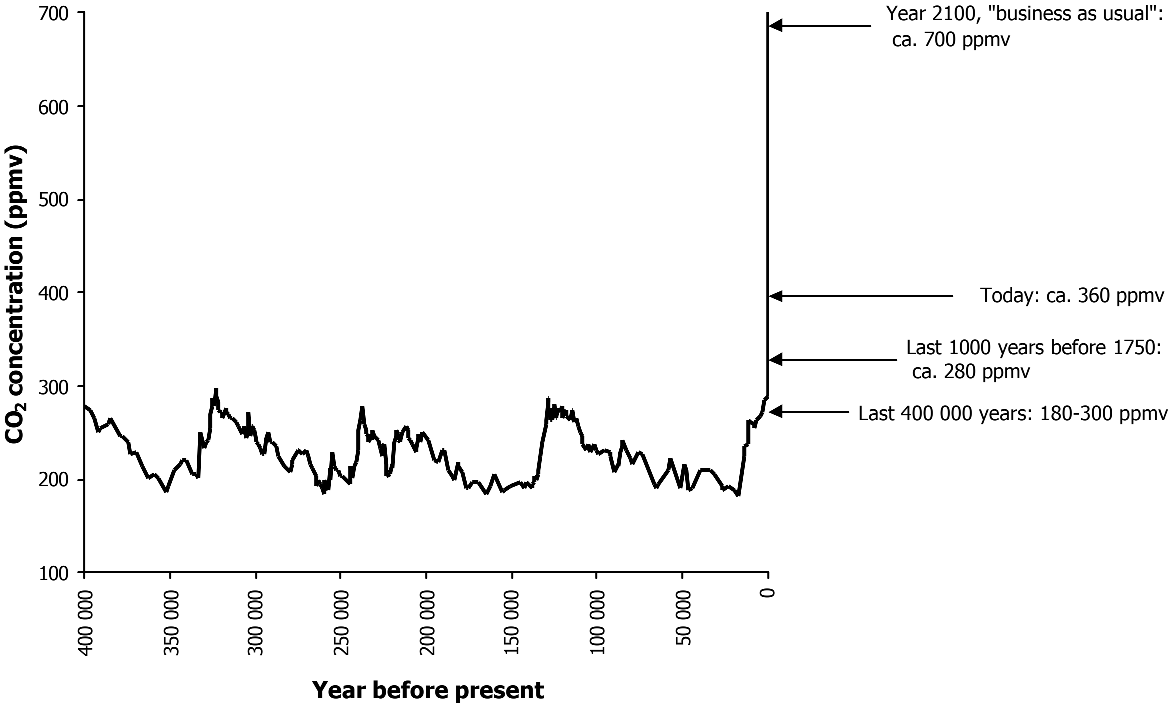

Figure 10. CO_2 concentrations over the last 400 000 years together with current and expected CO_2 concentration levels. Past measurements from Petit et al. (1999)

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[2] http://www.eb.com:180/cgi-bin/g?DocF=micro/281/28.html

After the end of the last ice age the climate not only became generally warmer, but also in an important way more stable (see for instance Severinghaus et al., 1998). There are increasing evidence that not only during cold periods with extended glaciation, but also in the previous warmer inter-glacial periods, the climate was characterised by large variability on a short (decadal) time scale.

Only after the last ice age seems the climate to some extent to have quieted down. It is noteworthy that agriculture only emerged ca. 7 000 – 8 000 years ago, i.e. a couple of thousand years after the end of the last ice age and only after a quieter and more stable climatic period started. This event, or the establishments of cities some thousands of years later, can perhaps be said to represent the start of the civilisation as we know it. Thus, our civilisation has only known our present calm and stable climate.

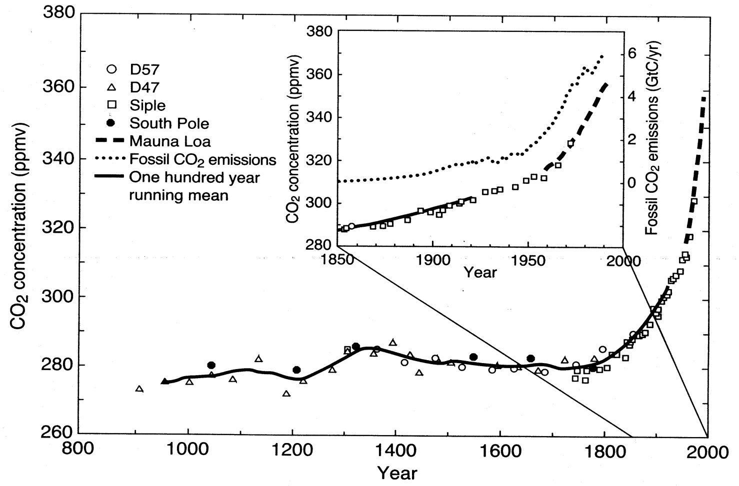


Figure 11. CO_2 concentration over the last 1000 years. Measurements since 1957, ice core estimates for earlier periods.
Source: IPCC (1996).

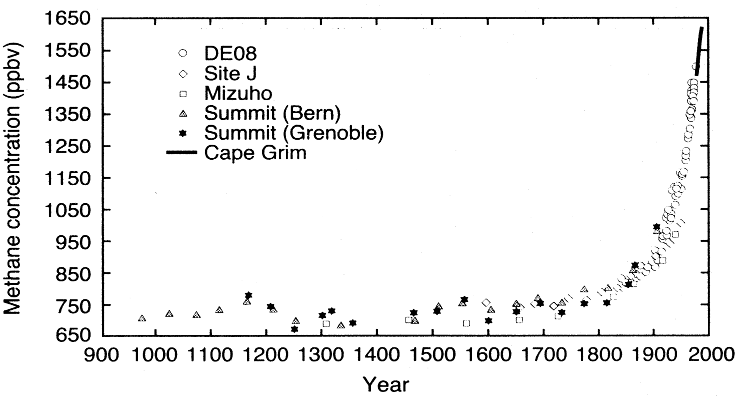


Figure 12. CH_4 concentration over the last 1000 years.
Source: IPCC (1996).

In this context it is instructive to take a look at a graph (figure 10) showing CO_2 levels in the atmosphere during the last four ice ages. Combined with current and future trends in CO_2 levels, the figure gives a vivid picture of the rate of change we are currently imposing on the atmospheric composition. Already, the CO_2 concentration at approximately 360 ppmv is far above anything we have experienced over the last 400 000 years. The near vertical increase in CO_2 concentration also gives an indication of the unprecedented rate of change we now impose on the climate system.

Figure 11 shows the development over the last 1000 years. While the CO_2 levels varied between approximately 190 and 300 ppmv over the last 220 000 years before industrialisation, it has now reached ca. 360 ppmv during the last two centuries (i.e. an increase of ca. 30% from the pre-industrial level).

The concentration of methane (CH_4) has increased even more; 145% since pre-industrial time, see figure 12. The pre-industrial range of variation since 220 000 years before present was 300 to 700 ppbv, while the present level is 1720 ppbv. In addition to these changes, man's activities have introduced new gases to the atmosphere that significantly affect the fluxes of radiation. Of particular importance are the halocarbons containing fluorine, bromine or chlorine.

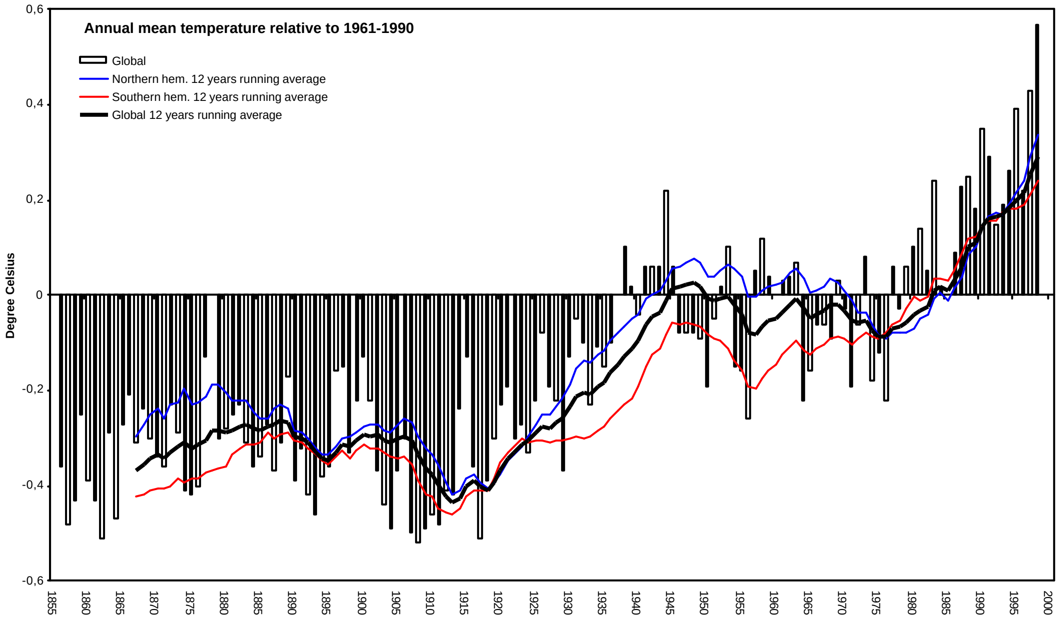
It has generally been assumed that there would be no period in the history of the earth where one could study the effects of a difference in emissions and uptake of greenhouse gasses similar to what is found today. However, this seems to be the case about 55 million years ago. Recent studies (Dickens, 1999, and Norris and U. Rõhl, 1999) have shown some interesting changes during a short period of time where concurrently with a rapid increase in temperature (5-7°C at higher latitudes) there was a decrease in the isotope ratio $^{13}C/^{12}C$. The studies conclude that there was an enormous emission of methane presumably from methanehydrates (these consist of methane gas and water and are stable at low temperatures, high pressure and high methane concentrations). The total emissions are estimated to 1200 - 2000 GtC during less than 10 000 years; probably more than 600 GtC were emitted during less than 1000 years. These emissions exceed both in amount and emission rate the current man-made emissions. From the beginning of the emission period until the earth had returned to pre-event conditions some 140 000 years had passed. The conditions 55 million years ago were of course different from those prevailing today. One must therefore be cautious in using these results to predict effects of toady’s emissions. However, the results are a new reminder that our actions today may affect the conditions on the earth for very many generations.

Taken together with the increasing acknowledgement of the potential natural instability of the climate system, also in warm inter-glacial stages, the picture presented above provides an important piece of motivation for the current concern about climate change and the work undertaken within the IPCC system.

2.3 The present

Returning to the opening statement from the Second assessment report of IPCC that “The balance of evidence, … suggests a discernible human influence on global climate”, it is a fact that the statement drew some criticism. This was partly due to the difficulties encountered when interpreting the current signals on climate change such as global mean temperature, see figure 13. Although the wording of IPCC is very cautious, it remains debatable whether we in fact today observe ‘a discernible human influence’. Recent studies such as those referred to in figure 14 and 15 from Mann et al. (1998, 1999), indicate, however, a steadily increasing role of greenhouse gases as an important explanatory factor behind the observed temperature increase.

What is not in doubt however, barring very large surprises, is that we in the future will see such influence on the global climate. Thus, the debate of the above statement is in a sense spurious and related only to a specific and very short period of time.



Source: P. D. Jones, D. E. Parker, T. J. Osborn and K. R. Briffa, Hadley Centre for Climate Prediction and Research, http://cdiac.esd.ornl.gov/trends/temp/jonescru/data.html

Figure 13. Average global mean temperature relative to the period 1961-1990. 12 years running average for the northern and southern hemisphere together with globale average.

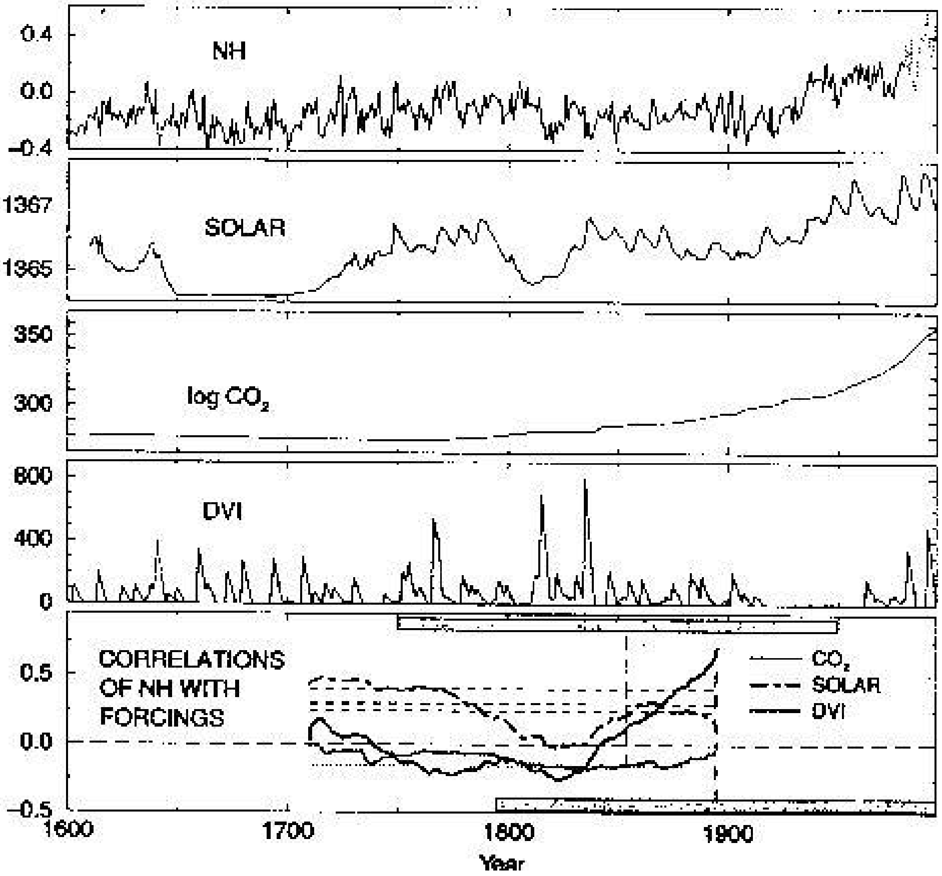


Figure 14. Correlation between Northern Hemisphere temperature (NH), solar intensity, CO_2-concentration and volcanic activity over the last 600 years. The lower panel shows an indication of the contribution to temperature variations from the various factors. Note the increasing role of CO_2. From: Mann et al. (1998)

Building on recent studies, Mann et al. reconstructed hemispheric temperature with proxy data networks for the past millennium. Though expanded uncertainties prevent decisive conclusions for the period prior to AD 1400, the results suggest that the latter 20th century is anomalous in the context of at least the past millennium. The 1990s was the warmest decade, and 1998 the warmest year, at moderately high levels of confidence. The 20th century warming counters a millennial-scale cooling trend which is consistent with long-term astronomical forcing (figure 15).

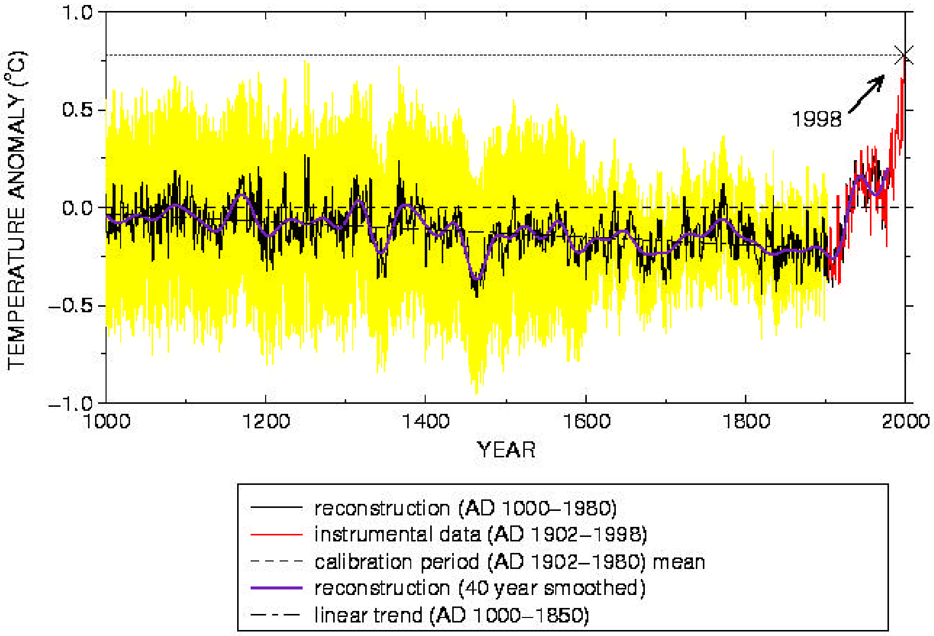
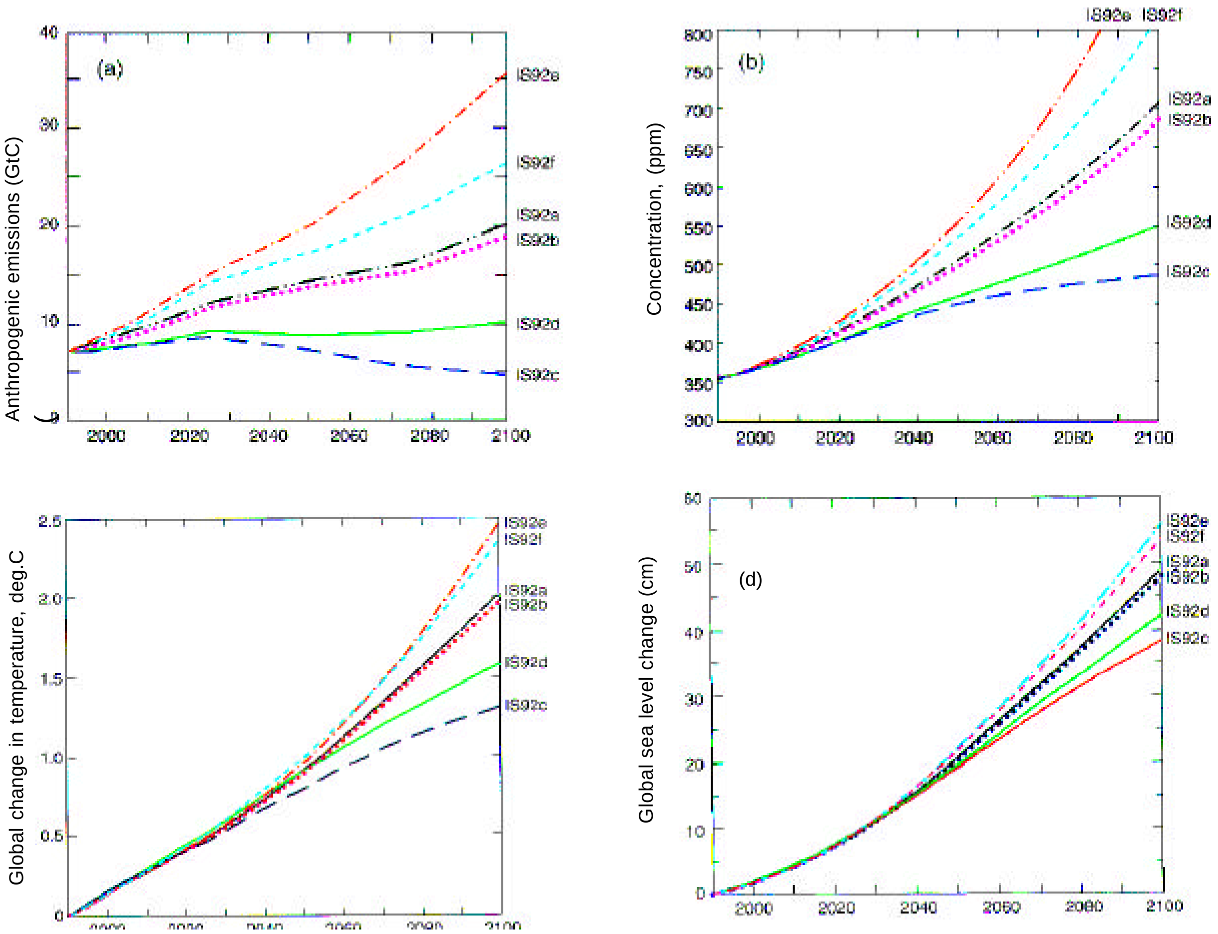


Figure 15. Northern hemisphere temperature anomalies. From Mann et al. (1999)

In addition to the analysis of development in global mean temperature, the statement from IPCC given above, relies also on so-called “fingerprint studies”. Changes in global mean temperature may have several causes, so in order to better understand the different factors behind climate change analyses taking seasonal, geographical and vertical patterns into account were performed. Comparing the results of model studies including the effects of greenhouse gases, sulphate aerosols (direct effect) and stratospheric ozone depletion with the observed patterns of temperature changes gives an indication of man-made effects on the temperature pattern of the atmosphere in time and space. In a study by Tett et al. (1999) they present a quantification of the possible contributions throughout the century from the four components most likely to be responsible for the large-scale temperature changes, of which two vary naturally (solar irradiance and stratospheric volcanic aerosols) and two have changed decisively due to anthropogenic influence (greenhouse gases and sulphate aerosols). The patterns of time/space changes in near-surface temperature due to the separate forcing components were simulated with a coupled atmosphere-ocean general circulation model, and a linear combination of these was fitted to observations. Thus the analysis is insensitive to errors in the simulated amplitude of these responses. Tett et al. find that solar forcing may have contributed to the temperature changes early in the century, but anthropogenic causes combined with natural variability would also present a possible explanation. The temperature change over the past 30-50 years is unlikely to be entirely due to internal climate variability and has been attributed to changes in the concentrations of greenhouse gases and sulphate aerosols due to human activity. It is worth noting that the climate forcing from tropospheric ozone as well as the indirect effect of aerosols have not been taken into account in the fingerprint studies so far. As can be seen from figure 8, these effects are probably significant components of the man-made interference with the energy balance of the Earth-Atmosphere system.

2.4 Future climate change

The future development of our global climate is determined by natural components and by man-made components. Concerning the possible future development of our global climate, IPCC has created a set of more or less likely emission scenarios based on various assumptions regarding population growth, economic development and technological progress to quantify the importance of the man-made components[3]. The implications of these scenarios on some global climate indicators have then been worked out based on our best current knowledge on how the climate system may respond to radiative forcing, see figure 16.



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[3] These scenarios are from 1992. Recently, IPCC WGIII has developed new scenarios to be presented in the Third Assessment Report (TAR) expected in 2001.

Figure 16. IPCC scenarios. The panels shows from top left to right, anthropogenic emission of CO_2, CO_2 concentration in the atmosphere, global change in temperature and global sea level rise. Source: IPCC (1996)

Based on analyses like these, the IPCC estimates that we during the next century may face an increase in mean global temperature of between 1 and 3.5 °C and a sea level rise of between 15 and 95 cm above current levels. The lower figures are obtained by employing a low emission scenario and assuming low climate sensitivity, i.e. a relatively low temperature increase per unit increase in radiative forcing. Similarly, the high numbers stems from combining a high emission scenario with relatively high climate sensitivity. It is worth noting, however, that assumption about future sulphate aerosol concentration (formed from SO_2 emissions) is crucial. Thus, assuming SO_2 emissions to stay constant at the 1990 level in the future, increases the maximum temperature estimate in 2100 to 4.5 °C above 1990 level.

During the last hundred years or so, the mean temperature has increased by approximately 0.6 °C and the sea level has risen by between 10 and 25 cm. However, these global indicators do not really tell us very much about the regional and local effects of climate change. Thus, while

- precipitation is thought to increase under generally warmer conditions, and the distribution of precipitation is probably going to be more extreme in that dry places will get drier while wet places will get wetter,
- the warming will be more pronounced over land than over oceans,
- the warming will be strongest in the north at high latitudes,
- and more days with extreme heat and fewer days with extreme cold are expected,

it is still too early to say with precision *where* these changes will take place. The task of determining the likely regional distribution of a possible global climate change is a main challenge for IPCC at the moment. We should, however, also recognise the possibility of surprises, i.e. the possibility of unexpected behaviour of the climate system as a response to human induced stresses.

2.5 The effects of the Kyoto Protocol

As a response to the threat of climate change, the international community negotiated and agreed on the so-called Kyoto Protocol in December 1997 (although it still needs to be ratified before entering into force). The protocol commits the industrialised countries (the so-called Annex B-countries) to reduce[4] their total greenhouse gas emissions in the period 2008-2012 relative to their 1990 emissions by 5.2 percent. Calculations show that currents commitments under the Kyoto Protocol will have very small effects on future CO_2 levels, temperature change and sea level rise over the next century (Wigley, 1998). In doing these calculations, assumptions are needed on future emission levels beyond the period regulated in the Kyoto Protocol (2008-2012). Wigley based his estimates on three different scenarios: a) No further reductions (designated NOMORE in figure 17), b) Annex-B emissions remain constant after 2010 (B=const.) and c) 1% annual decrease in CO_2 emissions (B=-1%). Furthermore, he explored the impacts of using three different climate sensitivities in the calculations representing various strengths of the internal feedback mechanisms in the climate system. Conventionally, these are measured as increase in global mean temperature in a scenario with CO_2 concentration equal to twice the value in pre-industrial times.

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[4] A few counties, Norway being among them, are allowed to increase their emissions somewhat.

In all cases the estimated reductions in global mean temperature due to the Kyoto Protocol are between 0.08 and 0.28°C for the year 2100, while the reductions in sea level rise are between 1.4 and 6.5 cm (see figures 17a and b).

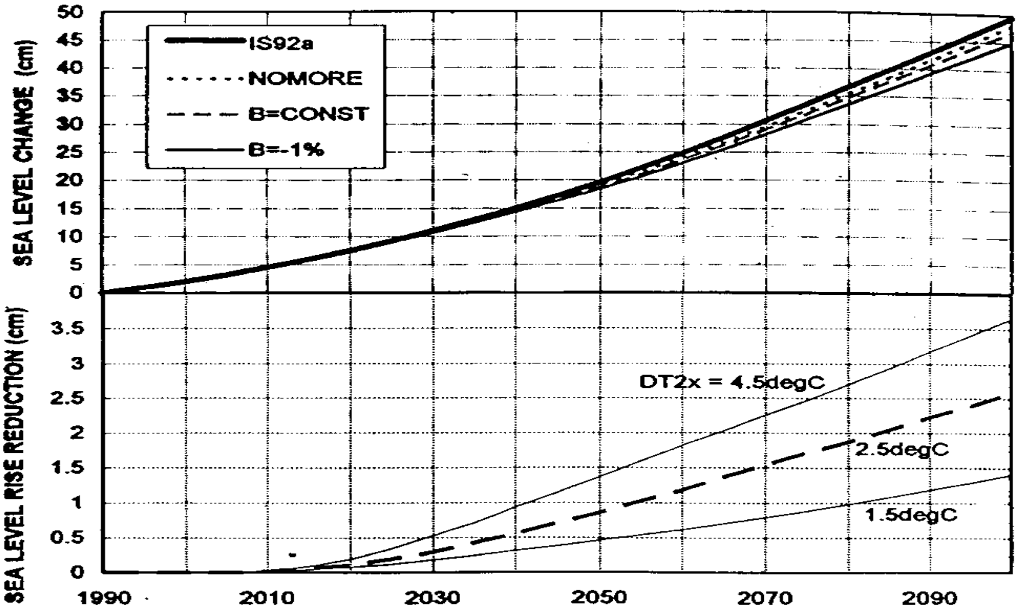


Figure 17a. Upper part of the figure: Global mean sea level changes for the baseline (IS92a) and the extended Protocol emissions cases using a climate sensitivity of 2.5°C warming for 2xCO$_2$. Lower part of the figure: Reductions in global sea level rise in the scenario with constant emissions in Annex B nations after 2010 for climate sensitivites of 1.5, 2.5 and 4.5°C (Wigley, 1998).

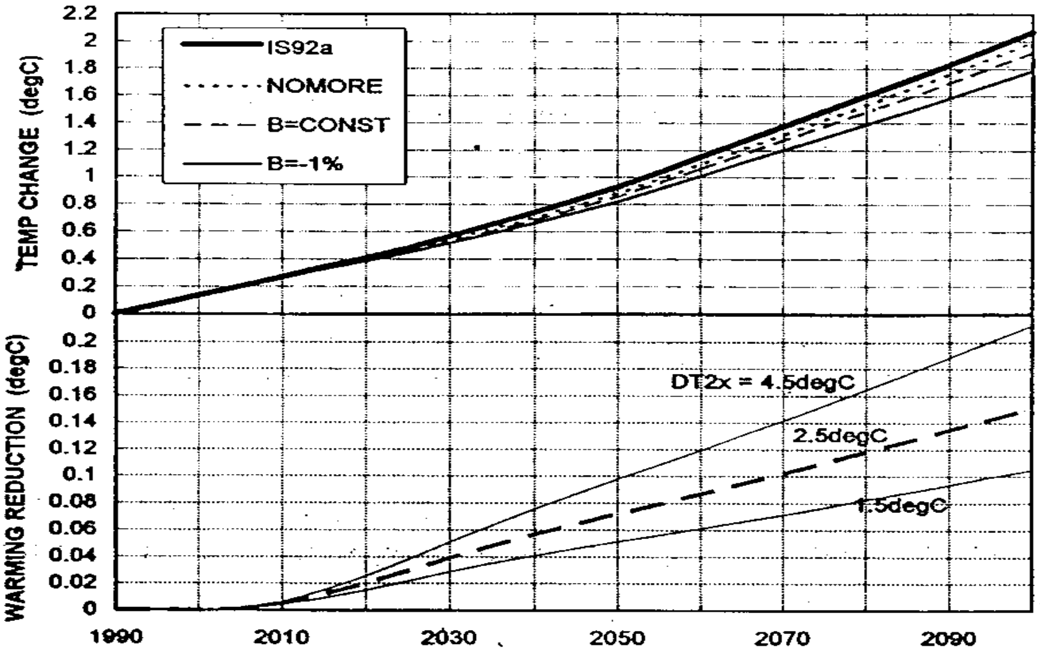


Figure 17b: As figure 17a, but for global mean temperature changes (Wigley, 1998).

2.6 Unresolved scientific questions

As emphasised earlier, the climate system is composed of several sub-systems interlinked in a non-linear fashion. Such systems are known to be able to behave in erratic and surprising ways. Any long-term forecast of climate change is therefore conditioned on the assumption that the system is only perturbed within boundaries where it behaves smoothly in some sense. Imprecise knowledge about where these boundaries are located gives additional uncertainty to the forecasts. However, even within this constraint, several important sub-systems and mechanisms remain less than well understood.

An intriguing part of the climate system in this respect is the clouds. Low altitude clouds are known to be mainly cooling, due to the increased albedo they entail and the relatively high temperature of the cloud tops. This high temperature ensures relatively intense outwards thermal radiation from the clouds. Oppositely, clouds at high altitude with cool cloud tops contribute mainly to global warming since their upward thermal radiation is much less. How increased greenhouse gas emissions, and also emissions of other pollutants leading to aerosol formation, affect the formation of clouds at different altitudes and their optical properties, is not well understood. Varying assumptions related to these mechanisms are often the main explanation why different climate models predict different increases in the mean global temperature from the same increase in greenhouse gas emissions.

Another indication on our incomplete knowledge of the climate system is the discrepancy between trends in observed surface temperatures and satellite measurements of the temperature of the lower troposphere (close to ground level). While unambiguous global warming over the last few decades is observed at surface stations, the satellite observations of the lower troposphere are more ambiguous (Christy, 1998). This may be a sign that the thermal coupling between the surface and the lower part of the atmosphere is more complex than assumed in most of the currently operating climate models. It may also indicate that the technique behind monitoring temperatures from satellites still is at an early stage. Over the last years, several corrections and improvements of the satellite series have been done, leading to a better agreement with the surface measurements. In addition to the temperature records mentioned above, surface temperature trends have been derived from temperature measurements in boreholes. The studies indicate that the Earth’s mean surface temperature has increased by about 0.5 °C in the 20th century and that this century has been the warmest of the past five centuries (Pollack et al., 1998).

Other substantial questions are related to the coupling of the atmosphere and the oceans, and the many natural cycles observed in the oceans (El Niño, North Atlantic Oscillation, etc.). These have a great impact on the regional climate. However, the coupling to the development of global climate change and vice versa is still unclear. Similar uncertainty exists with regard to the coupling to the biosphere and its responses to climate change.

Finally, the role of changes in solar activity is still not clear. As mentioned in section 2.1.1 there are some indications that the influence solar activity on our climate is incompletely understood at present.

Perhaps a good illustration of our incomplete understanding can be found in the temperature increase observed between 1910 and 1940 in the historical record, see figure 13. Certainly a better understanding of climate change over this period will increase our ability to predict future climate change with greater precision.
Regardless of our incomplete understanding of the climate system, some conclusions can be stated with a high degree of confidence (see also Box 3).

- The climate system, as an important part of the natural environment, has a major impact on our civilisation and way of life. Without a reasonable stable climate our way of life is going to be difficult, perhaps even impossible in the present form.
- We are currently interfering significantly with the climate system. Although this can not be proven beyond doubt at the present, the interference is steadily increasing over time. A possible transition to a more unstable climatic regime can not be excluded as a consequence of this disturbance. The potential adverse effects of such a change in climatic regime, make it reasonable to adopt a defensive attitude.
- Adoption of a defensive attitude is dependent on political and public acceptability. Thus, a main priority at present is to bring forward scientific information about what is known and what is currently unknown to the public at large and the political decision makers in particular.

Box 3. Knowledge status

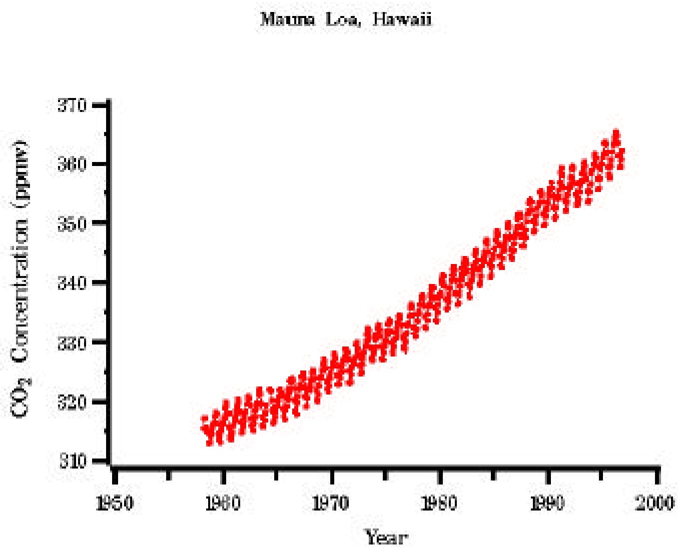
This we know	**This is probable**	**This is uncertain**
• We do have a *natural* greenhouse effect caused by the presence of clouds and greenhouse gases in the atmosphere. The most important greenhouse gases are: H_2O, CO_2, CH_4, N_2O and O_3. • Since pre-industrial times the concentrations of CO_2, CH_4 and N_2O have increased by 30%, 145% and 15%, respectively. • Over the last 100 years the mean global temperature has increased by 0.3-0-6 °C with a series of record breaking years in the late 1980s and the 1990s. • The sea level has increased by 10-25 cm	• Anthropogenic emission of greenhouse gases has probably contributed significantly to the observed changes in climate. • With current development in emissions we can expect by year 2100: - Global increase in temperature of 1-3.5 °C. - An increase in sea level of some 15-95 cm, and additional increased after 2100. - Loss of agricultural land. - Changes in precipitation patterns. - Changes in eco-systems. - Increased frequency of certain illnesses, e.g. malaria.	• Large and abrupt changes in climate have happened previously in the Earth's history. We know little of the causes of these changes. • The are large uncertainty regarding the regional impacts of a change in the global climate. • There is a lack of knowledge about - The feedback mechanisms, in particular related to the humidity of the atmosphere and cloud formation. - The cooling effects of aerosols and sulphur emissions. - Links to the sunspot cycle. - Impacts on and effects of hurricanes and

over the same period.		other extreme climatic events. - Changes in strength and pattern of the oceanic currents.

3 IPCC: The background, organisation and procedures

3.1 Background: The history of the establishment of IPCC

Scientific recognition of the potential of human activity to modify climate dates back at least to the early nineteenth century. Thus, in 1827, Baron Jean-Baptiste Fourier suggested that human activity can modify surface climate, and he was perhaps the first to suggest the now well known greenhouse effect of the atmosphere (Fourier, 1827, Ramanathan, 1988). The greenhouse theory of climate change was, however, only taken up in earnest later in the last century when in 1896 the Swedish scientist Svante Arrhenius published his first estimate of a man-made global temperature change caused by industrial emissions (Arrhenius, 1896, Rodhe et. al., 1997). His main insight was that burning of fossil fuels and the release of CO_2 could affect the escape of heat from the Earth.



Source: Dave Keeling and Tim Whorf (Scripps Institution of Oceanography)

Figure 18. Measurements of CO_2 concentrations at Iouna Loa, Hawaii

The next milestone can perhaps be said to relate to research carried out by Roger Revelle and Hans Suess at the Scripps Institute of Oceanography. Their research indicated that the oceans only seem to absorb about half on the man made CO_2 emissions to the atmosphere. This research led in turn to the establishment of a monitoring network under the guidance of Charles Keeling from the same institute. This monitoring firmly established that the CO_2 concentration in our atmosphere is increasing and is now far above the level believed to have existed in pre-industrial times (280 ppmv), see figure 18.

Scientific interest in man's potential impact on global climate was stirred by the research and monitoring initiated in the 1950's, and this interest was further mobilised through conferences, loose research networks and assessments especially from the 1970's onwards (Agrawala, 1998a, b).

The starting point for the recent international efforts to better understand climate variations and the possible problem of a human-induced climate change is generally regarded to be the UN Conference on Human Development in Stockholm in 1972. At this conference results from a numerical climate model predicting climate development into the next century were presented. Further refinement of this type of model, together with a report from the University of East Anglia highlighting that the 1980s contained several of the warmest years in the historical record, created widespread concern about climate change as a man-made global environmental problem.

In 1979 the World Climate Conference was held in Geneva, and the World Climate Programme (WCP) was launched. The creation of the WCP set forth a series of workshops held in Villach, Austria, in 1980, 1983 and 1985, and organised under the auspices of the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP) and the International Council of Scientific Unions (ICSU) (Agrawala, 1998). At the 1985 Villach meeting an international group of scientists reached a consensus that, as a result of the increasing concentrations of greenhouse gases in the atmosphere, a rise in the global mean temperature "greater than any in man's history" could occur in the first half of the next century. This group of experts also stated that "…the understanding of the greenhouse question is sufficiently developed that scientists and policy-makers should begin active collaboration to explore the effectiveness of alternative policies and adjustments" (WMO, 1985).

In combination with a set of other factors, especially anomalous weather conditions in Europe and America, the 1985 Villach meeting was instrumental in bringing the climate issue onto the international political agenda. In 1986 the Advisory Group on Greenhouse Gases (AGGG) was set up under the joint sponsorship of WMO, UNEP and ICSU. Each of these bodies nominated two experts, and the panel consisted of six members: Gordon Goodman, Bert Bolin, Ken Hare, G. Golitsyn, Sukiyoro Manabe and M. Kassas (Agrawala, 1998).

During the latter half of the 1980's the climate issue increasingly gained saliency among the public, scientists and policy-makers, not least through the work of the so-called Brundtland commission (WCED, 1987). At the Toronto Conference of the Atmosphere, where more than 300 scientists and policy-makers from 48 countries, UN organisations, IGOs and NGOs participated, an explicit policy recommendation calling upon national governments to reduce CO_2 emissions by 20% from 1988 levels by 2005 was agreed upon.

Meanwhile, the WMO and UNEP in close co-operation with various US agencies agreed that an intergovernmental mechanism was needed to undertake further internationally co-ordinated scientific assessments of climate change, and invitations to governments to the first session of the Intergovernmental Panel on Climate Change (IPCC) were sent out early 1988. The first plenary session of the IPCC took place in November 1988. The AGGG set up in 1986 was gradually replaced by the IPCC and has not met since 1990.

3.2 The function and products of the IPCC

The main function of the IPCC is to provide assessment reports of state-of-the-art knowledge on climate change. The objective of the IPCC, as formulated by the governing bodies of WMO and UNEP, is twofold:

i) To assess the scientific information related to the various components of the climate change issue and the information needed to evaluate the environmental and socio-economic consequences of climate change, and

ii) To formulate “realistic response strategies for the management of the climate change issue” (Report of the first session of the IPCC).

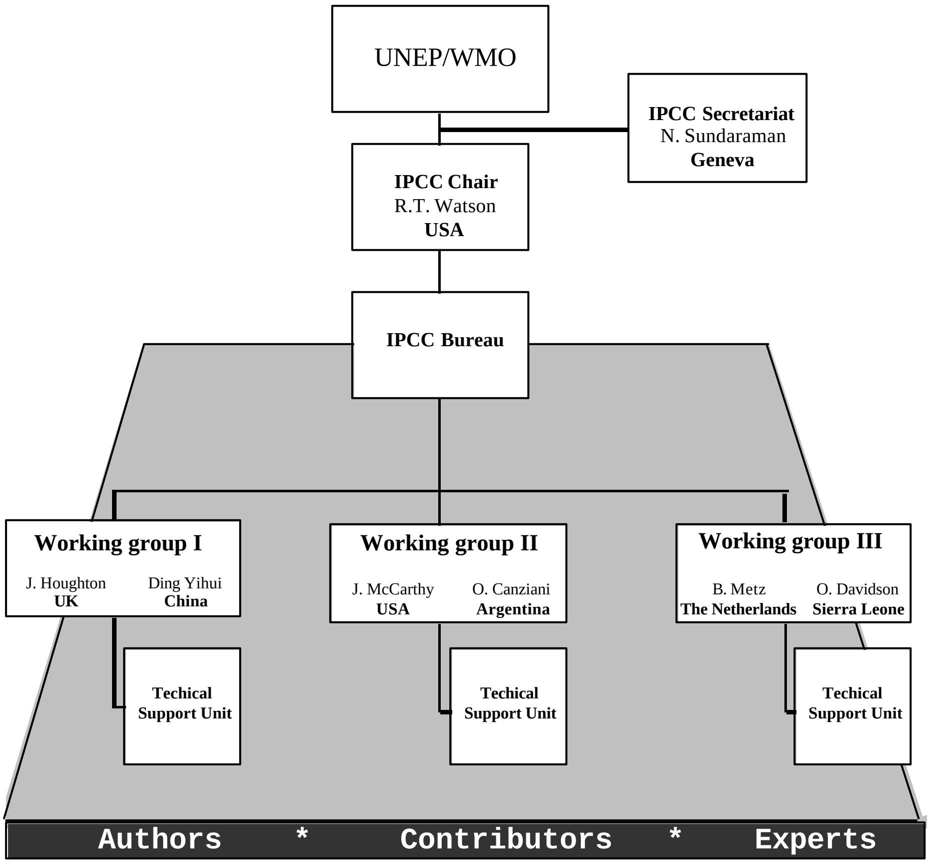


Figure 19. IPCC organisation

In 1988, three Working Groups (WGs) were set up to attain this objective (figure 19):

- *Working Group I (WGI)* was assigned the task of assessing available scientific information on climate change,
- *Working Group II (WGII)* was assigned the task of assessing environmental and socio-economic impacts of climate change, and
- *Working Group III (WGIII)* was assigned the task of formulating response strategies.

In 1992, the IPCC structure was slightly changed: Working Groups II and III were merged in Working Group II, while a new Working Group III was set up to deal with socio-economic and other cross-cutting issues related to climate change.

IPCC has as one of its main tasks to assess “scientific information”. All IPCC WGs conduct assessments on the basis of published literature within relevant fields and disciplines. Thus, IPCC do not, contrary to a common misunderstanding, carry out scientific research. Furthermore, the term “scientific information” is generally taken to mean that only published or other peer reviewed scientific material is taken into account.

In connection with the planned Third Assessment Report (TAR), a slight readjustment of the mandate for the three working groups has been suggested as follows:

- Working Group I will assess the *scientific aspects* of the climate system and climate change (as before);
- Working Group II will assess the scientific, technical, environmental, economic and social aspects of the *vulnerability* (sensitivity and adaptability) to climate change of, and the negative and positive consequences (impacts) for, ecological systems, socio-economic sectors and human health, with an emphasis on regional sectoral and cross-sectoral issues;
- Working Group III will assess the scientific, technical, environmental, economic and social aspects of the *mitigation* of climate change, and through a task group (multi-disciplinary team), will assess the methodological aspects of cross-cutting issues (e.g., equity, discount rates and decision making frameworks).

Box 4. IPCC reports:

- *Assessment Reports*: The full scientific assessment with status as "Reports accepted by WGs". Accepted by WG plenary, but not subject to discussion.
- *Executive summaries and Summaries for Policy-makers*: Summaries of the full scientific assessment with status as "Reports approved by WGs and accepted by the Panel". Subject to line-by-line approval by WG plenary. Accepted by full panel plenary, and not subject to discussion at this decision-making level.
- *Synthesis Reports*: Synthesis of the reports of all WGs, developed by the WG leadership in co-operation with lead authors and specially invited experts with status as "Reports approved by the Panel". Subject to line-by-line approval by full panel plenary.
- *Special Reports*: Assessments on special issues. Subject to the review, acceptance and approval procedures of the assessment reports in general.
- *Technical Papers (since 1995*): Reports on specific issues, based on existing assessment reports, not submitted to the acceptance and approval procedures of the assessment reports.

The main products of IPCC are the assessment reports. However, also other types of reports are produced, see box 4. The First IPCC Assessment Report was presented to the Second World Climate Conference in 1990, where it was accepted as an adequate basis upon which to start climate negotiations. The first step was the Framework Convention on Climate Change (FCCC) agreed upon in Rio de Janeiro in 1992. In December 1995, the IPCC Plenary accepted the Second IPCC Assessment Report in time for the negotiation of the Kyoto-Protocol finalised in December 1997. Work on a Third Assessment Report (TAR) is underway (current work plans suggest finalisation in 2001).

3.3 The Assessment Process

The IPCC is organised in three decision-making levels that serve different functions in the assessment process: the "scientific core", the WG plenaries, and the full panel (IPCC) plenary at the top of the institution, see figure 20.

At WG and panel plenaries, all UN members and members of the IPCC's two sponsoring organisations, the WMO and UNEP, can participate. Participation at these levels is, therefore, in principle open. Governmental authorities nominate all members of national delegations.

At the start of an assessment process, the leadership of each WG develops a work-plan for the assessment, which is subsequently approved by the plenary of the WG and accepted by the full panel plenary. Governments nominate teams of lead- and contributing authors. The bureau (chair and vice-chairs) of each WG select lead authors from the nomination lists provided by governments. Contributing authors may also be specially invited; however, with due consideration of the geographic balance of the groups, particularly with regard to ensuring participation by scientists from developing countries. Lead authors participate in their personal capacities.

The assessment reports are developed in the scientific core of the IPCC, in a series of meetings in task forces and sub-groups established for particular issues, workshops and conferences, and most importantly, in regular lead- and contributing author meetings. The summaries to the assessments – the summary for policy-makers and the executive summary – are also developed at this level. Scientists active in research dominate participation in the scientific core.

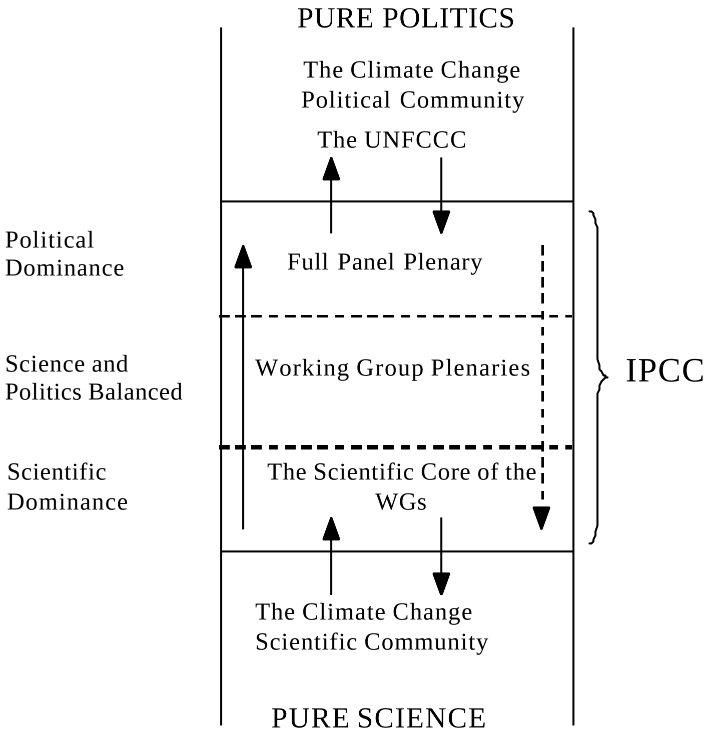


Figure 20. The different levels of the IPCC process

When a draft report has been developed, it is submitted to an extensive, two-phased review procedure, including both expert and government review. According to the rules of procedure of the IPCC, lead authors, WG chairs, sub-group chairs and vice-chairs are responsible for incorporating comments from the review "as appropriate". In this regard, lead authors, chairs and vice-chairs are encouraged to arrange wider meetings with principal contributors and reviewers to discuss particular aspects or areas of major differences, as deemed necessary and if time and funding permits. It is also emphasised in the rules of procedure that the assessment reports "describe different (possibly controversial) scientific or technical views on a subject, particularly if they are relevant to the political debate".

The revised draft of the assessment and its summaries are then submitted to the WG plenary for acceptance and approval. At this level, the discussion takes on quite a different character. While the full scientific assessment report is accepted by the plenary en bloc and usually without further discussion, the summaries – the Executive Summary (ES) and the Summary for Policy-makers (SPM) – undergo a detailed and time consuming revision where the formulations of the documents are discussed and negotiated line-by-line.

The main bulk of participants to WG plenaries are national delegations, comprising government officials, low-level policy-makers and/or scientists with governmental affiliations. National governments to a varying extent send independent scientists as members of national delegations to WG plenary meetings.

Mainly representatives of the teams of lead authors represent scientists at this decision-making level. Lead authors have acquired a special status as authorities in the debate, and substantive changes to the text of the summaries are not made without consent from the lead authors of the chapter in question. Thus, while government officials at this level may outnumber scientists, the scientists still have a significant amount of “control” over the documents.

The WG plenary discussions represent the first step towards acquiring a political acceptance of the knowledge base developed in the scientific core and its substantive conclusions. Having undergone this thorough and detailed treatment, where alternative formulations and interpretations of the corresponding formulations in the bulk report have been discussed and negotiated, the substantive conclusions of the knowledge base are in a sense “tried out” and “digested” by policy-makers. Having survived this intense scientific and political scrutiny with their scientific credibility and authority intact, the substantive conclusions come out as more robust.

The accepted and approved assessment report and summaries are then submitted to the full panel plenary for acceptance. The full panel plenary can not, however, amend a report that has been accepted or approved by the WG plenary. This institutional device, formally established in the 1993 revision of the IPCC rules of procedure, is important for ensuring consistency between the summaries and the assessment report upon which the summaries are based. At the WG plenary, lead authors’ scientific authority is used as a vehicle for ensuring this consistency and also to prevent scientifically unsubstantiated formulations from entering the summaries. While lead authors usually participate at the WG plenary level, they usually do not participate in the full panel plenary meetings. The inability of the full panel plenary to amend text that has been approved by the WG plenaries also prevents the reopening in the full panel plenary of controversial issues already settled in the WG plenaries.

Thus, while the assessment process is formally finalised with the acceptance of the assessments and summaries by the panel plenary, it is in practice finalised with the acceptance and approval of the reports by the WG plenary (according to the 1993 rules of procedure).

The panel plenary also approves the Synthesis Report drafted by the leadership of each of the three WGs in co-operation with a specially invited group of scientists, lead authors and experts. The 1995 Synthesis Report was developed and discussed at several conferences with broad participation. The procedure by which consensus on the Synthesis Report is developed in the panel plenary is, in form, similar to the negotiations taking place in WG plenary meetings. A notable exception is the near absence of scientists at this decision-making level. This places a special burden and challenge on the members of the drafting team that are present and the scientific leadership of the WGs and the panel.

3.4 Decision Rules and Recruitment Procedures

The IPCC has been criticised for forging a scientific consensus in an area characterised by scientific uncertainty and controversy. The scientific core of the IPCC, in which the assessments are developed, does not, however, operate under a consensus rule. On the contrary, a fair representation of the scientific debate is regarded as a main objective. The development of an assessment which reflects the scientific debate with its inherent uncertainties and controversies and which, thus, is acceptable to all parties in the debate is considered an important objective of the IPCC process. In this regard, therefore, the IPCC assessments may be considered a consensual representation of state-of-the-art knowledge in the fields covered.

The IPCC plenaries, on the other hand, operate under a decision rule of consensus. The 1991 rules of procedure state that, “in taking decisions, drawing conclusions, and adopting reports, the IPCC Plenary and Working Groups shall use all best endeavours to reach consensus.” Furthermore, in the 1991 rules of procedure it is stated that, “if consensus is judged by the relevant body not possible…for conclusions and adoption of reports, differing views shall be explained and, upon request, recorded.” (“Principles governing IPCC work” from 1991, item 6). Thus, in cases where consensus can not be achieved, dissenting views may be recorded in footnotes to the text. In WGI, however, this has never been necessary. Even in the most fierce discussions, WGI has largely managed to develop formulations acceptable to all parties[5]; government officials as well as scientists.

The lead authors of the IPCC have a major responsibility in the development of the assessments, as well as in the WG approval of the summaries. They are key players in the selection of contributors and expert reviewers (and also, on some occasions, in the selection of other lead authors). Above all, they bear the main responsibility for incorporating into the assessments all scientifically substantiated viewpoints and findings of the scientific community, as communicated to them by contributors and reviewers, in a representative and balanced manner.

While lead authors are selected from lists of nominations by governments, the actual choice lies with the scientific leadership of the WGs. Scientists not on the nomination list are never chosen as lead authors, but the IPCC leadership have on some occasions approached governments to have particular scientists nominated (personal communication with Bert Bolin). The procedure whereby lead authors are chosen has become increasingly formalised during the course of the process, but even with the formalisation of procedures in 1993, there are relatively few formal requirements guiding the choice. It is, however, emphasised that due consideration is given to scientists “known through their publication or work”. The “technical ability” of the lead

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[5] There are some footnotes of dissent in the Synthesis report.

author and their "ability to work to deadlines" are also emphasised as important criteria. Finally, it is pointed out that teams of lead authors "should reflect a fair balance of different points of view".

4 Concluding remarks: On the nature of the climate problem

The much-discussed expected increase in global temperature is an important aspect of the problem of climate change. However, it must be taken into account that local effects on temperature and precipitation may be much more severe. Perhaps even more important is the potential variability and instability of the global climate and the local weather. We now know that the climate system in the past has shown great and rapid fluctuations for ‘natural’ causes. The relatively stable climate regime observed after the last ice age is currently perturbed by the large outpouring of greenhouse gases due to human activities of many kinds. The question then is whether the stability of the current climate regime is able to withstand this kind of disturbance. The answer to this we really do not know at present. Furthermore, if the climate system should change to a more unstable regime, it is very difficult to predict the local and even regional consequences with any precision. Thus, the problem of climate change is riddled with uncertainties, and the main challenge for us in this situation is to devise a rational response to this uncertainty. Certainly we should be willing to pay some form of insurance premium in order to reduce the risk of damaging climate change, but how high a premium? And how much of the premium should be in the form of greenhouse gas emission reductions and how much in the form of investments in better defence against a more unstable climate?

IPCC’s work is important in allowing us to get a best possible scientific foundation for answering these questions. However, providing an academic answer is one thing, to get a politically feasible answer is another. The merging of the scientific knowledge and the political realities is therefore necessary, and the processes in the plenary sessions of IPCC are therefore important steps in the direction of providing practical answers to the challenge of climate change.

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