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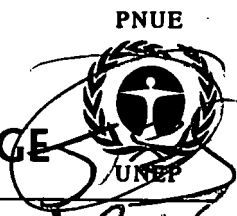
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INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



First Meeting of the
IPCC Drafting Team
Athens, 1-3 May 1995

DOCUMENTATION ENCLOSED

1. Agenda
2. Letter from Prof. Bolin
3. Zero-order draft of the IPCC Synthesis Report (ISR)
4. Timetable for the completion of the ISR
5. Draft Summary for Policymakers of the contribution of Working Group I to the IPCC Second Assessment Report (This is yet to undergo the reviews; the peer and governments' reviews will be combined in a single operation.)
6. Draft Summary for Policymakers of the contribution of Working Group II to the IPCC Second Assessment Report (This has undergone peer review and is undergoing government review; deadline for receipt of the governments' reviews is 28 April.)
7. Summaries for Policymakers and Other Summaries of the IPCC Special Report (1994).

YOU WILL RECEIVE IN ATHENS:

- * the revised final draft Summary for Policymakers of the contribution of Working Group III to the IPCC Second Assessment Report. This has undergone the peer and governments' reviews;
- * Report of the Fortaleza Workshop on Article 2 of the FCCC.

N. Sundararaman
Secretary of the IPCC
20 April 1995

Meeting with Lead Authors and Contributing Authors to
IPCC Synthesis Report 1995

Athens, 1-3 May 1995

Agenda

1. Opening of the meeting and welcome to participants
2. Presentation of the purpose of the meeting. The character and structure of the Synthesis Report as envisaged by the IPCC Chairman and Working Group Co-chairmen. Discussion.
3. Discussion of Chapters 1 through 6, writing assignments.
4. Draft of Summary for Policy Makers.
5. Reassessment of the Synthesis Report as a whole.
6. Time table for preparation of next draft and its circulation for peer review.
7. Preparations for second meeting, 3-5 July 1995.
8. Time table for completion of the report.
9. Meeting adjourned.

Meeting with Lead Authors and Contributing Authors to
IPCC Synthesis Report 1995

Athens, 1-3 May 1995

Material available for meeting participants.

1. Zero-order draft of report

This draft is a "strawman" prepared for the initiation of discussions. Its structure has been based on suggestions from the lead authors (the IPCC Chairman, the IPCC Secretary, the Co-chairmen of the three Working Groups and the heads of the Technical Support Units). Still, it can of course be modified.

The total length of the report is expected to be 35-40 pages of the present size, i.e. 13,000 to 15,000 words. In addition there would be about 10 figures and perhaps some tables. It is important that the writing be carefully based on the material in previous IPCC Reports and in the Second Assessment that is presently being prepared. In order to provide for smooth reading, references will be made through footnotes to a reference list at the end of the report. Wherever "(note)" is found in the present text, there would be a footnote as indicated at the beginning of the draft.

It is my intention that we produce a report that will have a clear line of logic: "A story is being told". It will then be more widely read. This does not mean that it should be very general and sweeping in its character. Details are important, although not in an amount that would become a burden for the reader. The present writing does not yet satisfy these criteria. Some details have been included in order for the draft team to fully understand my reasoning. I am indeed looking forward to constructive criticism.

Some sections of the report have been drafted, other parts may be available in draft form at the beginning of the meeting. These should be discussed in detail.

Other sections will be prepared by participants at the meeting and be incorporated later into the report.

The report as a whole is the responsibility of the lead authors with full recognition of the role of the other participants in the Athens meeting as contributing authors. It need not be approved line by line in an IPCC plenary session, but merely "accepted". We are, however, obliged to consider comments that will be received in the scientific peer review process as well as in the government review and to try to accommodate them, if they have scientific support in the basic material found in the Second Assessment Report (see further below). The Summary for Policy Makers (3-5

pages), on the other hand, does require formal line-by-line approval of the IPCC in plenary.

2. Latest version of the Summaries for Policy Makers of the Second Assessment Report (SAR) as prepared by the three IPCC Working Groups. Some have been distributed, some will be available at the meeting. The full report is a bulky document in three parts and consisting of altogether about 60 chapters. It will be the responsibility of the heads of the Technical Support Units to make sure that there is proper interlinkage between the Synthesis Report and these supporting documents.

3. Report from the IPCC Special Workshop on Article 2 of the United Nations Framework Convention on Climate Change, held in Fortaleza, State of Ceará, Brazil, October 17-21, 1994.

Looking forward to seeing you in Athens!

Stockholm, 20 April 1995



for

Bert Bolin
Chairman of the IPCC

IPCC 1995 SYNTHESIS REPORT

Scientific and Technical Information to Serve as a Basis for Analysis and Interpretation of Article 2 Objectives of the Framework Convention on Climate Change

SUMMARY FOR POLICY MAKERS

Conclusions. Total length 3-5 pages. To be discussed at the Athens meeting and a first draft to be prepared.

1. Why do we care about the climate?

Man's fundamental dependence on nature and climate.

During the six to eight thousand years that have gone by since the last ice age ended, the human race has developed from some tribes scattered over the various continents probably constituting merely some few million people, to about 5,500 millions today that are found everywhere where food and adequate shelter can be secured. The distribution of the world population today is obviously primarily determined by climate, the availability of water and of soil for food and fibre production. Climate has been changing during this post-glacial time but not markedly so and quite slowly. People have largely adapted to prevailing conditions including seasonal variations and interannual variability, but extreme events may still cause serious damage particularly in developing countries.

The development of industrialization in parts of the world during the last few centuries has provided new tools for the exploitation of natural resources, which in a sense has made people more protected against the variable weather, while less and the least developed countries still often are victims to unexpected changes. On the other hand, the security in the developed countries has largely been built on past experience of variations of weather and also the modest changes of climate that have occurred. Recent major investments in modern technology have made these countries more vulnerable to extreme events, since variability has not been considered adequately in the course of the development of today's social structures. There are numerous examples of this (note).

Many people have an intuitive sense of the importance of climate for their well being. This is of course particularly so for those working in the sectors of society that are directly exploiting the living resources of nature, i.e., agriculture, forestry and

fishery. They have learned from past experience and more recently, particularly in developed countries, also been able to take advantage of research and development in their pursuits for securing a living. However, in many developed countries, merely some three to five percent of the population are today engaged in providing the rest of the people with food, while on the other hand, many developing and particularly the least developed countries still employ more than half of their population in this sector of society. They therefore also differ markedly with regard to their vulnerability to climate variability and change. Rich countries can more easily buy what is not available nationally.

But we are dependent on nature not only for supply of goods for our basic needs. It also constitutes a fundamental part of our life in all its different cultural forms around the globe.

It is becoming increasingly clear that there is a genuine risk that man is changing the global climate. What may such a change of climate imply for people, countries and for the world as a whole? Will the present distribution of terrestrial and marine ecosystems change? How will availability of food and water change? Will storms become more frequent or not? Is there going to be an increased risk for floods in coastal regions? Will there be more heat waves and droughts, heavy rainfalls and floods or may a climate change in some places even be more benign? Will peoples' health be affected? Concerns of this kind are becoming more common.

The Framework Convention on Climate Change has been negotiated and agreed to serve as an instrument to address these global issues. It is a prime task for the IPCC to serve this political process by providing assessments of scientific and technical information that is relevant in this context. A first assessment¹ was published in 1990 and a Supplementary Report² became available in 1992. As a preparation for the first session of the Parties to the Framework Convention on Climate Change a Special Report³ was issued in 1994. A Second Assessment Report (SAR) is becoming available in 1995. The present report, however, has a more limited but not less important aim in considering information of relevance in an analysis of the Article 2 of the Convention on Climate Change, i.e.: the Objectives of the Framework Convention on Climate Change⁴.

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Article 2: Objectives

The ultimate objective of this Convention and any legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference of the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

The analysis is based on the earlier IPCC assessment reports and in particular the Second Assessment Report (SAR), of which this report is a part. SAR brings together present knowledge from all relevant fields of science, including the socio-economic sciences, and also gives an account of technological progress. The present report in the other hand, attempts to extract those aspects of this general over-view that are of crucial importance for addressing the issue of stabilization of greenhouse gases in the atmosphere as defined in the Article 2 of the Convention. The presentation is given in a more sequential form and is intended for Policy Makers in addressing this particular issue, especially when considering the issue of the adequacy of commitments as required in the Convention.

2. Why are we concerned? – What is happening?

2.1 Man is changing the concentrations of greenhouse gases and aerosols in the atmosphere

We know for sure that the composition of the atmosphere is changing. The following changes of concentrations of greenhouse gases and aerosols have been observed (note):

- Carbon dioxide has increased from about 280 ppmv (note) about 200 years ago to 358 ppmv in 1994 , i.e., by about 28%.
- Methane has increased from about 0.72 to 1.70 ppmv during this same period, i.e., by about 145%. About 25% of the anthropogenic emissions (which are about twice as big as the natural preindustrial emissions) are related to fossil fuel use and about 75% to our use of biospheric carbon (in agriculture, forestry and handling of biogenic waste, etc).

- Nitrous oxide has increased from about 0.275 to 3.10 ppmv, i.e., by 13%. The anthropogenic emissions primarily come from cultivated soils, cattle and feed lots, about 70% (most of which is emitted in developing countries), while industrial emissions account for about 20% and biomass burning about 10%.
- CFC-gases have increased to ???, but will probably stabilize within a few years due to the agreements reached within the framework of the Vienna Convention in the protection of the ozone layer. Their substitutes also act as greenhouse gases, but their life times in the atmosphere are much shorter and their concentrations still negligible (note)
- Stratospheric ozone has decreased by about 6% due to the increase of chlorine and bromine compounds in the atmosphere. The decrease in polar regions, particularly over the Antarctic during austral spring is, however considerably larger (up to 60%), while it is less in tropical and subtropical latitudes at most a few percent (note).
- Tropospheric ozone has doubled or tripled in and around industrialized regions, which is closely associated with the increasing air pollution in these areas.
- Sulphate aerosols have increased in spite of the reductions of sulphur emissions by developed countries because of their acidification of precipitation, rivers, lakes and soils. Sulphate aerosols and other aerosols stay in the atmosphere only for days to weeks and so are their negative contributions to a change in the radiative forcing. Sulphate aerosols are formed from sulphur dioxide primarily emitted when oil and coal are burned and are accordingly primarily found in and around regions with high fossil fuel use.
- Other aerosols have been increasing because of wide-spread burning of grassland and deforested areas, primarily in tropical and subtropical regions of the earth.

All these changes are due to emissions to the atmosphere as a result of human activities.

2.2 Radiative forcing has changed

The globally averaged radiative forcing due to solar radiation (about 240 W/m^2) has increased by $2.7 \pm 0.5 \text{ W/m}^2$ due to the enhanced greenhouse gas concentrations (figure 1). The changes of stratospheric and tropospheric ozone are, however, not evenly distributed over the globe but rather patchy, the former primarily occurring in Polar regions and the latter in regions of enhanced air pollution (due to emissions of hydrocarbons and nitrogen oxides). To the best of our knowledge the globally averaged

negative forcing due to aerosols is somewhat larger than the global positive forcing due to enhanced tropospheric ozone (-0.9 ± 0.5 and $+0.4 \pm 0.2$ W/m², respectively). The total change of forcing of the climate system due to increased greenhouse gas concentrations is equivalent to an increase of atmospheric carbon dioxide by about 50% which number is reduced to 30-40% if also considering the temporary compensation due to aerosols. The spatial distribution is, however, very patchy (figure 2).

2.3 How much has climate changed?

Figure 3 (note) shows the changes of the global mean temperature since 1860. In considering this curve in relation to man's emissions of greenhouse gases, it is to be recalled that about 70% of the enhanced greenhouse concentrations has occurred since 1950, about 90% since 1900. The increase of the aerosol loading by and large paralleled the emissions of carbon dioxide, until air pollution became a serious problem after the second world war and more concerted actions were initiated in developed countries to take preventive measures.

The direct forcing of the atmosphere corresponding to doubling of carbon dioxide concentrations in the atmosphere would change the mean temperature of the atmosphere only modestly. It would lead to an increase of the global mean surface temperature by only about 1.2°C (note). It is most likely however, that an increase of global mean temperature is associated with an increase of the total amount of water vapour in the atmosphere (the most powerful greenhouse gas), whereby the direct change of the greenhouse effect due to man's emissions would be further enhanced. In the assessment of this positive feed back mechanism it has often been assumed that the relative humidity in the atmosphere remains constant. Experiments with advanced climate models confirm that this is by and large so, but significant differences of the estimated radiative forcing result from already rather small deviations. For this reason and also the sensitivity of climate models to a realistic inclusion of cloud processes, there is still considerable uncertainty about the magnitude of the climate response to a change of the radiative forcing. This is the main reason for still giving the interval 1.5-4.5 °C for the likely warming (at final equilibrium) due to doubling of carbon dioxide concentration in the atmosphere (note)

Recent transient experiments with climate models now show improved agreement between model projections and past observed changes of the global mean temperature (figure 3). There is also some similarity between the regional distributions of temperature changes as deduced with models and as observed. It seems therefore now more plausible that a major part of the observed changes during the last about fifty years are due to man's emissions and that the sensitivity of the climate system to increasing greenhouse gas concentrations is within the range as given above.

While a temperature increase clearly has occurred during the last century, it is more difficult to ascertain whether global precipitation has changed or not. It seems likely, however, that some increase has occurred, which also would be expected because of the likely intensification of the global hydrological cycle, if the global mean temperature increases. There are, however, marked differences between different parts of the globe. Precipitation has increased at high latitudes during summer and possibly over the oceans. On the other hand, extensive droughts that have prevailed in the Sahel region during the 1970s and 80s and also elsewhere in Africa, similarly in parts of Brazil, Australia and more recently in the south-west of Europe and in the south-west of the North American continent. Some of these changes seem to be associated with the changes of the El Niño phenomenon, but it is not yet possible to say if and to what extent they and the El Niño have been caused by a slow global warming. (IS THIS DESCRIPTION BALANCED? WGI).

References have also been made to the possible increase of the frequency of extreme events that some maintain have occurred during the last few decades. Convincing evidence, is still lacking and it is statistically difficult to prove that an increase actually has taken place (ARE THERE EXEMPTIONS'). A marked increase of the insured costs for the insurance industry has however, occurred, particularly due to flooding (a factor of about 20 since 1960, adjusted for inflation) (note). There may however, be several reasons for the escalation of the costs for severe weather events. Developed countries have become wealthier, more people live in coastal areas with costly infrastructure, personal goods and business process have generally become more vulnerable to water damage (note). Even if the frequency of severe weather events has increased in some parts of the world, this might be due to natural variations of the weather.

3. What will happen in the absence of climate change policies?

3.1 Projected future emissions of greenhouse gases and aerosols

The 1992 Supplementary Report (note) presented a set of six emissions scenarios, IS92a through IS92f, in order to illustrate the implicit uncertainty of such scenarios of the future. The 1994 Report (note) evaluated these scenarios. Working Group II (note) has further analysed the reliability of the macroeconomic models that are being used in the development of such scenarios.

Macroeconomic models are aggregate models based on historical relationships between energy consumption, prices and income and analyse how changes in each sector of the economy affect all other sectors and in doing so considers the interplay between different regions of the world. On the other hand, so called bottom-up models analyse the detailed structures of the economy in different countries and considers, for example, the possibilities of more efficient use of energy using presently available

technology and also considering its plausible developments. The differences that have been common between these models are diminishing and the analyses more trustworthy. The differences between different macroeconomic models seem primarily to be caused by differences in input assumptions rather than model structure, although the derived cost estimates still diverge. The use of historical relationships between parameters in the models, on the other hand, precludes the development of more drastic changes (e.g. paradigm shifts) in the world economy. In this sense these models are conservative.

The central scenario IS92a assumes economic growth in the world in the future to be on average 2.3 - 2.9% per year (note). It is further assumed that remaining oil and gas supplies are about 2.5 and 5 times respectively of what so far has been used and that coal is available until well after 2100, however, at increasing prices. Solar energy and biofuels will gradually be more used as they successively become competitive primarily during the latter part of the 21st century. The world population will have increased to about 11.3 billion people by then. Present efforts to control emissions of sulphur and nitrogen oxides in developed countries are expected to be maintained and also successively be introduced in developing countries by the middle of next century. Halocarbon concentrations are assumed to decrease gradually. Sulphur emissions increase in the scenario (a) by about 75% until 2050, and decreases thereafter slowly.

The low scenarios imply that much less oil and gas is available, that cost for nuclear energy declines (c), while solar energy becomes substantially cheaper and biofuels is introduced on a large scale (d). Further (e) assumes an average growth rate of merely 1.2 - 2.0% per year, while (d) adopts values between 2.0 and 2.7 but assumes, on the other hand, that the world population will only be about 6.4 billion in 2100. The high scenarios on the other hand imply that fossil fuels, particularly coal, will be the main source for energy supply throughout the 21st century and (e) in addition assumes that the average global growth rate will be high, between 3.0 and 3.5% per year.

There are certainly different views about what the most likely economic development would be in tomorrow's world, if no measures are taken. The scenarios (a) to (c) represent six somewhat arbitrary compositions that span a wide range. The low population figures used in (d), although taken from UN statistics, can probably not be used as a basis for international agreements nor for planning mitigation or adaptation efforts. In addition, the assumed limited resources of oil and gas are unrealistically low both for (c) and (d) (note).

Many developed countries have announced that they are aiming at stabilizing their emissions of greenhouse gases by the year 2000. Some, but probably not all will be able to reach that goal, and their share of the increase may become close to zero some few years into next century. In any case a smaller and decreasing part of the total

increase of carbon dioxide emissions in the world was due to OECD countries during the years 1985-93 (about 63%) (note). The Confederation of Independent States that formerly were part of the Soviet Union as well as the Eastern European countries have been decreasing their emissions so far during the 1990s in the ongoing process of restructuring their economies. Many developing countries, on the other hand, increase their emissions in striving for development.

The increase of radiative forcing due to increasing concentrations of greenhouse gases corresponds according to the central scenarios (a) and (b), to an average increase of the equivalent carbon dioxide concentrations in the atmosphere during the years 1990 - 2100 by 0.8% per year. The CO₂ concentrations projected for 2100 for the central scenarios (a) and (b) is 650 - 700 ppmv (note), while the equivalent carbon dioxide concentration rather is 720 - 770 ppmv. Scenario (a) has usually been used for deducing transient changes of climate, see further below.

3.2 Projected changes in climate

Changes of the global mean temperature

The most advanced climate models have recently been used to project the globally averaged surface temperature assuming emissions in accordance with scenario IS92a, see figure 4 (note). The projected emissions of sulphur dioxide has however, been somewhat modified taking into consideration more recent information (note). The two transient temperature curves agree in general terms with the observed temperature changes and it is interesting to find that the inclusion of sulphur emissions improves this agreement. A sensitivity of the models to greenhouse gas warming in the middle rather than in the lower part of the range of 1.5 - 4.5°C gives good agreement with observations when also including of the cooling effect due to aerosols.

Simple climate models have been used to compare the change of the global mean surface temperature based on the six scenarios (a) through (f), see figure 5. The range of uncertainty of temperature projections due to uncertainty about future emissions is clearly shown.

It should be emphasized that the computed global mean temperature lags 30-50% behind the temperature corresponding that at any one time corresponds to equilibrium conditions. The inertia of the climate system partly hides a change that ultimately will be established even if further emissions were completely stopped.

There is some agreement between computed and observed regional changes of surface temperature in the past and also between the two model computations that are available, but this does not yet justify the use of such projection into the future as a basis for more detailed impact studies. Also the uncertainty for projected change

increases as the size of the area being considered decreases. This is due to natural regional variability that cannot be predicted. Some regions, e.g. the North-Atlantic and the Weddell Sea area may even experience cooling for several decades in the case of a globally averaged increase of surface temperature. Earlier projections of drier conditions in the interior of the major continents remains unchallenged.

Derivations of possible or likely changes of climate, if the equivalent carbon dioxide concentration were tripled or quadrupled, are most uncertain. One cannot disregard non-linear and rather abrupt changes (on the times scales of decades). Such changes are and will, probably for quite some time, remain unpredictable. (SOME FURTHER MATERIAL MAY BE ADDED WGI)

3.3 Projected impacts of climate change

Changes of sea-level

In a warmer world, mountain (Alpine) glaciers will melt more rapidly and the oceans will slowly become warmer, but the heating penetrates into deeper layers of the oceans only slowly. Sea water expands if heated. The ocean level has increased between 13 and 25 cm during the last century, but it has only been possible to explain an increase by 2-4cm to be due to the retreat of glaciers and 2-7 cm to be due to the expansion of the sea water. Additional contributions may have come from the huge ice sheets of the Antarctica and Greenland, but it is not clear from observational evidence whether the ice sheets are currently expanding, contracting or in balance. The ice sheets remain the major source of uncertainty regarding both past and future changes in sea level.

As a matter of fact, the volume of the Antarctic ice sheet may rather increase if the climate becomes warmer. More moisture would then be transported in over the continent, whereby the accumulation of snow might be enhanced. A possible prevailing balance between accumulation due to snow fall and loss due to outflow of ice from the Antarctic continent to the surrounding seas would then become disturbed and it would take centuries or even millennia before the losses would increase sufficiently to balance an enhanced accumulation. The Greenland ice sheet, on the other hand also melts in summertime at its rim on land. Even if the accumulation at higher elevations probably would increase in a warmer world the melting would be adjusted more quickly and might even become more significant than the enhanced accumulation. It seems more probable that in a warmer climate the Antarctic ice sheet might be accumulating ice while rather the opposite might be the prospects for the Greenland ice sheet. One cannot however, exclude temporary, more rapid, changes of ice sheet (surges), but such changes do not seem likely, until a major and sustained warming has occurred in these areas.

For forcing scenarios IS92a-f, sea level is projected to be ?? to ?? cm higher than today by the year 2050, using the 'best-estimate' of model parameters. By the year 2100, the sea level rise might range between ?? and ?? cm. These estimates are somewhat lower than those presented before (note). Most of this difference is due to reduction of the estimates in global temperature change due to the inclusion of the cooling effects of aerosols in the model computations. It is finally also important to emphasize that changes of the ice sheets will not stop even if the climate is stabilized. Their adjustment to a new equilibrium will continue and may take centuries to millennia to complete (note).

Available of water, WG II

Natural ecosystems, WG II

Forestry, WG II

Agriculture, WG II

Health, WG II

3.4 Projected damage costs

WG III

Available information relates almost exclusively to impacts associated with doubled concentrations of carbon dioxide. It is, therefore, probably necessary to make clear to the reader that we are not at present able to discuss other concentration levels meaningfully. Estimates of costs should highlight

the importance of non-market damages

the regional variations in damage

the uncertainty of the estimates

(Jim Bruce)

4. **Options available for adaptation to climate change**

4.1 Adaptation of natural systems

WG II

4.2 Adaptation options for managed systems

WG II

This section might conclude with material from WG III on estimates of damages.

4.3 Potential benefits of increasing resilience of systems through sustainable management practices

WG II

5. What is required in order to stabilize greenhouse gas and aerosol concentrations and hence eventually climate?

5.1 Emissions trajectories for stabilization

Article 2 of the Framework Convention on Climate Change defines as an ultimate objective "to achieve the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system". As a guiding principle the Convention also prescribes that policies and measures should be comprehensive and cover all relevant sources, sinks and reservoirs of greenhouse gases. It is therefore important first to describe the constraints on future emissions that arise, if we aim at stabilizing the different greenhouse gas and aerosol concentrations individually and then to analyse the implications of various combinations of mitigation measures. Such a final analysis cannot be fully comprehensive, but the examples chosen below should give a general idea of the possibilities and limitations that exist.

Carbon dioxide

A number of research groups have developed models that describe the circulation of carbon in nature (note). Such models are of course approximate, but they have been tested by the consideration also of the transfer of both stable and radioactive tracer isotopes, particularly carbon (^{13}C , ^{14}C), tritium (^3H , in water), for which observations are available for the last few decades. General Ocean Circulation models have been employed to assess the exchange of carbon between the atmosphere and the oceans and the transfer into deeper layers of the oceans (note).

The main uncertainty concerns the way terrestrial ecosystems may have served as a sink during the last century, compensating for the carbon losses due to deforestation. Some regrowth of temperate and boreal forests has probably occurred in North America and Europe after the rather ruthless exploitation that took place during the 19th century. This uptake may have been enhanced by the deposition of nutrients (particularly nitrogen oxides) also formed when burning fossil fuels. On the other hand, acidification of soils both from nitrogen and sulphur emissions presumably has reduced carbon uptake by vegetation. Finally, the increased carbon dioxide concentration in the atmosphere may well have led to a fertilisation of the terrestrial systems. It is difficult to determine the relative importance of these different processes, but they seem presently to about compensate for the losses due to deforestation.

Still, there is considerable uncertainty with regard to the future role of the terrestrial systems. This will ultimately depend on how well forests on earth will be managed in the future.

Systematic analyses have been carried out of the permissible emission paths (due to fossil fuel use and deforestation), if stabilization of atmospheric carbon dioxide concentrations at a set of prescribed concentrations [350, 450, 550 (approximately doubling of pre-industrial concentrations), 650 and 750 ppmv], that is being aimed for (Figure 6). Different smooth transitions of past and future increases of atmospheric concentrations into a level for stabilization have been chosen (note). Because of the inertia of the socio-economic system, rapid changes should be avoided because of higher costs (note). They would lead to a more rapid turn over of the capital stock, i.e. capital destruction. Figure 7 (note) shows an example of possible choices, but analyses of optimal emission paths have merely begun.

Scenario IS92a can be followed at most for another decade or possibly two, if stabilization at 450 ppmv is to be achieved. This means in reality that measures must be taken now, since it takes considerable time before persistent changes of emissions are achieved. Major investments in energy saving devices and in power plants that are required necessarily will also take time. The higher the stabilization level the more time is available for taking necessary measures. A stabilization at 750 ppmv permits emissions according to scenario IS92a well into next century, but planning should begin earlier and a gradual transition be aimed for.

The requirement of stabilization of atmospheric carbon dioxide concentrations primarily puts a constraint on the permissible accumulated emissions until such a stabilization is achieved. The following table (note) gives the accumulated emissions until 2050 and 2100 due to fossil fuel combustion for the different target concentrations [Note: 50 GtC (for the period 1990-2050) and 80 GtC (for the period 1990-2100) have been deducted from the total amounts given in the 1994 IPCC Special Report because net deforestation continues during next century according to scenario IS92a] .

Stabilization case	Accumulated emissions Gt Carbon		Mean annual emissions Gt Carbon/year	
	1990-2050	1990-2100	1990-2050	2050-2100
450 ppmv	350-450	560- 760	5.9- 7.5	4.2- 5.4
550 ppmv	420-560	800- 980	7.0- 8.0	5.6- 8.4
650 ppmv	470-600	920-1160	7.8-10.0	9.0-11.2
750 ppmv	520-620	1140-1340	8.7-10.3	12.4-14.4

It should be pointed out that total emissions due to fossil fuel combustion so far have been about 240 Gt, of which about half has come from the use of oil and gas.

The total reserves and resources of oil and natural gas (the resource base) are presently estimated to correspond to emissions of 200-300 Gt and 200-350 Gt respectively. The coal reserves are, on the other hand, about a factor ten larger, the size largely dependent of the costs for exploitation (note).

It is also of interest to relate these emissions scenarios to the estimated changes of world population during the 21st century projecting 9.5 and 11.2 billion for 2050 and 2100 respectively (UN projections). The following values for per capita emissions are then obtained. These numbers are given to illustrate the major constraints that stabilization imposes on the use of fossil fuels. It is not an implicit recommendation about principles for achieving stabilization.

Stabilization case	Emissions, ton Carbon per capita		
	2050	2100	maximum*
450 ppmv	0.5-0.7	0.2-0.4	1.1
550 ppmv	0.7-1.1	0.5-0.8	1.3
650 ppmv	0.9-1.4	0.8-1.1	1.6*
750 ppmv	1.1-1.6*	1.0-1.3	1.6*

* The maximum values are the highest possible deduced in the scenarios that were constructed.

Halocarbons and stratospheric ozone

CFC-gas concentrations in the atmosphere are becoming stabilized within a few years and the decrease of ozone in the stratosphere will then likewise stabilize. A slow return to natural concentrations will take place during the 21st century. ---- Other halocarbons generally have rather short lifetimes in the atmosphere (years to a few decades). Their contributions to enhanced greenhouse gas forcing is slight at present, but the projected increase of emissions of HCFC-22 and HCFC-134 (that have comparatively long lifetimes, 13 and 18 years respectively) according to scenario IS92a implies that they, a decade or two into next century, may contribute to radiative forcing by more than 0.1 W/m^2 . Some very long-lived greenhouse gases are also being emitted into the atmosphere, although still in modest amounts, e.g. sulphur hexafluoride (SF_6) and perfluoromethane (CF_4) having lifetimes of 3 200 and 50 000 years respectively. The need to take preventive measures to stabilize their concentrations demands careful consideration.

Aerosols

Aerosols stay in the atmosphere only days to a week or two. Their atmospheric concentrations are therefore directly proportional to the emissions and are quickly reduced, if the use of fossil fuels is reduced (note). While decreasing emissions of carbon dioxide still would add to the atmospheric content of carbon dioxide (its lifetime is long, 50-200 years) concentrations of sulphur aerosols would decrease. Their cooling effect would then also diminish and the greenhouse warming that had been hidden would be unmasked.

Air pollution and tropospheric ozone

The present enhancement of tropospheric ozone due to the emissions of air pollutants, particularly hydrocarbons and nitrogen oxides, will increase further as long as additional preventive measures are not taken, particularly in the rapidly growing megacities and industrialized regions of developing countries. Ozone is formed in direct response to the concentrations of air pollution and decreases in parallel with emissions.

A comprehensive approach

The reductions of emissions that are necessary in order to stabilize concentrations of the key greenhouse gases, carbon dioxide, methane, nitrous oxide and halocarbons, and thereby implicitly stratospheric ozone can be combined in different scenarios for stabilization of the total global forcing. In addition, the forcing due to changes of tropospheric ozone and aerosols, which both are short-lived and therefore have an inhomogeneous distribution over the globe, should be considered.

As an illustration we consider the alternative levels of stabilization of total greenhouse gas forcing at 450, 550, 650 and 750 ppmv. Other choices can of course be analysed. In each case we assess which stabilization of carbon dioxide is required, if demanding that methane and nitrous oxide either are stabilized at present level or are permitted to increase according to IS92a until 2050 and then stabilize, which might be viewed as an upper bound of what these greenhouse gases might contribute during next century. The present radiative forcing due to carbon dioxide, methane, nitrous oxide, halocarbons and stratospheric ozone is at present, according to IPCC Special report 1994, 2.3 W/m², of which 1.55 W/m² is due to carbon dioxide. This is equivalent to CO₂ concentration of about 420 ppm(v). If methane and nitrous oxide are permitted to increase according to the scenario IS92a, the concentration of methane would increase from presently 1.7 to about 2.5 ppm(v) and nitrous oxide from presently 0.31 to 0.34 ppm(v). We then deduce the following levels of stabilization of carbon dioxide (ppmv):

Level of stabilization of total forcing due to greenhouse gases equivalent to CO ₂ ppm(v)	450	550	650	750
Radiative forcing (W/m ²)	3.2	4.4	5.4	6.2
Methane and nitrous oxide concentration stabilized at present concentrations	385	480	565	650
Methane and nitrous oxide increase according to IS92a until 2050 and stabilize thereafter	365	455	535	610

Uncertainties of the numbers in this table are about +/- ppm(v).

We notice that stabilization of equivalent carbon dioxide concentration at 450 ppmv would require a stabilization of CO₂ below about 385 ppmv, if concentrations of methane and nitrous oxide was not stabilized at present concentrations. A temporary increase of CO₂ increase beyond this level would be permissible because of the negative forcing due to aerosols, but sulphate aerosols would diminish quickly when the use of fossil fuels was reduced as would be required. This scenario is hardly possible to achieve (Cf. Figure 7).

Stabilization of equivalent carbon dioxide concentrations at 550 ppmv (almost doubling of pre-industrial carbon dioxide concentrations) would require a stabilization of CO₂ at about 480 ppmv provided methane and nitrous oxide would be stabilized at present concentration levels. Figure 7 shows that carbon dioxide emissions could hardly be permitted to rise much above 9 GtC/year and must start to decline within a few decades into the 21st century. Some more leeway would be available if methane, nitrous oxide and tropospheric ozone concentrations could be decreased. Also, sulphate aerosols would hide the full effects of the enhanced greenhouse gas warming until their concentrations would decrease, when the use of fossil fuels would have to be reduced well before the middle of next century. This scenario deserves a more detailed analysis.

Considerably more flexibility is possible, if higher stabilization levels of equivalent carbon dioxide concentrations were chosen e.g. 650 or 750 ppmv or higher. Still, the former would, for example, require a stabilization of CO₂ at about 560 ppmv, i.e. at the level of doubled pre-industrial concentrations.

It should be emphasized that the discussion above has been based on emission scenarios derived with the aid of models that describe the circulation of carbon in nature. These are of course approximations of reality. The outcome is, however, reasonably robust, but pre-supposes that

- deforestation gradually declines during 21st century
- terrestrial ecosystems are not negatively affected by the impact of a beginning change of climate
- enhanced growth of forests due to the fertilizing effect of increasing carbon dioxide concentrations continues
- the uptake of carbon dioxide by the oceans in principle remains unchanged.

The numbers given should, therefore, be used with care, but the principal picture as it emerges is hardly expected to change drastically.

5.2 Climate change for alternative levels of stabilization

5.3 Technical feasibility of stabilization

Potential mitigation options can be summarized from WG II. However, the section needs a summary of the options that are consistent with stabilization of concentrations at different levels. In particular, can methane options yield stabilization at current levels or only at some higher levels? The same question should be asked with regard to stabilization of nitrous oxide. (Jim Bruce).

5.4 Costs and policy instruments

WG III. Note particularly the WG III conclusions.

- no single measure is sufficient nor perfect, rather a portfolio of actions that varies by country and must be adjusted over time as necessary
- the initial actions are relatively insensitive to the level at which concentrations are to be stabilized.

Socio-economic considerations should particularly emphasize equity implications of how costs and impacts are shared over space and time. (Jim Bruce).

6. **An integrated assessment of alternative levels of stabilization**

6.1 Governments must determine what is "dangerous"

It is not possible for the scientific community to determine "objectively" the level of GHG concentrations that is dangerous, because impacts will vary across systems and in different regions and because different governments societies have different values and levels of risk aversion. (Watson, Moss).

6.2 Decision under uncertainty

There are risks associated with delaying action, just as there may be unnecessary costs associated with acting "prematurely". (Watson, Moss). Extract from WG III.

6.3 Decision making framework

The decision about what emissions/concentrations targets can be considered with a variety of decision-making frameworks and in the context of other policy issues. (Watson, Moss). Extract from WG III.

6.4 Conclusions

- Policymakers will need to choose the level and date at which concentrations are to be stabilized.
- Their choice will be influenced by the impacts of climate change and the costs of achieving stabilization at a different level by different dates.
- Many gaps remain on our knowledge of the impacts and costs, including changes to regional climate, impacts on natural and managed ecosystems and costs of mitigation. Since climate change affects the long term future, the impacts and costs will always remain somewhat uncertain.
- Action is warranted now. The short term actions are not very sensitive to the level at which concentrations are ultimately stabilized. Many opportunities to adjust mitigation actions will be available over the coming decades. (Jim Bruce).



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



Time Table for the completion of the IPCC Synthesis Report (ISR)

All dates are in 1995

Activity	Deadline
Zero-order draft distributed to Drafting Team	April 20
First meeting of the Drafting Team to produce the first draft for review by selected experts and to select experts for such review	May 1-3 Athens
First draft mailed for review by selected experts	May 15
Experts' review due in IPCC Secretariat	June 12
Reviews collated and sent to Drafting Team	June 19
Second meeting of the Drafting Team to produce the second draft for governments' and organizations' (G&O) review	July 3-5 London
Dispatch of the second draft for G&O review. Time mandated in IPCC procedures: 6 weeks	July 10
Deadline for receipt of G&O reviews	September 14
Third meeting of the Drafting Team to produce the final draft	September 20-22 Washington D.C.
Dispatch of the final draft to governments. Time mandated in IPCC procedures: one month	October 30
Approval of the Summary for Policymakers and acceptance of the rest of ISR, IPCC-XI	December 11-15 Rome

20 April 1995

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1 EXECUTIVE SUMMARY

Human activities are increasing the concentration of greenhouse gases and aerosols in the atmosphere, which is projected to lead to regional and global changes in temperature, precipitation, soil moisture, and sea level. While it is unclear the degree to which climate will become more variable, the incidence of floods, droughts, fires and pest outbreaks is expected to increase in some regions. The fact that large uncertainties remain does not mean that potential impacts on ecological and socio-economic systems can be dismissed. Due to the sensitivity of many ecological and socio-economic systems to changes in climate variables, profound influences on a number of these systems can be expected.

Vulnerability to Climate Change

Common Conclusions

- The most vulnerable systems are those whose sensitivity to changes in climate is greatest and for which adaptation options are limited, for example unmanaged ecosystems and the cryosphere.
- While there will be some beneficial effects of climate change, there will be many adverse effects, with some being potentially irreversible. The net impact will be determined by the degree of success in implementing adaptation options and the ability to move towards sustainable management practices. The efficacy and cost-effectiveness of adaptation strategies will depend upon management, institutional, legal and regulatory practices.
- Adaptation options for managed systems such as agriculture and water supply are generally improving because of technological advances. However, access to these technologies is not evenly distributed around the globe. Moreover, societies are becoming more vulnerable to extreme climatic events as population density increases in river basins, coastal plains, hill slopes, and marginal lands.
- Measures to assist adaptation in unmanaged ecosystems, such as design of migration corridors, are not well developed. Human activities fragment most landscapes, thus limiting adaptation potential. Ecological systems disrupted by climate change will take decades to centuries to recover, if they can recover at all. Species extinction can never be reversed.
- Human-induced climate change represents yet another serious stress in a world where many systems are already threatened by other pressures including air and water pollution, acid deposition, increasing UV-B penetration, and intensification of resource use. Because of these interacting stresses and the complexity of these systems, it is unlikely that ecological and socio-economic impacts can be attributed unequivocally to climate change.

Terrestrial and Aquatic Ecosystems

Aquatic and terrestrial ecosystems provide food, transportation, timber, flood control, water supplies, and recreation, all of which are sensitive to changes in climate.

- **Forests.** Global models project that, as a consequence of possible changes in temperature and water availability, 14-65% with a global mean of 34% of existing forested areas of the world will undergo major changes in vegetation type, with implications for commodity extraction and forest management practices, especially in tropical developing countries. Net primary productivity may increase, but standing biomass may not due to stresses caused by changes in species range, disturbance regimes (fires, pests, and diseases), and increased temperatures (which increases respiration). Because the maximum rate at which carbon can be lost is greater than the rate at which it can be gained, transiently large amounts of carbon may be released into the atmosphere as forests decline in response to changing climate and before better suited forests replace the former vegetation.
- **Rangelands.** Temperature increases should not lead to major alterations in tropical rangelands, but altered rainfall seasonality and amount may have severe consequences. Increases in carbon dioxide concentration are likely to result in reductions of forage quality because of increasing carbon to nitrogen ratio. Shifts in temperature and precipitation in temperate rangelands may result in dryer growing seasons, resulting in the shift of grasslands to shrublands. Tundra systems are expected to be highly sensitive to climatic warming. Arctic permafrost in a warmer climate will probably result in a net source of carbon and methane into the atmosphere.
- **Cryosphere.** It is likely that by the end of the next century, between one-third and one-half of all mountain glaciers could disappear. The reduced extent of glaciers and depth of snow cover will also affect the seasonal distribution of river flow water supply for hydroelectric generation and agriculture.
- **Mountain Regions.** A warmer climate will affect hydrologic systems, soil stability, and related economic systems. Species with climatic ranges limited to mountain tops may become extinct because their habitats will disappear. Mountain resources such as food and fuel for indigenous populations may be disrupted in many developing countries. Recreational industries, of increasing economic importance to many regions, are also likely to suffer.
- **Oceans and Marine Ecosystems.** Changes in climate will result in sea-level rise and could alter ocean circulation, vertical mixing, wave dynamics, and ice coverage. Potential consequences include changes in ocean productivity, thus affecting biogeochemical cycling. Freshwater influx

from melting glaciers and river runoff could weaken the global thermohaline circulation which controls the distribution of heat and carbon dioxide within the oceans. Coral reefs are particularly sensitive to increases in sea-water temperature, which compound their vulnerability to local pollution.

- **Coastal Systems and Wetlands.** Changes in climate could affect water flow and flooding, with implications for important wetland functions including sediment trapping, flood control, recharging of aquifers, waste processing, wildlife habitat, nurseries for fisheries, and biogeochemical cycling. Loss of salt-water marshes, mangrove ecosystems, and coastal wetlands may increase due to the interaction of sea-level rise and human development. The most vulnerable areas are those currently experiencing rapid erosion rates and with very low geographic relief.

Water Resources

- Climate change could have major impacts on regional water supplies and demands. Reductions in natural water availability could result in chronic shortages in regions and nations that are already under stress, and for which there is already competition among users. Relatively small changes in temperature and precipitation can have large effects on runoff, particularly in arid and semi-arid areas. GCMs currently do not provide sufficient information to assist water managers in making decisions. The increased uncertainty in the future supply and demand of water resources is a key issue for water management.
- Experts disagree over whether the currently inadequate water systems in many developing and some developed countries will evolve sufficiently in the future to cope with the additional stresses that climate change may impose. For a number of countries, water availability per capita already falls below commonly-accepted minimum standards (e.g. Kuwait, Jordan, Israel, Rwanda, Somalia, Algeria, Kenya), or is expected to fall below this standard in the next two to three decades (Libya, Egypt, South Africa, Iran, and Ethiopia). In addition, a number of countries in conflict-prone areas are highly dependent on water originating outside their borders (for example, Cambodia, Syria, Sudan, Egypt, and Iraq).

Food and Fiber

- **Agriculture.** The aggregate effects of climate change on global agricultural production are likely to be small to moderate if appropriate adaptation measures are undertaken. However, even with this optimistic

perspective, simplifying the problem as one of global supply and demand ignores the projected regional and local differences in food production, especially in tropical areas where many of the world's poorest people live and are most at risk of hunger. Many of these at-risk populations are found in Sub-Saharan Africa, South, East, and South East Asia, as well as some Pacific Island Nations.

- Access to means for adaptation such as new crops and crop varieties, improved water management and irrigation systems, and such information as optimal planting times, will be important in limiting negative effects and taking advantage of beneficial changes. The extent of adaptation depends on the affordability of measures, access to know-how and technology, and biophysical constraints such as water availability, soil characteristics, and crop genetics. The incremental costs of these adaptation strategies could create a serious burden for some developing countries.
- **Fisheries.** Climate change effects will interact with those of pervasive over-fishing, diminishing nursery areas, and extensive inshore and coastal pollution. Positive effects, such as from longer growing seasons, lower natural winter mortality, and faster growth rates in higher latitudes, may be offset by negative factors such as changes in established reproductive patterns, migration routes, and ecosystem relationships. Principal impacts will be felt at the national and local levels as species mix and centers of production shift.

Human Infrastructure

- Small islands and low-lying coastal areas are particularly vulnerable to climate-change effects such as rising sea levels and increases in flooding, coastal erosion, and storm frequency or intensity, with tens of millions of people at risk. Many low-lying areas, such as parts of the Maldives, Egypt, and Bangladesh would be inundated and made uninhabitable by a 50 cm sea level rise. Integrated Coastal Zone Management could help both developing and industrialized countries to achieve the twin objectives of addressing immediate socio-economic concerns while developing responses to longer-term events, such as climate change. However coastal zone management costs would be very large as a proportion of GNP for many small island and developing countries.
- In general, the sensitivity of the energy, industry and transportation sectors is relatively low, while the capacity for autonomous adaptation is expected to be high, if climate change is relatively gradual. The sub-sectors most sensitive to climate change include agro-industry, renewable energy production including hydroelectric generation, construction, offshore oil and gas pro-

duction, and manufacturing heavily dependent on water supplies. The most vulnerable human settlements are located in damage-prone areas of the developing world that do not have the resources to cope with impacts.

- Property insurance is vulnerable to extreme climate events. The insurance industry is currently stressed from a series of "billion dollar" storm events every year since 1987, resulting in drops in capacity and dramatic increases in losses. If the frequency or severity of extreme events were to increase as a result of climate change, insurance in vulnerable areas could be withdrawn, with implications for other economic sectors, including banking. The cost of such incidents could increase insurance rates world-wide.

Human Health

- Direct health effects include increased exposure to very hot weather events and more frequent weather hazards (droughts, floods and severe storms), and are projected to increase the loss of life.
- Indirect effects will include increases in the potential transmission of vector-borne diseases (malaria, dengue and yellow fever, and schistosomiasis) via extension of the geographic distribution of disease vectors; increased transmission of contagious diseases (e.g. cholera); and potential impairments in nutritional status.
- Quantifying the predicted impacts is difficult because the seriousness of climate-induced health disorders depends on many other factors including environmental and socio-economic circumstances, nutritional and immune status, water purity, population density, and access to and quality of health care services.

Options to Control the Sources and Enhance the Sinks of Greenhouse Gases:

An extensive array of technologies and policy measures capable of mitigating greenhouse gas emissions is available. There is significant controversy regarding ease and cost of implementation of these technologies and measures, however, due to potential social, institutional, financial, market and legislative barriers to their application and implementation. Without effective policy intervention, the actual contribution of these options to mitigation of emissions may be limited.

Agriculture, Rangelands, and Forestry

- Sustainably managed agricultural lands, rangelands, and forests can play a key role in reducing current emissions of carbon dioxide, methane, and

nitrous oxide. Emissions can be reduced, or carbon sequestered, through improved management of agricultural soils, restoration of degraded agricultural lands, establishment of plantations, agroforestry, forest regeneration, and slowing of deforestation. There are significant uncertainties associated with estimating the amount of carbon that can be conserved and/or sequestered.

Energy Demand/Supply

- Energy production from fossil fuels is responsible for the largest portion of greenhouse gas emissions. In 1990, commercial primary energy use was approximately 350 EJ, resulting in the emission of about 6 Gt. C. It grows to approximately 540-840 EJ by 2025 and 540-2500 EJ by 2100 (IPCC IS92). The mix of fuels and the geographic sources of emissions are expected to change substantially over this time period. While the likely rate of demand growth is less certain, advanced technologies can significantly reduce both energy demand and resulting emissions.
- Over the course of the next century, the world's energy infrastructure will be replaced completely at least twice, offering opportunities to change the energy system in step with the corresponding investment processes.
- Advanced technologies can significantly reduce energy demand in all sectors. The most promising options in the industrial sector are more efficient motors, control systems, co-generation, energy cascading, and materials recycling. Changes in vehicle design, propulsion systems and fuels, as well as measures to influence driving behavior, could reduce emissions by 40 percent in 2025 relative to a high emission scenario. Projected growth in energy demand in commercial and residential structures could be cut by one-half over the next 35 years with more efficient heating, cooling, lighting, and appliances. Even low-tech, "good housekeeping" measures can lead to significant reductions in energy use.
- The most promising technology-based approaches for reducing greenhouse gas emissions from energy supply include: gas turbine technologies, coal and biomass gasification technologies, production of transportation fuels from biomass, approaches to handling intermittent generation of electricity, wind energy utilization, electricity generation with photovoltaics and solar thermal electric technologies, fuel cells for power generation, and hydrogen as a major new energy carrier, produced first from natural gas and later from biomass, coal, and electrolysis.
- Renewable energy sources could provide a substantial portion of foreseeable energy needs of the world over the next century; potentially most promising is biofuels for electricity generation and transportation fuel. Considerable uncertainty exists regarding the costs and rate of market penetration without major policy interventions.

2. SCOPE OF THE ASSESSMENT

The charge to Working Group II of the Intergovernmental Panel on Climate Change (IPCC) was to review what is known, unknown, uncertain, and controversial about the impacts of climate change on physical and ecological systems, human health, and socio-economic sectors. It was also charged with reviewing the available information on the technical and economic feasibility of a range of potential adaptation and mitigation strategies. The assessment activities of Working Group II have been closely coordinated with those of Working Groups I and III, and this report builds upon the 1990 and 1992 assessments.

This assessment provides scientific, technical and economic information that policymakers can use to begin to evaluate whether the projected range of plausible impacts constitutes "dangerous anthropogenic interference with the climate system" at the local, regional or global scales as discussed in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC). However, the assessment does not attempt to quantify "dangerous anthropogenic interference with the climate system", because interpretation of what is considered to be "dangerous" involves political judgment, and is the role of governments and the Conference of Parties to the UNFCCC.

Article 2 of the UNFCCC explicitly acknowledges the importance of natural ecosystems, food security, and sustainable economic development. This report directly addresses these and other issues of societal importance, including water resources and human health. Knowledge of the impact of climate change on terrestrial and aquatic ecosystems, human health, and socio-economic systems at varying spatial scales, and to some extent the vulnerability of the systems to climate change, is assessed.

Ultimate Objective of the UNFCCC (Article 2)

"...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to: (i) to allow ecosystems to adapt naturally to climate change; (ii) to ensure that food production is not threatened; and (iii) to enable economic development to proceed in a sustainable manner."

The vulnerability of a system to climate change is a function of its sensitivity to changes in climate and its ability to adapt. The assessment of vulnerability attempts to take into account the different economic and institutional circumstances of developed and developing countries. In

addition, the assessment recognizes that most of these systems are strongly influenced by non-environmental stresses (e.g., population demographics, land-use practices, industrialization, resource exploitation, and consumption patterns) and to some degree by other environmental factors (e.g., air and water pollution, acid deposition, atmospheric concentrations of carbon dioxide (via photosynthesis and water-use efficiency), and increased levels of UV-B radiation). Where possible, this assessment attempts to evaluate the sensitivity of systems to: (i) changes in mean climate; (ii) changes in extreme weather events; (iii) changes in variability; and (iv) the rate of climate change. The potential for adaptation is also assessed. To begin to standardize impact analyses, the IPCC published technical guidelines for assessing climate change impacts and adaptations in 1994.

This assessment also reviews approaches to mitigate greenhouse gas emissions and thus anthropogenic climate change. Practices and technologies that reduce emissions of greenhouse gases arising from the production and use of energy, and that enhance the sinks and reduce the emissions of greenhouse gases from agricultural, forestry and rangeland systems are analyzed. Methodologies for assessing mitigation options are also presented.

Policymakers are faced with responding to the challenges posed by anthropogenic emissions of greenhouse gases in the face of significant scientific uncertainties. Decisions taken during the coming years, whether to act or not, may limit the range of possible options in the future. In large part this is because climate-induced environmental changes are difficult to reverse due to the long timescales (decades to millennia) associated with the climate system. Consequently, policymakers will have to decide to what degree they want to take precautionary measures and "buy insurance" by enhancing the resilience of vulnerable systems or mitigating greenhouse gas emissions. Uncertainty does not mean that a nation or the world community of nations cannot position itself better to cope with the broad range of possible impacts under climate change or protect itself against potentially costly future outcomes. Delaying anticipatory measures may leave a nation or the world poorly prepared to deal with changes that do occur and may increase the possibility of impacts that are irreversible or otherwise very costly. Options for adapting to change or mitigating change that can be justified for other reasons today (e.g., abatement of air and water pollution), and make society more flexible or resilient to anticipated adverse effects of climate change, may be particularly desirable.

Time Scales of Processes Influencing the Climate System

- Equilibration of carbon dioxide between the atmosphere and oceans takes place over timescales of centuries to millennia; hence there is a lag time of centuries between stabilization of emissions and stabilization of atmospheric concentrations of carbon dioxide;
- Equilibration of the climate system takes decades after stabilization of greenhouse gas concentrations;
- Sea level takes centuries to equilibrate with a new equilibrium climate;
- Restoration/rehabilitation of damaged ecological systems takes decades to centuries, and species extinction can never be reversed; and
- Without premature retirement, turnover of the capital stock responsible for emissions of greenhouse gases (e.g., power plants) takes some decades.

3. THE NATURE OF THE ISSUE: PREDICTED CHANGES IN CLIMATE

The Earth's climate has been relatively stable over the past 10,000 years. Over this period society has evolved, and adapted to the prevailing local climate and its natural variability. Society now faces changes in climate, because human activities are changing the Earth's radiation balance by altering the chemical composition of the atmosphere (gases which enhance the greenhouse effect, and aerosols which tend to partially offset the greenhouse effect). The atmospheric concentrations of greenhouse gases have increased since the pre-industrial era (~1750); carbon dioxide by about 30%, methane by a factor of two, and nitrous oxide by 15%. Regional and global changes in temperature, precipitation, soil moisture, and sea level are predicted to have wide-ranging and potentially adverse effects on physical and ecological systems, human health, and socio-economic sectors. Human-induced climate change can affect the economy and the quality of life for this and future generations.

Future emissions of greenhouse gases and the sulfate aerosol precursor, sulfur dioxide, are uncertain over time scales of many decades. They are sensitive to changes in demographic, economic, technological, policy and institutional developments, including growth in population and gross domestic product (GDP), technological development and the rate of diffusion into the market place, production and consumption patterns, land-use practices, energy intensity, and the price and availability of energy. Most projections suggest that greenhouse gases will increase significantly during the next century in the absence of policies specifically designed to address the issue of climate change. Figure 1 shows plausible ranges of carbon dioxide emissions in the absence of emissions abatement policies projected over the next 100 years by the Intergovernmental Panel for Climate Change (IPCC) in 1992.

Based on the accepted range of climate sensitivities¹ and plausible ranges of greenhouse gas and aerosol precursor emissions, general circulation models (GCMs) calculate that the global mean surface temperature could increase by 0.1 to 0.4°C per decade, thus 1 to 4°C by 2100 (Figure 2). Temperature changes are expected to differ by region with high latitudes projected to warm more than the global average. A global-average temperature change of this magnitude would be greater than recent natural fluctuations and would also occur at a rate significantly faster than observed changes in the last 10,000 years.

Model calculations also suggest that evaporation will be enhanced as the climate warms, leading to an increase in global mean precipitation and the frequency of intense rainfall. However, not all land regions will experience an increase in precipitation, and even those land regions with elevated precipitation may experience decreases in soil moisture, because of enhanced evaporation. Seasonal shifts in precipitation are also projected. In general, precipitation is projected to increase at high latitudes in winter, and soil moisture is projected to decrease in some mid-latitude continental regions during summer.

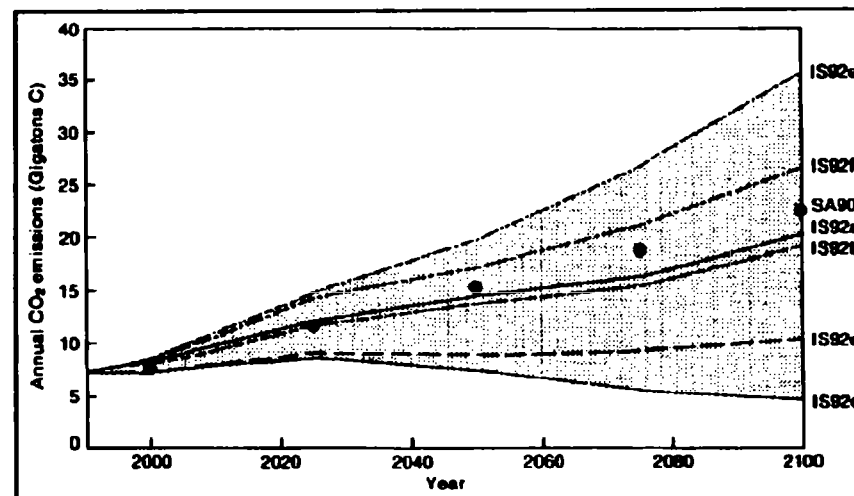


Figure 1. Annual CO₂ Emissions from Energy, Cement Production, and Tropical Deforestation for the Six IPCC 1992 Scenarios (IS92a-f) and for the 1990 IPCC Scenario A (SA90)—from "IPCC Special Report, 1994," chapter on Evaluation of Emissions Scenarios.

¹ Climate sensitivity is the equilibrium change in global annual mean surface temperature due to a doubling of atmospheric concentration of carbon dioxide (or equivalent doubling of other greenhouse gases).

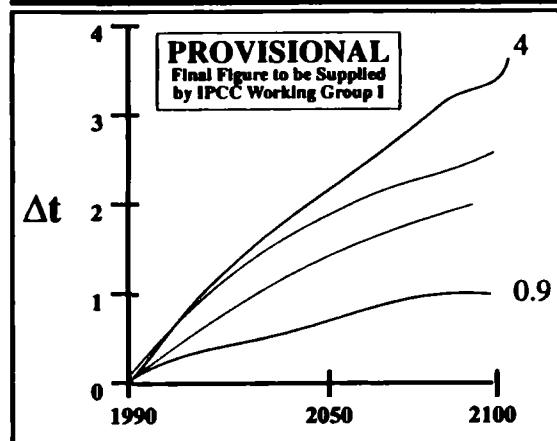


Figure 2. Plausible Ranges of Global Mean Surface Temperature Increase

While the incidence of floods, droughts, fires and pest outbreaks is expected to increase in some regions, it is unclear whether there will be changes in the frequency and intensity of hurricanes, tornadoes, and extreme temperature events.

By 2100, sea level is projected to increase by 10 - 75 cm, with a best estimate of 50 cm, as a result of climate change. The main causes are the thermal expansion of the oceans and the melting of glaciers and ice sheets.

4. VULNERABILITY TO CLIMATE CHANGE: IMPACTS AND ADAPTATION

This section discusses the vulnerability of physical and ecological systems, human health and socio-economic sectors to changes in climate. It begins with a summary of a number of common conclusions. The report then describes to the extent possible: (i) the functions and current status of each system; (ii) the sensitivity of each system to climate change and other environmental and human-induced factors; and (iii) the vulnerability of each system to climate change, taking into account adaptation options and impediments to adaptation.

While much progress has been made in understanding the climate system and the consequences of climate change, there are still large uncertainties. In particular, our understanding of some key ecological processes remains incomplete, the current ability to predict regional changes in climate is limited, and it is unclear to what degree climate will become more variable. Changes in climate variability and in the frequency and intensity of extreme weather events would have important implications for both ecological and social systems.

Common Conclusions

While there will be some beneficial effects of climate change, there will be many adverse effects, with some being potentially irreversible. Most systems which

have been evaluated are sensitive to changes in climate, hence societies will be confronted with changes and the need to adapt to them. Some systems are more sensitive to climate change than others, and the effects will vary from one location to another. The following conclusions are common to many ecological and socio-economic systems:

- Human-induced climate change represents yet another important stress in a world where many systems are already threatened by non-sustainable management practices. Although climate change may be the major stress factor affecting some systems during the coming decades, e.g., the cryosphere, this may not be the case for other systems such as agriculture, water resources, human health, tropical forests, and fisheries.
- Quantitative projections of the impacts of climate change on any particular system are difficult because: (i) regional scale climate change predictions are uncertain; (ii) our understanding of many critical processes is limited; and (iii) the systems are subject to multiple environmental and non-environmental factors. Moreover, most impact studies have assessed how systems would respond to a climate change resulting from an arbitrary doubling of atmospheric carbon dioxide concentrations from today's levels. Very few have considered the dynamic response to steadily rising greenhouse gas concentrations. These factors, coupled with the dearth of adaptation studies, precludes a detailed quantitative assessment of vulnerabilities and risks.
- Elevated levels of carbon dioxide in the atmosphere have important direct effects on plant growth; this has implications for the productivity of natural and managed systems and for the interactions among species.
- The more that future climate scenarios extend beyond the boundaries of empirical knowledge (i.e., the documented impacts of climate variation in the past), the more likely it is that actual outcomes would include unpredicted outcomes.
- The ability to adapt to a changing climate is improving because of technological advances. However, the majority of human beings do not have access to such technological capabilities. The efficacy/cost-effectiveness of adaptation strategies will often depend upon existing management, institutional, legal and regulatory practices, which may themselves exacerbate vulnerability to climate stresses.
- Measures to assist adaptation in unmanaged ecosystems, such as design of migration corridors, are not well developed. Human activities have fragmented most landscapes, thus limiting potential for adaptation.
- Society has made itself more vulnerable to natural climatic variability and extreme climatic events (floods and severe storms) by increasing the population density in sensitive areas such as river and coastal plains, hill slopes, and marginal lands.

- Incorporation of environmental and sustainability concerns into resource-use and development decisions and plans for regularly scheduled investments in infrastructure will enhance society's resilience to climate change.
- Unambiguous detection of climate-induced changes in most ecological and social systems will be extremely difficult in the coming decades given the complexity of these systems and their sensitivity to a large number of environmental and non-environmental factors that are all expected to change simultaneously.

Terrestrial Ecosystems

Terrestrial ecosystems such as forests, rangelands, and deserts are regulated by numerous aspects of the physical environment including atmospheric composition, soil properties, topography, and climate variables such as temperature, precipitation,

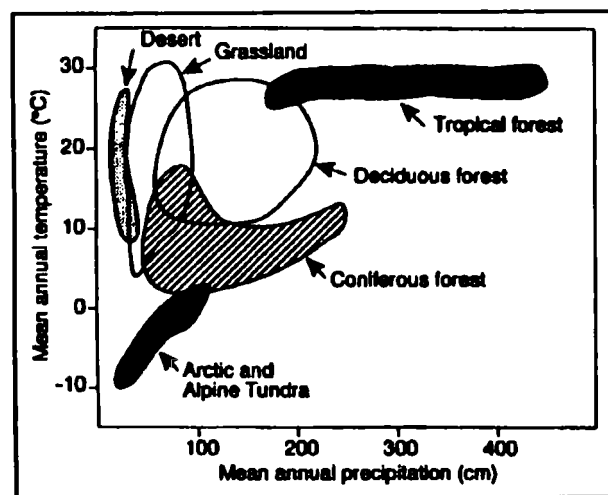


Figure 3. Approximate Distribution of the Major Biotic Regions [Note: Based on mean annual temperature and mean annual precipitation. To convert C to F, multiply by 2.8 and add 32; to convert centimeters to inches, multiply by 0.394.]—adapted from A.L. Hammond, "Ecosystem Analysis: Biome Approach to Environmental Science," *Science*, vol. 175, 1972, pp. 46-48.

and cloudiness (see Figure 3). Changes in climate, and associated changes in the frequency of fires and prevalence of pests, could alter the structure (species composition and biological diversity), function and productivity of terrestrial ecosystems, thus affecting the goods and services they provide to society. These services include: (i) processing and storing carbon and other nutrients, which affect the atmospheric concentrations of greenhouse gases such as carbon dioxide, methane, and nitrous oxide; (ii) providing a source of food, fiber, and energy; (iii) regulating water runoff,

thus controlling floods and soil erosion; (iv) assimilating wastes and purifying water; and (v) providing opportunities for tourism. These systems are under major pressures from population increases and human decisions about land use. These disturbances will probably represent the greatest stress factors on most terrestrial ecosystems for the foreseeable future.

The response of species and ecosystems to elevated levels of atmospheric carbon dioxide concentration must be taken into account in analyzing the potential impacts of climate change. Elevated levels of carbon dioxide in the atmosphere may increase the net primary productivity of plants through its effects on photosynthesis and water-use efficiency. Such changes would alter species composition by changing the balance among different plants, in particular between C3 and C4 plants. While these effects have been quantified at the leaf to plant level in controlled settings, they have rarely been quantified at the ecosystem level because interactions among plants in their natural environments are complex and depend upon changes in other factors such as temperature, soil moisture, and availability of nutrients. Hence, the magnitude and persistence of the so-called "carbon dioxide fertilization effect" remains controversial. Despite possible increases in plant growth, the amount of carbon stored in an ecosystem may still decrease because decomposition of leaves and other plant organic matter is strongly stimulated by increases in temperature.

The consequences of climate change for some terrestrial ecosystems depend critically on the rate at which change takes place. The rate at which climate zones shift is important because different plant species migrate at different rates, depending on their growth and reproductive cycles.

Forests. Forests consist of a wide range of species with complex life-cycles, some of which span centuries. Forest ecosystems contain 80 percent of all above-ground carbon in vegetation, and about 40 percent of all soil carbon. Forests also play a major role in the carbon cycle as sources (through deforestation) and sinks (reforestation, afforestation, and enhanced growth resulting from carbon dioxide fertilization). Forests, particularly in the tropics, may contain as much as two-thirds of the world's biodiversity. They have a direct effect on local climate up to the continental scale by influencing ground temperatures, evapotranspiration, surface roughness, albedo, cloud formation, and precipitation. They are also important to human societies, providing subsistence, employment, and economically-important products.

Forest ecosystems are affected by a variety of biological, chemical, and physical factors in the environment. The number of forest species and forest productivity generally increase with increasing quantity and seasonality of precipitation, nutrient availability, and temperature. Forests are particularly vulnerable to changes in extremes of water availability (either drought or water-logging) and may decline

Regional Aspects of Climate Change on Forests and Rangelands

Tropical forests—Temperature increases are less likely to have significant impact on tropical forests compared to temperate and especially boreal forests. However, changes in seasonality and reductions in rainfall amounts could become important by accelerating forest loss in drier areas, introducing seasonality to present ever-wet forests, and increasing the current loss in biodiversity. In general, tropical forests are likely to be affected by human activities causing conversion to other land cover types. The CO₂ fertilization may have its greatest effect on net primary productivity, leading to a gain in net carbon storage because of the small rate at which the associated soil respiration increases in this zone.

Temperate forests—Warming and elevated CO₂ are likely to increase the net primary productivity of unstressed forests that are not nutrient-limited, but net carbon storage may not change much because of the associated increases in soil respiration. The impacts of climate change on temperate forests could be ameliorated by the fact that many are in developed countries; the latter have greater resources than developing countries to respond by, for instance, exercising fire control or undertaking afforestation.



Assessed Average Changes in Biomes under 2 x CO₂ Scenarios using MAPSS—after Neilson, 1993: "Vegetation redistribution: a possible biospheric source of CO₂ during climate change," *Water, Air and Soil Pollution* (70), 659-673.

Boreal forests—Boreal forests are likely to experience the largest impacts, where in addition to direct effects of climate change, indirect effects such as increased fire frequency and pest outbreaks are likely to decrease the average age, biomass and carbon storage. The transition between the temperate and boreal forest will undergo the largest movement, with temperate forests migrating northward. The net primary productivity of undisturbed forests is likely to increase in response to warming, partly mediated by increased nitrogen mineralisation. However, there may be a net loss of carbon from the ecosystem because of the associated increases in soil respiration.

Tropical rangelands—Temperature increases *per se* should not lead to major alterations in tropical rangelands, except along borders where some species may currently be limited by the infrequent frosts. The most severe consequence could be due to altered rainfall (seasonality and amount). In terms of productivity, a major impact would be the influence of increasing levels of CO₂ on photosynthesis.

Temperate rangelands—Temperate rangelands and associated savannas and shrublands are clearly vulnerable to climate change. Because of the high correlation between rangeland types and climate belts, any shifts in temperature and precipitation will be accompanied by corresponding shifts in rangeland boundaries. In continental areas which may experience drier conditions during the growing season, one possible influence of climate change may be the shift of grasslands to shrublands.

Tundra—Tundra systems are expected to be highly sensitive to climatic warming, which is expected to be greater at higher latitudes. Indirect temperature effects associated with increases in the amount of frozen soil and with changes in nutrient availability will result in shifts in species composition. It is expected that melting of Arctic permafrost in a warmer climate will result in a net source of carbon and methane into the atmosphere.

rapidly under changed conditions. Investigations show that increases in mean annual air temperature of only 1°C are sufficient to cause changes in the growth and regeneration capacity of many forest species, and hence in the composition of forest ecosystems. While it can be inferred that higher rates and larger magnitudes of change will impact forests more strongly, it is not possible to conclude whether change in ecosystems will be a linear or non-linear function of mean temperature change. Global models project that a substantial fraction (14-65% with a global mean of 34%) of the existing forested area of the world will undergo major changes in vegetation types, (i.e. transform from one equilibrium vegetation class

1 to another) in response to climate change (doubled carbon dioxide equilibrium
2 scenarios). Such a transition will have implications for commodity extraction and
3 management practices within forests, especially in tropical developing countries.
4 Climate change is expected to occur at a rapid rate relative to the speed at which
5 forest species grow, reproduce and re-establish themselves. A global average
6 warming of 1-4°C over the next 100 years would be equivalent to a poleward shift
7 of isotherms of approximately 160-640 km. This compares to forest migration
8 rates that are generally believed to be on the order of 4 - 200 km per century,
9 based on the paleoenvironmental record. Migration is dependent on a combination
10 of environmental factors and vectors responsible for seed dispersion and success-
11 ful establishment. Species composition of impacted forests is likely to change,
12 entire forest types may even disappear, while new assemblages of species and
13 hence forest ecosystems may be established.

14
15 Mature forests are a large store of terrestrial carbon. In general, temperate and
16 tropical forests contain as much carbon above ground as below ground, but boreal
17 forests contain most of their carbon below ground. Because the maximum rate at
18 which carbon can be lost during times of high forest mortality is greater than the
19 rate at which it can be gained through growth, large amounts of carbon may be
20 released temporarily into the atmosphere. It is unclear whether forests will contin-
21 ue to sequester carbon through growth under conditions of increasing stress,
22 because some experts emphasize resiliency of forest ecosystems, while others their
23 vulnerability. The concept of a time-lag built in the system will need to be taken
24 into account in forest management plans. Although the net primary productivity
25 of forests may increase, standing biomass may not because of stresses caused by
26 changes in species range, the extent and frequency of pest and disease outbreaks,
27 and the increasing frequency and intensity of fires.

28
29 Rangelands. Rangelands (unimproved grasslands, shrublands, savannas, hot and
30 cold deserts, and tundra) occupy 61% of the terrestrial land surface, contain about
31 26 % of the world's total carbon in living and dead biomass, include a large num-
32 ber of economically important species and ecotypes, and sustain millions of peo-
33 ple. Rangelands support fifty percent of the world's livestock, and provide approx-
34 imately 19 billion metric tons of forage (equivalent to 5-10% of net terrestrial pri-
35 mary production) for both domesticated animals and wildlife.

36
37 Rangeland productivity, species composition and fire potential are driven more by
38 climatic variability than mean values. Water availability and water balance are of
39 particular importance in controlling the productivity and geographic distribution of
40 rangeland ecosystems. Small changes in the frequency of extreme temperature and
41 precipitation (flood and drought) events may cause disproportionately large effects
42 which rangeland managers will need to address.

Increases in carbon dioxide are likely to result in reductions of forage quality and
palatability because of increasing carbon to nitrogen ratios and shrub encroach-
ment. These effects will be more evident in low- latitude rangelands where low
nutritional value is already a chronic problem.

Boundaries between rangelands and other biomes are likely to change as a result of
direct climate impacts on species composition as well as indirect factors such as
changes in wildfire frequency and land-use. These effects will be greatest in temperate
rangelands. Migration rates of rangeland vegetation appear to be faster than for forests.

Changes in precipitation and temperature associated with climate change may
change the role of high-latitude tundra systems in the carbon cycle. During the past
decade, tundra has changed from a net sink to a net source of carbon dioxide to the
atmosphere, perhaps due to decreased soil moisture associated with warmer sum-
mers. The tundra and taiga are responsible for 10 percent of the global atmospheric
input of methane. Warming-related changes may dry soils, increase surface oxida-
tion, and hence decrease methane flux, leading to a negative climate feedback.

Devising adaptation strategies for rangeland systems may be difficult in marginal
food producing areas where production is very sensitive to climate change, change
of technology is risky, and the rate of adoption of new techniques and practices is
slow. Decreases in rangeland productivity would result in a decline in overall con-
tribution of the livestock industries to national economies, with serious implica-
tions for food production in many developing areas with pastoral economies.
Adaptation options in more highly-managed pastures include management of for-
age, animal breeding, pasture renewal, and irrigation.

Desertification. The degradation of fragile ecosystems in arid, semi-arid, and dry
sub-humid zones ("desertification") is not primarily a function of observed fluctu-
ation in rainfall or temperature, but rather of land-use mismanagement. However,
droughts may trigger or accelerate desertification and land degradation. Growth of
important plant species is halted when precipitation falls below a certain threshold,
and thus land is likely to be stripped of cover if grazed under these conditions;
however the amount of precipitation needed to sustain growth varies with the tem-
perature, soil moisture capacity, and species. Reversibility of desertification is not
always possible. Irreversibility is more frequent as the environment becomes drier
and the soil shallower. Adaptation to drought and desertification may rely on the
development of diversified and multiple production systems such as agroforestry
techniques and ranching of animals better adapted to local conditions.

Mountain regions cover about 20% of continental surfaces and are a major water
source for most of the world's major river systems. Mountain ecosystems are

SUMMARY FOR POLICYMAKERS—IMPACTS, ADAPTATION, AND MITIGATION

1 under considerable human stress, and climate change will exacerbate existing con-
 2 flicts between environmental and other socio-economic factors.
 3
 4 In mountain regions, a warmer climate will substantially reduce the extent and vol-
 5 ume of glaciers; there will be marked reductions in permafrost and seasonal snow
 6 cover. This will have consequences on regional hydrology, where changes in the
 7 water availability in the source areas will have major impacts on downstream envi-
 8 ronmental characteristics such as soil stability and economic activities such as agri-
 9 culture, tourism, and hydro-power. Species with climatic ranges that are located
 10 close to mountain tops may become extinct because their habitats will disappear.
 11
 12 Because of their climatic and habitat diversity, mountains provide excellent loca-
 13 tions for maintaining biological diversity. In particular, large north-south mountain
 14 chains can facilitate migration under changing climate if appropriately managed.
 15
 16 Disruption of mountain resources such as food and fuel for indigenous populations
 17 in many developing countries may result from climate change. This will be espe-
 18 cially problematic in areas where mountain environments are used for subsistence,
 19 including production of cash crops. Recreational activities that are of increasing
 20 economic significance to many regions are also likely to be disrupted.
 21
 22 **Cryosphere.** Many components of the cryosphere (snow, ice and permafrost),
 23 which cover a substantial portion of the Earth's surface, are particularly sensitive to
 24 changes in atmospheric temperature because of their proximity to the melting point.
 25
 26 During the last century there has been a massive loss and retreat of mountain glaciers, a
 27 reduction in the depth of permafrost, and evidence of later freeze-up and earlier break-up of
 28 river and lake ice in many northern countries. These observations are consistent with an
 29 increase in the annual global mean temperature of between 0.3 and 0.6°C over the last centu-
 30 ry. Projected changes in climate will substantially reduce the areal extent and volume of the
 31 cryosphere over the next century. In particular, there will be pronounced reductions in moun-
 32 tain glaciers, permafrost, and seasonal snow cover. It is likely that by the end of the next cen-
 33 tury between one-third and one-half of all mountain glaciers could disappear. The reduced
 34 extent of glaciers and depth of snow cover may affect the seasonal distribution of river flow
 35 for hydroelectric generation and agriculture. An increase in temperature would increase the
 36 duration of the navigation season on rivers and lakes affected by seasonal ice cover.
 37
 38
 39 **Aquatic Ecosystems**
 40
 41 Aquatic systems encompass oceans, large lakes, wetlands, and coastal regions includ-
 42 ing those of small islands. These systems are sensitive to changes in temperature, pre-

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43 cipation and sea-level and in turn exert important feedbacks on climate by influenc-
 44 ing carbon fluxes. They provide a range of socio-economic values and benefits includ-
 45 ing food, energy, transportation, timber, flood mitigation, water supply, and recreation.
 46
 47 **Oceans** occupy 71 percent of the Earth's surface and are an important component of
 48 the climate system, due to their role in controlling the distribution and transfer of heat
 49 and carbon dioxide within the oceans and with the atmosphere. They provide vital
 50 mineral resources, an environment for living resources ranging from phytoplankton to
 51 whales, and support socio-economic activities such as transportation, fishing, and
 52 recreation. Oceans are sensitive to changes in temperature, freshwater flows and
 53 atmospheric circulation, and the interaction of these factors with other stresses, such
 54 as UV-B radiation and pollution (which is especially important in shallow inland seas
 55 such as the Baltic, and bays and other coastal areas). Climate change will lead to
 56 changes in water level, ocean circulation, vertical mixing and wave dynamics, which
 57 in turn may alter nutrient availability, biological productivity, and heat and carbon
 58 storage capacity, with important feedbacks to the climate system. Paleoclimatic data
 59 suggest that abrupt climatic changes could occur if freshwater influx from melting
 60 ice, glaciers, and river run-off significantly weakens global thermohaline circulation.
 61
 62 **Non-coastal wetlands** are important for water filtration, flood control, timber, fish,
 63 wildlife habitat, and recreation. For example, more than one-third of US endan-
 64 gered species use wetlands as their primary habitat, and numerous other species
 65 rely on wetlands for some part of their life cycles. Because of low decomposition
 66 rates due to anaerobic conditions, low temperature (in high latitude wetlands), and
 67 low pH, organic matter accumulates in many wetlands systems, causing them to
 68 serve as a sink of carbon. Boreal and subarctic peatlands have an estimated carbon
 69 store of 455 GtC (approximately one-third of global carbon stores).
 70
 71 Wetlands are particularly sensitive to changes in precipitation and temperature pat-
 72 terns, vegetation, and other factors that affect the flow of water through these sys-
 73 tems, with the depth, duration, frequency, and season of flooding being particular-
 74 ly important. Changes in wetlands will also affect runoff, evapotranspiration, sed-
 75 iment retention, flood control for downstream systems, recharging of aquifers,
 76 waste processing, and biogeochemical cycling.
 77
 78 The impact of climate change on greenhouse gas releases from wetlands will vary
 79 from site to site. Recent studies indicate that some areas of the arctic have shifted
 80 from carbon sinks of 0.1 GtC per year to sources of 0.1-0.6 GtC per year due to
 81 observed warming and related drying. This process constitutes a strong positive
 82 feedback on the climate system which could release up to 255 GtC. Reduced
 83 moisture in high latitude peat bogs would probably reduce methane emissions
 84 from these wetlands since methane formation is sensitive to changes in moisture.

1 **Coastal ecosystems.** Many commercially-important marine species depend on coastal
 2 wetlands for some part of their life cycle. Furthermore, these systems provide an
 3 important buffer from storms such as tropical cyclones for human infrastructure.
 4 Global climate change will constitute an additional, largely adverse series of impacts.
 5
 6 Coastal ecosystems are sensitive to changes in water level relative to land, as well as
 7 displacement of wetlands and lowlands, erosion of shorelines and habitat, increased
 8 salinity of estuaries and freshwater aquifers, altered tidal ranges in rivers and bays,
 9 changes in sediment and nutrient transport, and changes in the amount of light pene-
 10 trating into aquatic ecosystems. In many regions, intensive human alteration and use
 11 of coastal environments has reduced the capacity of ecosystems to retreat inland.
 12
 13 Impacts on coastal ecosystems will vary widely. Saltwater marshes, mangrove
 14 ecosystems, and coastal wetlands have been disappearing at a rate of 0.5-1.5% per
 15 year over the last few decades. These ecosystems are particularly vulnerable and
 16 will be further threatened by the interaction of climate change, sea-level increase,
 17 and human development. The rate of sea level rise may be faster than sediment
 18 accretion rates in many coastal areas so that existing wetlands will be lost faster
 19 than new ones can be established. Ecosystems on coral atolls and in delta settings
 20 are especially sensitive to climate and sea-level change. Changes in these ecosys-
 21 tems can be expected to have major negative effects on tourism, freshwater sup-
 22 plies, fisheries, and biodiversity. The coastal ocean and inland waters are already
 23 under considerable anthropogenically induced stress.
 24
 25 Increases in seawater temperature pose a major threat to coral reefs, which are the
 26 most biologically diverse marine ecosystems and important for fisheries, tourism,
 27 coastal protection and the maintenance of biodiversity. Sustained increases in water
 28 temperatures of 3-4°C above long-term average seasonal maxima over a 6-month
 29 period can cause significant coral mortality; short-term increases on the order of
 30 only 1-2° can cause "bleaching", leading to reef destruction. Indications are that the
 31 full restoration of coral communities could require several centuries. Coral reefs
 32 may also be sensitive to sea-level rise. While available studies indicate that even
 33 slow-growing corals can keep up with the "best estimate" of sea-level rise (approxi-
 34 mately 0.5 cm/year), these studies do not take account of multiple stresses.
 35
 36
 37 **Water**
 38
 39 Much of the world's agriculture, hydropower production, municipal and industrial
 40 water supply, water pollution control, and inland navigation is dependent on sur-
 41 face and groundwater resources. In turn, these resources are sensitive to the
 42 impacts of climate change on hydrological processes, which determine how pre-

43 cipitation is partitioned between ground and surface water storage (including
 44 snowcover), fluxes to the atmosphere, and flows to the oceans. Changes in precip-
 45 itation and other climatic characteristics will result in changes in evapotranspira-
 46 tion and soil moisture, and consequently may affect the magnitude and timing of
 47 runoff and the frequency and intensity of floods and droughts. In addition,
 48 changes in the hydrological cycle affect land cover and the surface energy balance,
 49 with important feedbacks on the climate system.
 50

51 High latitude regions may experience increased runoff due to increased precipi-
 52 tation, but lower latitudes may experience decreased runoff due to the com-
 53 bined effects of increased evapotranspiration and decreased precipitation. Even
 54 in areas where precipitation is projected to increase, higher evaporation rates
 55 may lead to reduced runoff. Areas where annual runoff increases or where
 56 there are fewer but more intense precipitation events may experience more
 57 flooding episodes and higher lake and river levels. Effects on run-off could be
 58 exacerbated in regions where there is a reduction in the amount of vegetation
 59 (e.g. deforestation, overgrazing, logging).
 60

61 In some continental areas, mountain regions are the most important sources of
 62 water. Changes in the spatial pattern of precipitation and temperature could lead
 63 to altered river flow regimes in mountain watersheds. For example, changes in the
 64 timing of snow-pack melting and/or a slight spatial shift in precipitation patterns
 65 in the mountains will considerably change the cycles of hydrological discharge in
 66 many river basins. These changes would have consequences for water storage and
 67 delivery systems and hydro-electricity production.
 68

69 Changes in vegetation and water management, in conjunction with projected
 70 changes in demand due to factors such as population growth and increased need
 71 for crop irrigation in some locations, complicate the assessment of the potential
 72 effects of climate change on water resources. Current understanding suggests that
 73 climate change can have major impacts on regional water supplies. General
 74 Circulation Models only provide outputs on a large geographic scale and do not
 75 agree on a likely range of changes in average annual precipitation for any given
 76 basin or watershed. Hence they do not provide sufficient information to assist
 77 water managers in making decisions.
 78

79 Reductions in water availability could result in chronic shortages in regions and
 80 nations that are already water limited, and for which there is a considerable
 81 competition among users. Water resources in arid and semi-arid zones are par-
 82 ticularly sensitive to climate variations because the volume of total runoff and
 83 infiltration is low, and because relatively small changes in temperature and pre-
 84 cipitation can have large effects on runoff.

SUMMARY FOR POLICYMAKERS—IMPACTS, ADAPTATION, AND MITIGATION

The increased uncertainty in the future supply and demand of water resources is a key issue for water management. Table 1 illustrates the potential impact on aggregate "per capita" water availability for each country taking into account the effects of projected population growth and climate. There will be significant differences in the regional distribution within each country. The results show that in all developing countries with high rate of population growth, future "per capita" water availability will decrease.

Options for dealing with the possible impacts of a changed climate and increased uncertainty about future supply and demand for freshwater include:

- Conservation through institutional arrangements (e.g. market and regulatory measures) to limit future demands on scarce water supplies.
- Construction of new reservoir capacity to capture and store excess flows produced by altered patterns of snow melt and storms (although

Table 1. Per Capita Water Availability (m³/year, per cap) in 2050—see Chapter 14, this volume.

Country	1990	No Climate Change–2050	GFDL 2050	UKMO 2050	MPI 2050
Cyprus	1,280	770	470	180	1,100
El Salvador	3,670	1,570	210	1,710	1,250
Haiti	1,700	650	840	280	820
Japan	4,430	4,260	4,720	4,800	4,480
Kenya	640	170	210	250	210
Madagascar	3,330	710	610	480	730
Mexico	4,270	2,100	1,740	1,980	2,010
Peru	1,860	880	830	690	1,020
Poland	1,470	1,200	1,160	1,150	1,140
Saudi Arabia	310	80	60	30	140
South Africa	1,320	540	500	150	330
Spain	2,850	2,680	970	1,370	1,660

Notes

- 1) Assumptions about population growth are from the IPCC IS92a scenario based on the World Bank (1991) projections; the climate data are from the IPCC WGII TSU climate scenarios [based on transient model runs of Geophysics Fluid Dynamics Laboratory (GFDL), Max-Planck Institute (MPI) and UK Meteorological Office (UKMO)].
- 2) The results show that in all developing countries with high rate of population growth, future "per capita" water availability will decrease independently of the assumed climate scenario.

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it is often difficult to plan new infrastructure in the absence of improved watershed climate information).

- More efficient management of existing supplies and infrastructure.
- Rehabilitation of vast and presently denuded tracts of upland watersheds, especially in the tropics

Water management is a continuously adaptive enterprise, responding to changing demographic and economic demands, information, and technologies. Experts disagree over whether water supply systems will evolve substantially enough in the future to meet the additional stresses imposed by climate change to infrastructure that will be taxed by potential increases in demand. To the extent that existing water supply and quality problems are not addressed, especially in developing countries, optimistic projections about the availability of adequate water supplies of sufficient quality will not hold. For a number of countries, water availability per capita already falls below commonly-accepted minimum standards (e.g. Kuwait, Jordan, Israel, Rwanda, Somalia, Algeria, Kenya), or is expected to fall below this standard in the next two to three decades (Libya, Egypt, South Africa, Iran, and Ethiopia). In addition, a number of countries in conflict-prone areas are highly dependent on water originating outside their borders (for example, Cambodia, Syria, Sudan, Egypt, and Iraq).

Food and Fiber

Agriculture and forestry are sensitive to two broad classes of climate-induced effects on the quality and quantity of harvestable yield: direct effects from changes in temperature, water balance, atmospheric composition, and extreme events; and indirect effects through changes in soils and the distribution and frequency of infestation of insects, diseases, weeds, and other predators. Fisheries are sensitive to direct climate-change effects such as increases in water temperature and sea level, and changes in precipitation, fresh-water flows, climate variability, and currents, as well as indirect effects such as shifts in food supply and the expansion of ranges where red tides and other biotoxins could lead to increased contamination of fisheries. The vulnerability of food and fiber production to climate change depends not only on the physiological response of the affected organisms, but also on the ability of the affected socio-economic systems of production to cope with fluctuations in yield.

Agriculture. Recent studies have confirmed the conclusion of the 1990 Assessment that the aggregate effects of climate change on global agricultural production are likely to be small to moderate. This conclusion rests on the assumption that without climate change, future agricultural production will rise at a rate that enables it to keep pace with population growth. An alternative view is that the historical trend of generally improving food supply will not be continued because of resource

1 degradation and the inability of technological advances to keep up with population
 2 growth. Simplifying the problem as one of global food supply is partly misleading
 3 because of large differences at *local and regional* scales. Studies tend to show
 4 more negative impacts for areas in the tropics where many of the world's poorest
 5 people live and where individuals are currently at greatest risk of hunger. Large
 6 yield losses in one location and for one type of crop are balanced by large gains in
 7 other locations, both within and among countries (e.g., frequently more than ± 20
 8 %) (see Table 2). Low-latitude, low-income populations depending on isolated, dry-
 9 land agricultural systems in semi-arid and arid regions are particularly vulnerable.
 10 Many of these at-risk populations are found in Sub-Saharan Africa, South, East,
 11 and South East Asia, as well as some Pacific Island Nations.

12
 13 Under such circumstances, access to means for adaptation such as new crops and
 14 crop varieties, improved water management and irrigation systems, and informa-
 15 tion regarding, for example, optimal planting times, will be important in limiting
 16 negative effects and taking advantage of beneficial changes in climate. There is a
 17 wide range of views on the potential of agricultural systems to adapt to climate
 18 change. Historically, farming systems have adapted to changing economic condi-
 19 tions, technology and resource availabilities, and population pressures. Scientists
 20 disagree whether the rate of change of climate and required adaptation would add
 21 significantly to the disruptions resulting from other socio-economic or environ-
 22 mental changes. The extent of adaptation depends in part, on the affordability of
 23 adaptive measures, access to technology, and biophysical constraints such as water
 24 availability, soil characteristics, topography, and genetic diversity that can be bred
 25 into crops. The incremental costs of these adaptation strategies could create a seri-
 26 ous burden for some developing countries.

27
 28 The studies on which these conclusions are based model the change in agricultural
 29 yields induced by climate change and elevated carbon dioxide. These studies
 30 presently do not include changes in insects, weeds, and diseases; direct effects of
 31 climate change on livestock; changes in soils and soil management practices; and
 32 changes in water supply caused by alteration in river flows and irrigation.
 33 Moreover, the studies have considered only a limited set of adaptation measures
 34 and are based on yield analyses at a limited number of sites. The fact that agro-
 35 nomic and economic models are not fully integrated limits the ability of these mod-
 36 els to consider transient climate scenarios and to fully address the costs and poten-
 37 tial of adaptation. The studies also assume that most major food crops, which are
 38 C3 plants, should benefit from improved water use efficiency and increased pro-
 39 ductivity because of enhanced levels of atmospheric carbon dioxide, in contrast to
 40 weeds (C4 plants). The mean value response (a 30 percent increase in C3 crop
 41 yields for a doubled carbon dioxide environment) has been confirmed by recent
 42 experiments, but the variation in response is wide (-10 to +80 percent). The results

Table 2. Yield Results Vary Widely by Crop, Climate Scenario, Study Methodology, and Site (selected crop study results for 2 x CO ₂ equilibrium GCM scenarios, except where noted otherwise).				
Geographic Scope	Crop(s)	Yield Impact (%)	Comments on Study	
AFRICA				
Egypt	Wheat	-75 to -18	Study included the CO ₂ effect; also temperature and precipitation sensitivity	
	Maize	-65 to +6		
Kenya	Maize; all crops	decr.; incr.	Carrying capacity fell 11 to 38% in Senegal; increase for all crops in Kenya with zonal shifts	
Senegal	Millet	-63 to -79		
South Africa	Biomass	decrease	Agrozone shifts, not summarized as average change for entire region	
	Maize	increase		
Zimbabwe	Maize	-5 to -40	Range over studies, climate scenarios; with CO ₂ effect; declining food availability projected	
SOUTHEAST ASIA				
Bangladesh	Rice	-13 to +8	Range over sites, studies, and GCM scenarios; with CO ₂ effect; adaptation results not reported but for rice genetic variation among rice varieties suggested significant scope for adaptation to high temps	
India	Wheat	-50 to +30		
	Rice	-12.2 to +22.8		
Pakistan	Wheat	-61 to +67		
Philippines	Rice	-21 to +12		
Thailand	Rice	-33.5 to +8		
Indonesia	Rice	-6.5 to +22.2	Range over sites, studies, seasons and GCM scenarios; with CO ₂ effect; some studies also consider adaptation	
	Soybean	± 10		
Malaysia	Maize	-65 to -25		
	Rice	-22 to +25.9		
	Maize	-20 to -10		
	Oil Palm	increase		
Mainland China	Rubber	-15		
	Wheat	-8	Study scaled an equilibrium GCM scenario to represent potential change by 2050; positive effects in NE and NW, negative in most of the country, no change in SW	
	Rice	-6		
	Cotton, Fruits,	-4 to +1		
	Oil Crops,			
	Potatoes, Corn			

Table 2 (continued)

Geographic Scope	Crop(s)	Yield Impact (%)	Comments on Study
Mainland China	Rice	-26 to -24	Range is across GCM scenarios; south China study was without CO ₂ effects; genetic variation of rice varieties provides significant scope for adaptation to higher temps Range over sites and GCM scenarios; with CO ₂ effect
South China	Rainfed rice	-78.1 to -6.1	
	Irrigated rice	-37 to +15	
Taiwan Province	Rice	+7.4 to +22.7	
Myanmar	Rice	-8.9 to +30.1	
ASIA AND THE PACIFIC RIM			
Japan	Rice	-45.5 to +29.8	Range is across sites, studies, and GCM scenarios; generally positive in north, negative in south
	Maize	-31 to +51	
	Wheat	-41 to +8	
New Zealand	Temperate pasture	+10 to +77	Range is with and without CO ₂ effect at 500 ppm; increases in milk production (24%), lamb meat and beef (30%) and wool (22%) due to increased stocking rates Range is across GCM scenarios; with CO ₂ effect
South Korea	Rice	-0.4 to +23.2	
LATIN AMERICA			
Argentina	Maize	-36 to -17	Range is across GCM scenarios; with CO ₂ for wheat; with and without CO ₂ for maize; better adapted varieties could eliminate most maize yield losses
Argentina, Uruguay	Wheat	-10 to -5	
Brazil	Wheat	-50 to -15	
	Maize	-25 to -5	Range is across GCM scenarios; with CO ₂ effect, without adaptation; adaptation scenarios did not fully compensate for yield losses; regional variation in response
	Soybean	-10 to +40	
Chile	Maize, Potatoes	increase	
Norte Chico	Wheat, Grapes	decrease	Mountainous area with wide ranging climate greatly limits validity of extrapolation from sites
Mexico	Maize	-61 to -6	
			Range is across GCM scenarios; with CO ₂ effect; adaptation only partly mitigated losses

Table 2 (continued)

Uruguay	Barley Wheat	-40 to -30 -30	Range is with and without CO ₂ effect; increased yield variability
FORMER SOVIET UNION			
Russia and Former Soviet Republics	Wheat	-19 to +41 -14 to +13 -27 to -2	Range is across GCM scenarios and region; with CO ₂ effect; grain and grassland yield scaled to 2050 and also considers ozone and soil degradation effects
EUROPE			
Finland	Potential yield	+10 to +20	Northward shift; with adaptation & CO ₂ effect; GISS, GFDL, UKMO Quality affected by temperature; longer season
France	Wheat	increase or decrease	
Northern Europe	Maize	increase	
	Maize (fodder)	increase	
Spain	Wheat	increase	
	Maize	-30 to -8	With adaptation and CO ₂ effect; irrigation efficiency loss
United Kingdom	Wheat/Grain Vegetables Lettuce	incr. or decr. increase level	Increased pest damage, lower risk of crop failure
NORTH AMERICA			
Canada	Wheat	-40 to +234	Range across studies, sites, GCM scenarios, and with and without adaptation; with CO ₂ effect, negative effects due to drought and insufficient precipitation
Alberta;	Oats, Barley	incr. and decr.	
Manitoba;	Flax, Canola,	for other crops	
Saskatchewan and Ontario	Hay, Maize, Potatoes		
USA			
Missouri, Iowa,	Maize	-23 to -6	Analog 1930's climate; more severe effect: without CO ₂ or adaptation; less severe or increase with CO ₂ and adaptation
Nebraska,	Sorghum	-20 to +36	
Kansas	Wheat	-11 to +17	
	Soybean	-26 to +2	
Sites across USA	Alfalfa	-5 to +22	Range across GCM scenario and sites; with CO ₂ , without adaptation; average for total USA: wheat, -2 to -20; maize, -15 to -30; soybean, +15 to -40
	Soybean	-96 to +58	
	Maize	-55 to +62	
	Wheat	-100 to +180	

cannot be extrapolated to a large scale and over the whole growing season, as transpiration and vapor pressure deficit may be altered. Moreover, temperature increases may have the opposite effect. An accurate multi-stress analysis of agricultural systems remains beyond the present state of our scientific knowledge.

Forestry. Future trends in annual forest stock growth rates (currently 2% per year) brought about by changes in climate and atmospheric composition are unknown: they may remain constant, increase from warming and enhanced atmospheric carbon dioxide concentration, or decrease from stress-induced growth declines and mortality.

Tropical forest product availability is likely to be limited by changes in land use rather than in climate and atmospheric chemistry, at least through the middle of the next century, by which time growing stock is projected to have declined by about half due to deforestation. This projected standing stock decline appears even after calculating changes in climate and atmospheric chemistry during this period, which could increase the productivity and area where tropical forests can potentially grow (see "Terrestrial Ecosystems: Forests", above). Rural and indigenous communities depending on forests in the tropics for fuelwood, nutrition, medicines, and livelihood will be most affected due to declines in forested area, standing stock, and biodiversity.

Temperate zone forests are likely to continue meeting requirements for forest products on a sustainable basis for at least the next century. This conclusion is based on projected climate and land use changes that leave temperate forest covering about as much land by the year 2050 as today, and on the assumptions that current harvests increase only slightly, that the annual growth increment remains constant, and that an increasing proportion of requirements for forest products will be met by imports from outside the temperate zone.

Harvests in boreal forests may be controlled by climate-induced irregular and large-scale mortality events that cannot be simulated or predicted with current models. In addition, current and future needs for boreal forest products are largely determined outside the zone by importers. Future requirements for forest products may exceed the projected availability of boreal industrial roundwood during the 21st century based on the analysis of temperate and tropical zone forest standing stocks and requirements.

Options for adapting to and ameliorating future potential global timber supply shortages must focus primarily upon modifying land clearance practices in the tropics (including reducing social pressures driving land-conversion for example by increasing crop and livestock productivity), on technological buffering of harvest shortfalls in temperate zones, and on adapting to potential climate-induced large-scale disturbance of boreal forests. Increased prices for forestry products can also be expected to lead to adaptation measures that will reduce demand.

Fisheries. Climate change effects will interact with other stresses on fisheries, including pervasive over-fishing, diminishing nursery areas, and extensive inshore and coastal pollution. While overfishing is a more important stress than climate change today, should fisheries management improve and climate develop according to the IPCC scenarios, the relative importance of climate change may increase during the last half of the next century.

Globally, marine fisheries production is projected to remain about the same, while higher latitude freshwater and aquaculture production are likely to increase, assuming that natural climate variability and the structure and strength of ocean currents remains unchanged. If either changes, there would be significant impacts on the distribution of major fish stocks, rather than on global production. Positive effects, such as from longer growing seasons, lower natural winter mortality, and faster growth rates in higher latitudes, may be offset by negative factors such as changes in established reproductive patterns, migration routes, and ecosystem relationships. Climate change can be expected to have the greatest impact on (in decreasing order of impact): 1) fresh water fisheries in small rivers and lakes, in regions with larger temperature and precipitation change; 2) fisheries within exclusive economic zones particularly where access regulation mechanisms artificially reduce the mobility of fisher groups and fishing fleets and thus their capacity to adjust to fluctuations in stock distribution and abundance; 3) fisheries in large rivers and lakes; 4) fisheries in estuaries, particularly where there are species without migration or spawn dispersal paths, or estuaries impacted by sea level rise or by decreased river flow; and 5) high seas fisheries. Where there is rapid change due to physical forcing (e.g. changes in currents and natural variability), production will usually favor smaller, low priced, opportunistic species that discharge large numbers of eggs over long periods. Loss of coastal wetlands may have significant adverse effects on fisheries due to loss of nurseries.

If institutional mechanisms do not enable fishers to move across national boundaries, some national fish industries may be negatively impacted. Subsistence and other small scale fishers, lacking mobility and alternatives, are often most dependent on specific fisheries and will suffer disproportionately from changes.

Several adaptation options exist. These include improvement of fisheries management systems, ecological and institutional research, and expansion of aquaculture.

Human Infrastructure

Human infrastructure is a key determinant of a region's productivity and development. It includes all varieties of human-made capital and assets: residential and

1 commercial properties; highways, railroads and other transportation facilities;
2 industries and manufactured goods; construction equipment; coastal embankments;
3 and equipment for energy production and distribution. Human infrastructure and
4 socio-economic systems including energy, industry and transportation may be
5 affected *directly* through changes in temperature, precipitation, sea-level, or
6 extreme events which can damage exposed infrastructure or affect outputs. Due to
7 the interconnectedness of economic activity, many of the impacts of climate
8 change in the industry, energy and transport sectors are expected to be *indirect*,
9 and transmitted by transactions within and between economic sectors. An addition-
10 al indirect mechanism that may put pressure on various components of human
11 infrastructures is human migration in response to, for example, chronic crop fail-
12 ures or regional flooding.

13
14 The lifetimes of most assets are relatively short and the normal cycles of planning
15 and investment occur on time scales much shorter than those that characterize cli-
16 mate change (see Table 3). In many sectors, the impacts of climate change will be
17 less than those resulting from changes in demography, technology, and markets.
18 This optimistic assessment must be balanced with the recognition that much capi-
19 tal is invested in locations that could be impacted by climate change; relocating or
20 defending this infrastructure can be expected to be costly and to require a high
21 degree of foresight and coordination.

22
23 Industry, Energy and Transportation. In general, most activities in these sectors
24 are relatively insensitive to climate change, while the capacity for autonomous
25 adaptation is expected to be high, as long as climate changes are gradual. The
26 sub-sectors most sensitive to climate change include agro-industry; construc-
27 tion; offshore oil and gas production; manufacturing heavily dependent on
28 water supplies; and renewable energy production including hydroelectric gener-
29 ation, biomass and wind. Hydroelectric power generation will depend upon the
30 balance between changes in the amount and timing of precipitation and evapo-
31 ration. Increased scarcity of fuelwood in dry and densely populated regions
32 could exacerbate problems caused by deforestation. Peak winter demand for
33 primary energy may decrease due to a reduction in space heating needs, but
34 peak summer demand for electricity may increase with greater cooling require-
35 ments in some regions.

36
37 In comparison with research on mitigation options, relatively few studies have
38 been conducted on climate change impacts on and adaptation options for the
39 industry, energy and transportation sectors. This situation reflects the perception
40 that vulnerability to climate change is generally low, as well as the fact that miti-
41 gation policies would generally have a much larger and more immediate economic
42 impact than the anticipated direct effects of climate change.

Coastal Zones/Small Islands. Many coastal zones and small islands are particularly
vulnerable to direct effects of climate change and sea-level increase. Present best
estimates of global average sea-level rise range from 10 to 75 cm for the year
2100, about 30% less than values reported in the 1990 Assessment. Still, the pre-
sent estimates represent a rate of sea-level rise that is two to four times that experi-
enced during the last 100 years. Recent scientific findings indicate that sea-level
rise may deviate from the global average by a factor of 2 or more due to regional
differences in the ocean salinity and climate change.

Sea-level rise can have negative impacts on tourism, freshwater supplies, fisheries,
exposed infrastructure, agricultural and dry lands and wetlands. Impacts may vary
across regions and societal costs will greatly depend upon the vulnerability of the
coastal system and the economic situation of the country. Sea-level rise will also
increase the vulnerability of coastal populations to flooding. Currently an annual
average of about 50 million people experience flooding due to storm surges; a 50
cm sea-level rise would increase this number to about 90 million, and a 1 meter
sea-level rise would put close to 120 million people at risk. The estimates will be
substantially higher if one incorporates population growth projections. Developing
country populations will be more vulnerable because their existing sea and coastal
defense systems are less well established and also because their population growth
rates are disproportionately higher, thus putting more people at risk. The total pro-
tection costs for OECD countries facing a sea-level rise of 50 cm by 2100 have
been estimated at US \$521 million per year.

Integrated Coastal Zone Management (ICZM) could help both developing and
industrialized countries achieve the twin objectives of addressing immediate socio-
economic concerns while at the same time developing responses to longer-term
events, such as climate change impacts. ICZM is not a unique strategy but rather
constitutes a portfolio of structural, legal, financial, economic and institutional
measures which countries may want to consider as part of their overall response
strategy. Constraints which could hinder successful implementation of ICZM
include technology and human resources capability; financial limitations; cultural
and social acceptability and political and legal bottlenecks.

Human Settlements. Climate change will affect human settlements in the context
of other environmental and socio-economic changes such as population growth,
migration, industrialization, and government policy. Settlements are most vulnera-
ble to climate change in locations already stressed by these forces. Besides coastal
communities and those dependent on subsistence rain-fed agriculture or commer-
cial fishing, vulnerable settlements include large primary coastal cities and squat-
ter settlements located in flood plains and steep hillsides. Many of the expected
impacts in the developing world will occur because climate change may reduce

Table 3. Examples of Climate Sensitivities in the Industry, Energy, and Transportation Sectors—see Chapter 11, this volume.

	Temperature (T); Precipitation (P)	Windiness (W); Frequency of Extreme Events (F)	Water Availability (WA); Sea-Level Rise (S)	Other
Energy Demand	• space heating, air conditioning (T)	• space heating (W)		• humidity effects on air conditioning
Energy Extraction	• reduced impacts of ice on offshore Arctic operations (T)	• offshore oil and gas operations (F)		
Energy Conversion	• efficiency of thermal generation (T)		• cooling water availability (WA) • coastal power stations, refineries (S)	
Renewables	• impacts on evaporation from reservoirs (T) • hydro-electric potential (P)	• wind, wave energy potential, reservoir evaporation (W) • many renewable systems vulnerable, especially wind turbines, solar systems (F)	• hydro-electric potential (WA) • design of tidal, wave systems (S)	• cloudiness effects on solar potential
Energy Transport/ Transmission	• permafrost and pipelines (T) • capacity of power lines (T)	• effects on power lines (F)		
Transportation Infrastructure	• effect of freeze-thaw cycles on roads (T)		• effects on coastal infrastructure, migration of coastal activity (S)	• changes in demand due to changes in movements of agricultural products; changes in settlement patterns
Transportation Operations	• road maintenance costs; air conditioning in cars (T) • ice and coastal shipping in high latitudes (T) • impacts of snow and ice on road and air transport (P)	• safety and reliability of operations (F)	• inland navigation during drought (WA)	• effects of fog, snow, rain, ice on operations and safety
Tourism/Recreation	• skiing (T, P)		• impacts on beach resorts (S)	• many climate variables will affect demand for and location of tourism/ recreation facilities
Construction	• building design (T) • changed productivity of construction activity (snow, rain) (P)	• impacts on construction activity, building design (F)	• markets created by coastal zone management (S)	
Manufacturing	• demand for space heating, air conditioning equipment (T) • markets for clothing, beverages (P)		• availability of process water for heavy users (WA) • industries heavily dependent on hydropower (WA)	
Pollution Control	• ozone formation and control (T)		• water quality and discharges (WA)	
Agro-Industry	• impacts on agricultural inputs (T,P)	• damage to crops, trees, industrial infrastructure (F)	• impacts on coastally sited fish processing (S)	• main impacts via agricultural inputs
Biomass	• impacts on agricultural inputs (T,P)	• damage to crops, trees (F)		• main impacts via agricultural inputs

1 natural resource productivity in rural areas and may thus generally accelerate
 2 rural-to-urban migration. Direct impacts on human settlements infrastructure
 3 would most likely occur through the effects of extreme events. This includes
 4 coastal storm surge, river floods and landslides induced by local downpours, wind-
 5 storms, rapid snowmelt, tropical cyclones, and forest and bush fires made possible
 6 in part by more intense or lengthier droughts.
 7
 8 **Insurance and financial services.** Within the sector of financial services, prop-
 9 erty insurance is the most vulnerable to direct climatic influence through
 10 extreme events. It is a perception of some in the insurance industry that there
 11 is a current trend towards increased frequency and severity of extreme climate
 12 events. Examination of the meteorological data does not support this percep-
 13 tion in the context of a long-term change, though there may have been a shift
 14 within the limits of natural variability. However, the insurance industry is cur-
 15 rently stressed from a series of "billion dollar" storm events every year since
 16 1987 (see Table 4), resulting in drops in capacity and dramatic increases in
 17 insured losses and premiums. If climate change were indeed to increase the
 18 cost of such incidents beyond its current historical high level, this could
 19 result in the effective withdrawal of insurance, particularly in coastal zones.
 20 Adaptation may prove difficult given the long-term nature of many financial
 21 commitments. The implications of climate change for financial services out-
 22 side of property insurance are less clear and generally have not been acknowl-
 23 edged by decision-makers in these sectors.

24
 25
 26 **Table 4. Insured Losses from "Billion Dollar" Storm Events since 1987**

28 Year	29 Event	30 Insured Loss (\$B)
31 1987	32 "Hurricane" (S.E. England/Brittany)	33 2.5
34 1988	35 Hurricane Gilbert (Jamaica/Mexico)	36 0.8
37 1989	38 Hurricane Hugo (Puerto Rico/South Carolina)	39 5.8
40 1990	41 European Storms (4 total)	42 10.4
43 1991	44 Typhoon Mireille (Japan)	45 4.8
46 1992	47 Hurricane Andrew (Florida)	48 16.5
49 1993	50 "Storm of the Century" (Eastern U.S.)	51 1.7
52 1994	53 Winter Storms in Germany	54 2.0

55
 56 Source: Munich Re, 1990: "Windstorm - New Loss Dimensions of a Natural Hazard,"
 57 Munich Reinsurance Company, Munich; Leggett, J., 1994: "Climate change.
 58 Presentation to the 26th Annual Meeting of the Reinsurance Association of
 59 America, 29 April, Laguna Niguel, California," Greenpeace International.
 60

Adaptation Options for Human Infrastructure. The literature remains weak on
 questions of adaptation. Adaptation will occur autonomously in many sectors
 because life cycles of planning and investment are shorter than those associated
 with climate change. Autonomous adaptation, however, depends on people and
 organizations being adequately informed about potential impacts. Incorporation of
 potential climate and sea-level changes in planning would reduce the risk that
 human infrastructure would be mal-adapted to future circumstances. The uncer-
 tainty about the rate and effects of climate change therefore often makes costly
 investment decisions difficult to make.

Many developing countries are currently very dependent on a limited number of
 crops or on fishing and are hence economically vulnerable to climate change
 through impacts on agro-industry. For these countries in particular, diversifying
 economic activity, coupled with integrated management practices, could consti-
 tute an important precautionary response and facilitate successful adaptation to
 climate change. Constraints hindering the implementation of such integrated
 management practices include but are not limited to: technology and human
 resource capability; financial limitations; cultural and social acceptability; and
 political and legal frameworks.

Human Health

Human health is sensitive to changes in climate and the impacts of climate change
 on food security, water supply and quality, and the distribution of ecological sys-
 tems. Projected changes in climate are likely to result in a wide range of health
 impacts, most of them adverse, and many of which would reduce life expectancy.
 Changes in climate could affect human health:

- **Directly** by increased exposure to very hot weather events and more frequent weather hazards (e.g., droughts, floods and severe storms)
- **Indirectly** by increasing the transmission of vector-borne diseases via increases in the geographic distribution of vector organisms of infectious diseases (e.g., mosquitoes that spread malaria, dengue and yellow fever; schistosome-spreading snails), and altering the life-cycle dynamics of both vector and infectious parasites.

Indirect effects could be substantial. For example, the potential transmission of malaria in 2100 could increase by approximately 20% (i.e., an extra 50-80 million prevalent cases) in response to the IPCC (1990) climate scenarios. Any such increase would primarily affect tropical, subtropical, and some less well protected temperate-zone populations, currently at the margins of endemically infected areas. Further indirect effects

may also include an impairment of nutritional status, in at least some developing country populations, because of regional decreases in food production; exacerbation of respiratory disorders and allergies caused by climate-enhancement of air pollution (ozone and particulates); and increased transmission of certain contagious diseases (e.g., cholera, including via an increase in algal blooms in warm coastal waters and wetlands).

Quantifying the predicted adverse health-related impacts of climate change is difficult. For many impacts, the use of forecasting techniques, especially modeling, is poorly developed. Further, the seriousness of climate-induced health disorders depends on many other coexistent (perhaps interacting) factors, including environmental circumstances and socio-economic factors such as nutritional and immune status, water purity, population density, social infrastructure, and access to health care.

5. OPTIONS TO CONTROL THE SOURCES AND ENHANCE SINKS OF GREENHOUSE GASES: MITIGATION

Common Themes and Conclusions

- An extensive array of technologies and policy measures capable of mitigating greenhouse gas emissions is available. However, social, institutional, financial, market, and legislative barriers to their application and implementation limit their actual contribution to mitigation, i.e., realized potential is often significantly less than technical potential.
- Actions to reduce greenhouse gas emissions are likely to be easier to implement if they are designed to simultaneously address other concerns that impede sustainable development and will be more effective if they use well-integrated mixes of policies, tailored for local situations and developed through consultation with stakeholders.
- Continued commitment to research is essential if technologies are to be developed that will lead to a reduction in greenhouse gas emissions.

Agriculture, Rangelands, and Forests

Well managed agricultural lands, rangelands and forests can play a key role in reducing current emissions and/or enhancing the sinks of carbon dioxide, methane, and nitrous oxide. While the emissions of carbon dioxide far exceed those of methane and nitrous oxide, the global warming potentials of these gases are relatively high, hence these gases are significant contributors to the anthropogenic greenhouse effect (methane about 20% and nitrous oxide about 7%) and controlling their emissions can make an important contribution to reducing radiative forcing.

Agriculture is responsible for nearly 50% of anthropogenic methane emissions and nearly 70% of anthropogenic nitrous oxide emissions.

Proposed options for conserving and sequestering carbon and reducing other greenhouse gas emissions in the forestry and agriculture sectors are consistent with other objectives of land management such as sustainable development, industrial wood and fuelwood production, traditional forest uses, protection of other natural resources (e.g., biodiversity, soil, water), recreation, and increasing agricultural productivity.

Carbon Dioxide. Over the long term, some management of forest and agricultural lands for the production of biomass to substitute for fossil fuels can be more effective than management of lands to increase carbon storage. Biomass for the production of energy (electricity or liquid fuels) is more beneficial because it can be continually harvested and regrown to substitute for fossil fuels and produces an income to the landowner (see section on energy supply), while carbon storage in vegetation and soils would saturate over time.

In the forestry sector, under baseline conditions (present climate and no change in the estimated area of available lands over the period of interest), the cumulative amount of carbon that could feasibly be conserved and sequestered over the period 1995-2050 could be between about 60 and 90 GtC (see Table 5; 1 GtC = 1 billion

Table 5. Estimates of the amount of carbon that could be conserved and sequestered in their forestry (including vegetation and soil) and agriculture (soil only) sectors over the next 50 years—see Chapters 23 and 24, this volume.

Management Option	Potential Area (Mha)	GtC
Establishment of plantations	275	31
Establishment of agroforestry	70	7
Forest regeneration	220	12-29
Slowing deforestation	140	11-21
Improved management of agriculture soils ¹	1600	20-30
Restoration of degraded agricultural lands	1200	4-12
Improved management of rangelands	3700	5-25
Total		90-155²

¹ Increased crop yields and residue returns, and reduced tillage.

² 90-155 GtC is equivalent to 16-26% of the projected IPCC IS92a scenario cumulative fossil fuel carbon emissions over the same period.

tons of carbon). The tropics have the potential to conserve and sequester the largest quantity of carbon (80% of the global total), more than half of which would be due to promoting forest regeneration and slowing deforestation. Tropical America has the largest potential for carbon conservation and sequestration (46% of tropical total), followed by tropical Asia (34%) and tropical Africa (20%). The temperate and boreal zones could sequester about 20% of the global total, mainly in the USA, temperate Asia, Former Soviet Union, China, and New Zealand.

There are three primary reasons for the significant uncertainties associated with estimating the amount of carbon that can be conserved and/or sequestered: (i) estimates of land availability for forestation and regeneration programs; (ii) the rate at which tropical deforestation can actually be reduced; and (iii) the long-term use (security) of these lands. The net amount of carbon per unit area conserved or sequestered under a particular forest management practice is relatively well understood.

Land availability in the tropics for the implementation of forest management mitigation options could significantly decrease in the future because of conversion of these forests to other uses, for example, agriculture. Tropical forests will be lost unless improvements in agricultural technology can improve soil productivity to decrease new land requirements. In addition, there is a need to reduce the dependence of several billion people on the unsustainable use of forests for fuelwood and charcoal.

The cumulative cost, excluding land costs, to conserve and sequester the above amounts of carbon in forests range from about US\$250 billion to \$300 billion at a unit cost of about \$2-8 per ton of carbon. Costs per unit of carbon sequestered or conserved generally increase from low to high latitude nations, and from slowing deforestation to establishing plantations. However, the cost estimates could be several times higher if additional costs of land and of establishing infrastructure, protection, training programs, and tree nurseries were included.

In addition, about 30 to 70 GtC could be sequestered worldwide in agricultural and rangeland soils over a 50 year period by improved management practices that increase productivity and below-ground carbon inputs (Table 5).

Methane and Nitrous Oxide. Significant decreases in methane emissions from agriculture can be achieved through improved nutrition of ruminant animals and better management of paddy rice fields (e.g., irrigation, nutrients, use of new cultivars). Additional methane decreases are possible with altered treatment and management of animal wastes and by a reduction of agricultural biomass burning. These combined practices could reduce methane emissions from agriculture by 25 to 100 Tg/yr. Sources of nitrous oxide in agriculture are mineral fertilizers, legume cropping, animal waste, and biomass burning. These agricultural emis-

sions could be reduced by 0.3 to 0.9 Tg N/year by improving fertilizer and manure-use efficiency with presently available techniques.

Energy Demand and Supply

The production (supply) and use (demand) of fossil fuel energy is responsible for significant atmospheric releases of greenhouse gases, in particular carbon dioxide and methane. In 1990, energy production and use was approximately 350 EJ (1 EJ = 10^{18} J), resulting in the emission of about 6 GtC. The combustion of fossil fuels is also the primary anthropogenic source of sulfur dioxide, the sulfate aerosol precursor.

Global energy demand has grown at an average annual rate of approximately 2% for almost two centuries. During that time, the mix of fuels has changed dramatically (see Figure 4). OECD nations have been and remain major

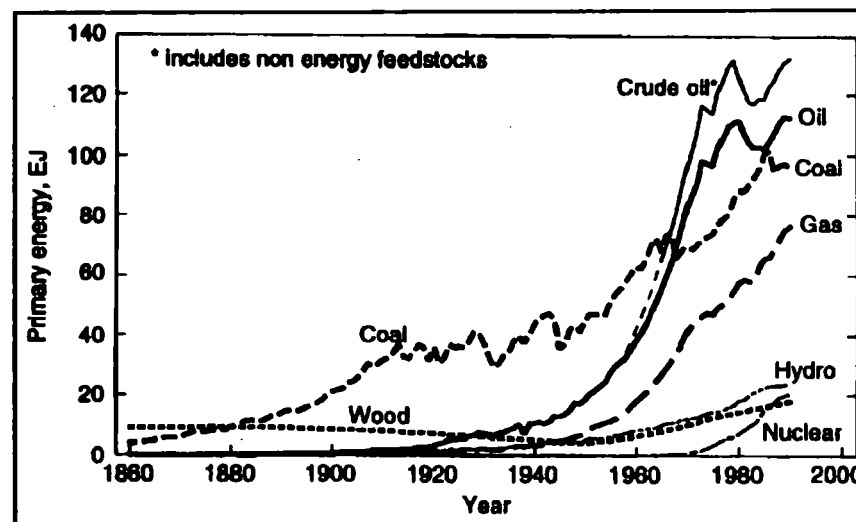


Figure 4. Global Primary Energy Consumption by Source, total in EJ/year (data for crude oil are given including/excluding non-energy feedstocks and excluding draft animals)—adapted from BP, various volumes; IEA, 1993: "Potential applications of Combined Heat and Power Generation Systems." IEA Greenhouse R&D Programme, CRE, Stoke Orchard, UK; Marchetti, C. and Nakicenovic, N., 1979: "The Dynamics of Energy Systems and the Logistic Substitution Models," RR-79-13, IIASA, Laxenburg, Austria.

energy users and fossil fuel carbon emitters, though their share of global fossil fuel carbon emissions has been declining. The contribution to global fossil fuel carbon emissions contributed by the Former Soviet Union and Eastern Europe has grown, though recently economic restructuring has reduced emissions. Developing nations, taken as a group, still account for a smaller fraction of total global carbon emissions than OECD nations, but emissions are growing rapidly with the exception of sub-Saharan Africa (see Figure 5).

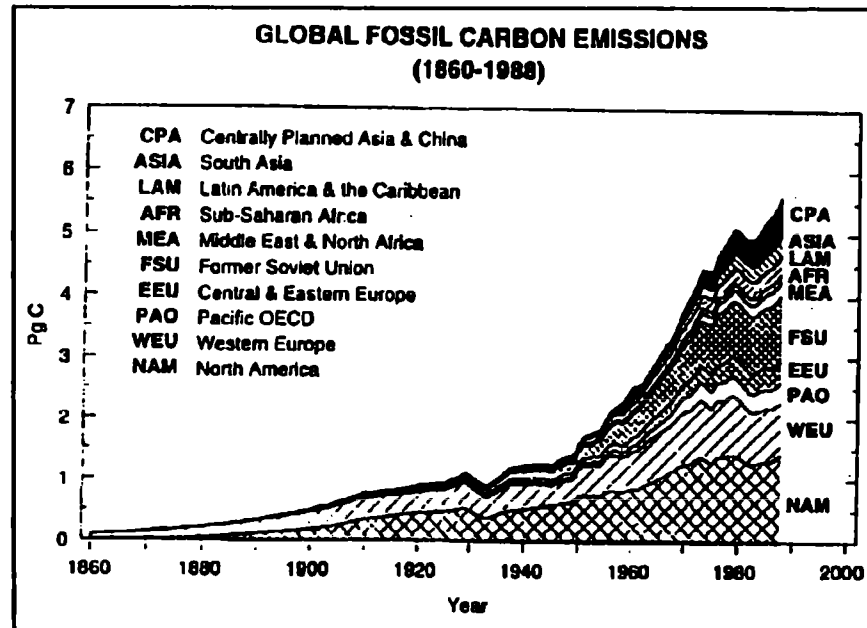


Figure 5. Global Energy-Related CO₂ Emissions by Major World Region (cumulative totals) in PgC/Year—from Marland, G. et al. 1993: "National, Regional and Global CO₂ Emissions Estimates 1950-1991". NDP-030/RS. Carbon Dioxide Information Center, Oak Ridge National Laboratory, Oak Ridge, TN, USA; Grubler, A. and Nakicenovic, N., 1992: "International Burden Sharing in Greenhouse Gas Reduction," Environment Working Paper No. 55, World Bank Environment Department, Washington, DC, USA; Fujii, 1990: "An Assessment of the Responsibility for the Increase in the CO₂ Concentration and Inter-Generational Carbon Accounts," WP-90-55. IIASA, Laxenburg, Austria.

Future energy demand is anticipated to continue to grow, at least through the first half of the next century. The production and use of energy in developed countries greatly exceeds that in developing countries on a per capita basis. As the standard of living and populations increase in developing countries the level of energy services will need to be enhanced. Thus the increase in the rate of energy demand in developing countries will significantly exceed that of developed countries, but the per capita energy demand in developing countries will still remain below that of developed countries.

Conventional oil and gas resources worldwide contain limited amounts of carbon, approximately 300 GtC, as compared to the atmospheric content of about 750 GtC in 1990. Carbon stored in the form of coal is estimated to be 3,100 GtC, and offers no near term physical barrier to the continued growth in emissions of energy related carbon dioxide. The carbon to energy intensity ratio of the different fossil sources of energy varies by almost a factor of two: coal, ~24 MtC/EJ; oil, ~19 MtC/EJ; and natural gas, ~14 MtC/EJ. Renewable energy sources (discussed in more detail later) are sufficiently abundant that they could technically provide all of the foreseeable energy needs of the world over the next century.

Energy Demand

This section covers the three major sectors: industry, transportation and human settlements (residential and commercial). The energy demand projections are from IPCC IS92, are expressed in terms of secondary energy consumption (fuels and electricity), and assume no improvements in the efficiency of energy production and transmission.

Emissions Mitigation in the Industry Sector. Industry accounts for one-third of the final energy used to provide humanity with manufactured materials and products and, consequently, for a comparable share of energy-related carbon emissions. Industrial energy use could, without policy intervention, rise from about 113 EJ in 1990 to 170-270 EJ and 120-450 EJ per year in 2025 and 2100, respectively. Developing countries now account for only about a quarter of global industrial final energy use, but are expected to account for over 90 percent of industrial energy demand growth over the next century.

A few basic processes, including production of iron and steel, chemicals, building materials, and food, account for more than half of all energy use in the industrial sector. Industry's performance in reducing energy intensity has been impressive over the past two decades. Improvements in energy efficiency have, in some countries, permitted major increases in production with little or no increase in

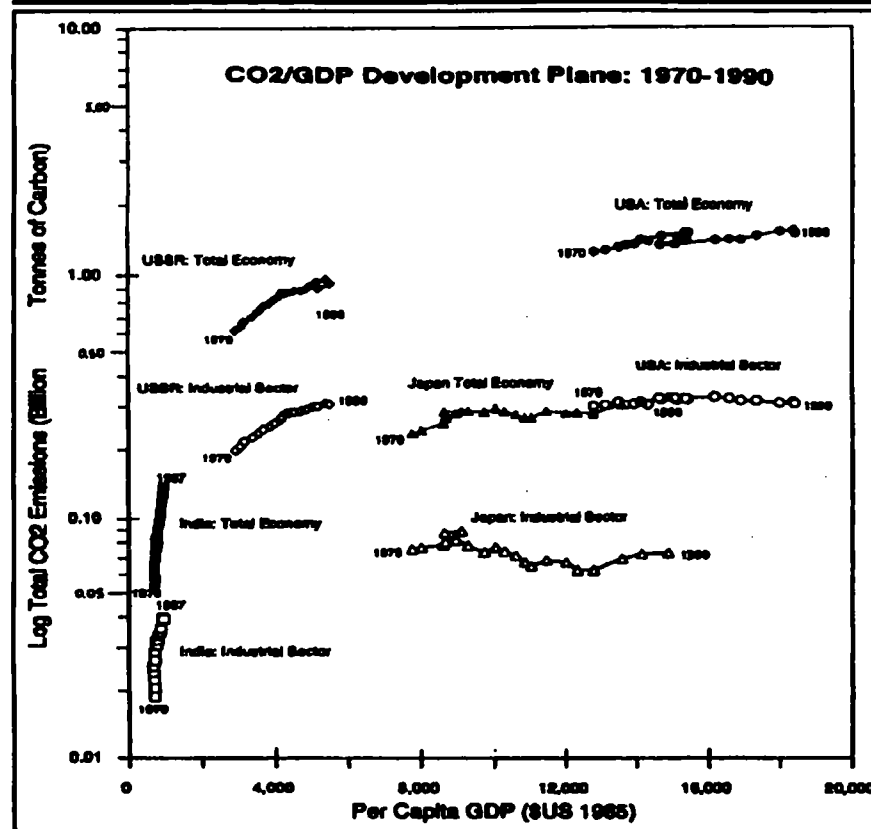


Figure 6. USA, Japan, USSR, and India—CO₂ Development Plane: 1970 - 1990—see Chapter 20, this volume.

energy use. Factors pushing this drive to energy efficiency include international competition, technological improvements, temporary energy price increases (over the past few decades, energy prices have risen and fallen, but are now nominally lower than in the 1970s), rapid turnover of capital stocks, and economic restructuring in the transition economies. This historical perspective does not suggest that the relationship between GDP and carbon dioxide emissions will be the same in developing countries as it was in developed countries given that technology options are quite different now (Figure 6).

Some developing countries, with rapid growth in the demand for steel, use twice as much energy as Japan to produce a ton of steel. However, opportunities exist for using advanced technologies to reduce emissions significantly in each of the

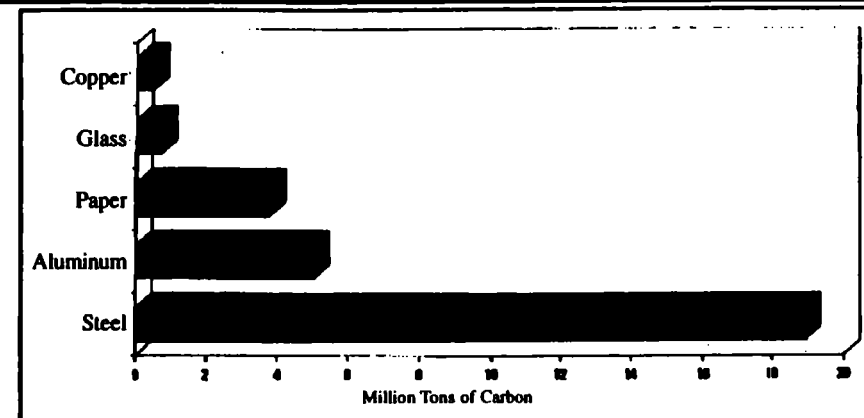


Figure 7. Tons of Carbon Avoided by OECD Countries by Increasing Recycling by 10 Percent—from IIASA, 1993: "Long-term strategies for mitigating global warming," International Institute for Applied Systems Analysis, Laxenburg, Austria.

major energy-consuming industries. Even low-tech, "good housekeeping" measures can lead to significant reductions in industrial energy use.

Some technologies such as electric motor drives, heating, and evaporation are used across many industries and thus offer large opportunities for energy savings. Electric motor drives, for example, use over half of all electricity in many developing countries, including China and Brazil. Investments in motor speed controls and more-efficient motor components can save 10-40 percent of electric power used in industrial motor applications, and with an internal rate of return on investment of 30-50 percent.

Industrial greenhouse gas emissions can be reduced by the efficient use of materials. Recycling materials can reduce energy requirements substantially (see Figure 7). Recycling of iron and steel scrap, for example, cuts the energy required per ton of steel produced to half the current level in Japan, the world's most-efficient steel-producing nation. Not all steel scrap can be recycled, however, and so recycling cannot be viewed as a panacea.

A systematic approach to energy conservation is particularly important in newly industrializing countries. New regional development presents opportunities for integrating industrial and residential-commercial energy use, by establishing energy management systems for surplus industrial energy utilization in heating and cooling systems for residential-commercial areas.

The implementation of more energy-efficient industrial technologies will depend on a number of factors. Chief among them are financing, energy and materials prices.

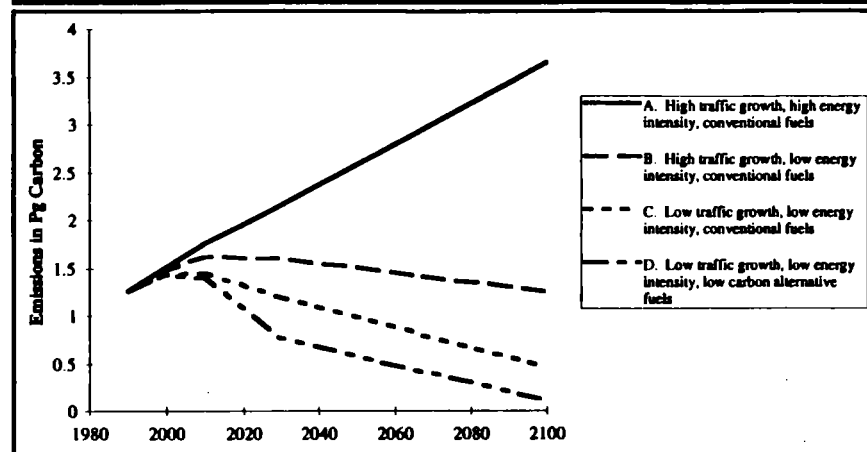


Figure 8. Transport Carbon Emissions (PgC/Year)—modified from Walsh, M.P., 1993: "Global Transport Scenarios," in Towards a Fossil Free Energy Future: The Next Energy Transition, Greenpeace International, Amsterdam.

ing, market imperfections, research and development, and the extent of assistance for technology transfer from developed to developing and transition economies.

Emissions Mitigation in the Transportation Sector. Transportation ranks among the most rapidly growing sources of greenhouse gas emissions (see Figure 8). Transportation worldwide consumed 68 EJ, mainly in oil products, in 1990. Depending on energy efficiency gains and traffic growth, energy use could rise to 100-170EJ in 2025 and 100-520EJ by 2100. In scenarios with accelerated energy efficiency gains and reduced traffic growth, energy use could be kept down to about 65EJ by 2025 and fall to 30EJ or lower by 2100. While industrialized countries are responsible for about 75% of current energy use and greenhouse gas emissions from this sector, the greatest growth is expected in developing countries and countries with economies in transition. By 2100 these could account for over 80% of emissions.

Transportation energy demand has historically been closely linked to GDP growth, although it is influenced by fuel prices (see Figure 9). However, two key opportunities have been identified to reduce emissions significantly from road transportation:

- Changing the design of all vehicle types to use more efficient drive-trains, body shapes and materials, as well as switching energy sources for propulsion. Improved vehicle energy efficiency might reduce

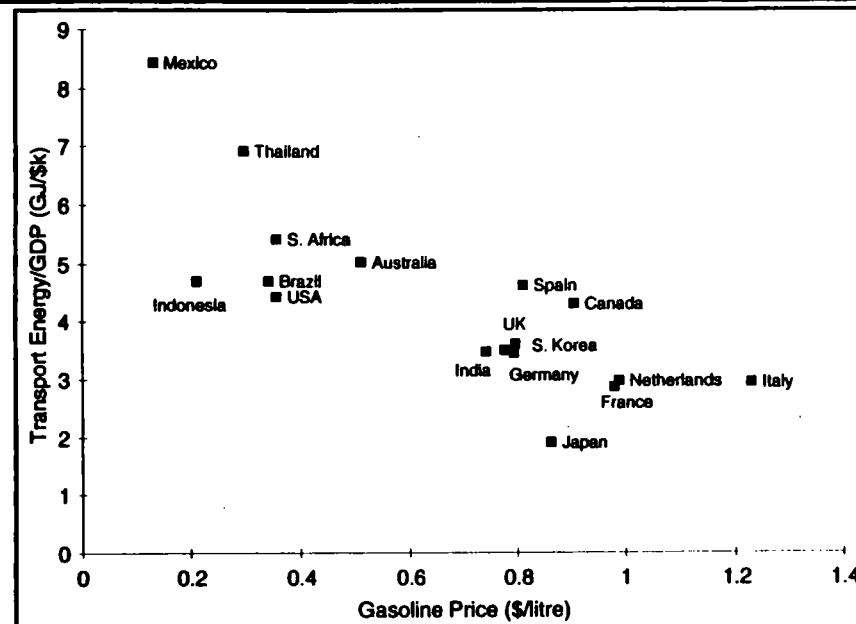


Figure 9. Energy per Unit GDP vs. Gasoline Price in 1990: 17 of the World's Largest Transport Energy Users (excluding China, Russia, and Ukraine)—from International Energy Agency, 1993: "Energy Statistics and Balances of Non-OECD Countries, 1990-1991." OECD, Paris; International Energy Agency, 1993: "Energy Balances of OECD Countries, 1990-1991." OECD, Paris; International Energy Agency, 1994: "Energy in Developing Countries: A Sectoral Analysis," OECD, Paris.

greenhouse gas emissions per vehicle mile traveled by 20 to 50% by 2025 relative to today's vehicles, without changes in vehicle performance and size; 60 to 80% if vehicle performance and size were changed, and nearly 100% if energy efficiency were combined with the use of non-fossil fuel energy sources.

- Altering land-use patterns and life styles to reduce the level of passenger and freight transport activity and to effect a shift to less energy intensive transportation modes. Measures to bring about these changes may be adopted primarily to address objectives related to urban development.

Transport plays an increasingly important social and economic role and measures to reduce emissions may not be implemented if they are perceived to compromise this role. Success

1 in reducing carbon emissions will require integrated approaches, and will probably depend
 2 on simultaneously addressing other problems such as congestion and air pollution.
 3
 4 Many lessons have already been learned on the effective use of policies such as fuel and
 5 vehicle taxes and fuel economy standards to encourage energy efficiency improvements.
 6 An important role is also played by policies that affect traffic volume, such as: road tolls;
 7 the restriction of car access and parking in town centers; and provision of infrastructure for
 8 non-motorized transport in town centers. Research will continue to be needed to develop
 9 cheap, lightweight, recyclable materials, advanced propulsion and vehicle control systems.

10
 11 **Emissions Mitigation in the Commercial/Residential Buildings Sector.** Human
 12 settlements, in particular energy use in residential and commercial buildings, cur-
 13 rently account for about one-third of greenhouse gas emissions. Historical energy
 14 use and carbon emissions from the developed world, industrialized countries and
 15 the former Soviet Union and Eastern Europe are shown for residential and com-
 16 mercial buildings for 1973, 1983 and 1990 in Table 6. Energy use could, in the
 17 absence of policy initiatives, increase from about 78 EJ in 1990 to 100-150 EJ and
 18 107-460 EJ in 2025 and 2100, respectively. While industrialized countries are cur-
 19 rently responsible for about 60% of these emissions, at least 80 percent of all
 20 growth during the next century is expected in the developing countries.

21
 22 Technologies exist, however, which could cut projected growth in emissions in human
 23 settlements by half over the next 35 years, and more in the longer run, without dimin-
 24 ishing energy services. Some examples of technologies to reduce carbon dioxide
 25 emissions by reducing energy use include more efficient space-conditioning systems;
 26 reduced heat losses through walls, ceilings and windows; more efficient lighting; and
 27 more efficient appliances, including refrigerators, water heaters, cook stoves, etc. In
 28 addition, measures to counter the trends of higher ambient temperatures in urban areas,
 29 through increased vegetation and greater reflectivity of roofing and siding materials,
 30 can yield significant reductions in space-conditioning energy requirements and at the
 31 same time reduce heat island effects on human health. Finally, technologies for cap-
 32 turing methane and converting it to useful purposes exist and are cost-effective in
 33 many applications. Other technologies that can reduce or prevent the formation of
 34 methane (e.g., in landfills) are also increasingly available. Implementing these tech-
 35 nologies, however, would require well-crafted policies to overcome barriers.

36
 37 This assessment suggests that three types of activities could provide the greatest
 38 reduction in emissions growth in buildings:

- 39
- 40 • Support for energy efficiency policies (energy pricing strategies, regu-
 41 latory programs including minimum energy efficiency standards for
 42 buildings and appliances, utility demand-side management programs,

and market pull and demonstration programs that stimulate the devel-
 opment and application of advanced technologies;

- Enhanced research and development in energy efficiency;
- Enhanced training and added support for financing of efficiency pro-
 grams in developing countries and transition economies.

Energy efficiency and R&D programs have been carried out, primarily in industri-
 alized countries, and many have achieved significant energy savings. While the

Table 6. Primary Energy Use and CO₂ Emissions from Energy Use in Residential and Commercial Buildings (1973-1990)

	Residential		Commercial		Total	
	Energy ¹	Emissions ²	Energy	Emissions	Energy	Emissions
OECD						
1973	755	694	378	347	1133	1041
1983	704	626	400	355	1104	981
1990	780	666	476	407	1256	1073
FSU/EE						
1973	254	133	85	44	339	177
1983	352	197	117	66	469	263
1990	499	225	150	75	649	300
LDC						
1973	140	109	60	47	200	156
1983	265	154	114	66	379	220
1990	381	225	164	97	545	322
World						
1973	1149	936	523	438	1672	1374
1983	1321	977	631	487	1952	1464
1990	1660	1116	790	579	2450	1695

Source: Total Residential/Commercial Energy from IEA. Emissions for OECD Res/Com calculated independently based on Lawrence Berkeley Laboratory energy data.

Residential share of LDC emissions taken from Sathaye, J. and A. Ketoff, 1991: "CO₂ Emissions from Major Developing Countries: Better Understanding the Role of Energy in the Long-Term," *The Energy Journal*, 12(1), 161-171. Residential shares of FSU/EE emissions taken from Cooper, R.C. and Schipper, L.J., 1991: "The Efficiency of Energy use in the USSR, An International Perspective", *Energy*, 17(1), 1-24.

¹ Energy use is presented in million tonnes of oil equivalent (mtoe), with electricity counted in terms of resource energy.

² Emissions of CO₂ are presented in million tonnes of carbon.

1 technical and economic potential for further savings is high, aggressive implemen-
2 tation of policies will be required.

3
4 Strategies to reduce emissions will likely be more effective if they use well-inte-
5 grated mixes of policies, tailored for local situations and developed through con-
6 sultation with stakeholders.

7
8 Since the 1990 assessment, there has been an increasing recognition of the impor-
9 tance of engaging developing countries and countries with economies in transition
10 on measures that can increase energy efficiency, thus reducing the growth of
11 greenhouse gas emissions and under proper circumstances, providing other eco-
12 nomic benefits.

15 *Energy Supply*

16
17 Since the preparation of the IPCC 1990 and 1992 assessment reports, there have
18 been some significant advances in understanding the prospects for reducing green-
19 house gas emissions by utilizing modern energy supply technologies and techno-
20 logical innovations. The most promising approaches for reducing greenhouse gas
21 emissions include: gas turbine technologies, coal and biomass gasification tech-
22 nologies, production of transportation fuels from biomass, approaches to handling
23 intermittent generation of electricity, wind energy utilization, electricity generation
24 with photovoltaics and solar thermal electric technologies, fuel cells for transporta-
25 tion and cogeneration, and hydrogen as a major new energy carrier, produced first
26 from natural gas and later from biomass, coal, and electrolysis.

27
28 Greenhouse gas emissions reductions can be achieved through:

- 29
30 • **More efficient conversion of fossil fuels**—New technology offers
31 considerable increased conversion efficiencies for power production,
32 an increase from the current average efficiency of 30-35% to over 60%
33 in the longer term.
- 34 • **Switching to low carbon fossil fuels, and suppressing their emissions**—
35 The role of coal in power generation can be reduced by switching to natu-
36 ral gas, especially in areas where large resources exist. In these areas low-
37 capital cost, highly-efficient advanced combined cycle technology is
38 reducing electricity costs considerably. However, natural gas resources are
39 much smaller than coal resources, thus limiting its longer-term role.
- 40 • **Decarbonization of fuels, flue gases and carbon dioxide storage**—
41 The removal and storage of carbon dioxide from the flue gases of fos-
42 sil fuel power stations is expensive. This contrasts to the relatively

low cost of sequestering the carbon dioxide produced in making hydro-
gen-rich fuels from fossil fuel feedstocks. If conversion technologies
such as fuel cells become available to take advantage of these hydro-
gen-rich fuels, then this becomes a relatively low cost approach for
reducing carbon dioxide emissions.

- **Switching to renewable sources of energy**—In addition to already uti-
lized biomass, hydro and geothermal technologies, new technological
advances offer fuels and electricity from biomass, wind, and solar energy.
In the longer term, renewable sources of energy could meet the major
part of the world's energy demand. Renewable energy forms have no
direct net release of carbon associated with their generation. While bio-
mass sources of energy release carbon during combustion at rates similar
to coal, they are usually treated as a net neutral source because biomass
crops absorb approximately the same amount of carbon from the atmos-
phere during primary production as they release on combustion.
Renewable sources of energy are often beneficial for local and regional
environmental problems such as urban air pollution and acid rain, and, in
the case of biomass, rural income and employment generation.
- **Switching to nuclear energy**—Nuclear energy could replace baseload
fossil fuel electricity generation in most parts of the world, if generally
acceptable responses can be found to concerns about reactor safety,
radioactive waste disposal, and nuclear proliferation.
- **Methane capture**—Methane emissions can and are being reduced
using cost-effective technologies that capture and use methane from
coal mines and landfills.

The costs for these technologies have been coming down and there is every expecta-
tion that this trend will continue, making these technologies more competitive in
the market place. Consequently, there exist significant options for emissions
reductions that are either cost-effective today, as evaluated through standard eco-
nomic accounting, or could become so with the removal of subsidies, the incorpo-
ration of external costs/benefits in energy prices, targeted R&D efforts, and stimu-
lation of market introduction.

Over the course of the next century, the energy supply system will be replaced
completely at least twice, offering opportunities to change the energy system in
step with the corresponding investment processes. Thus, future emissions will
depend on the nature of the technologies chosen during each successive generation
of energy system. However, it is not possible to identify a least-cost future energy
system for the longer-term, as the relative costs of options will depend on resource
constraints that are imperfectly known and on actions that may be taken by gov-
ernments and the private sector.

Many combinations of low-carbon energy supply systems exist that, if realized (especially when combined with a high level of energy end-use efficiency), would significantly reduce global greenhouse gas emissions from fossil fuels projected for the next century (Figures 10 and 11). Such emissions reductions might plausibly be achieved at little or no extra costs to society, as most of the technologies involved are projected to provide energy services at costs comparable to those of conventional sources of energy.

Market penetration of different energy sources ultimately depends on the relative costs of fossil and alternative energy forms, as well as other attributes such as abundance, accessibility, institutional arrangements, and regulations and policies. Because costs vary by location and application, the wide variety of circumstances creates opportunities for new technologies to penetrate the market.

Some of the technology options identified such as combined cycle power generation could compete in a market structure resembling that of today. To realize other options, however, governments would have to take action based on an integrated

approach. Such actions would include correcting market distortion by eliminating permanent subsidies for energy, finding new ways to internalize external costs of using energy, by accelerating research, development and demonstration efforts on low and zero carbon-emitting technologies, and by providing incentives for early commercialization of such technologies.

Controversy exists regarding costs and market penetration, regarding the likelihood that RD&D will be adequate to spur the required technological innovation, and whether the investment climate will be conducive to the realization of cost-effective opportunities for low-carbon energy production and more efficient energy use.

5. TECHNICAL GUIDELINES FOR ASSESSING CLIMATE CHANGE IMPACTS AND ADAPTATIONS

(Note: The text in Section 5 of this document has already been approved by governments as part of the review of the IPCC 1994 Special Report)

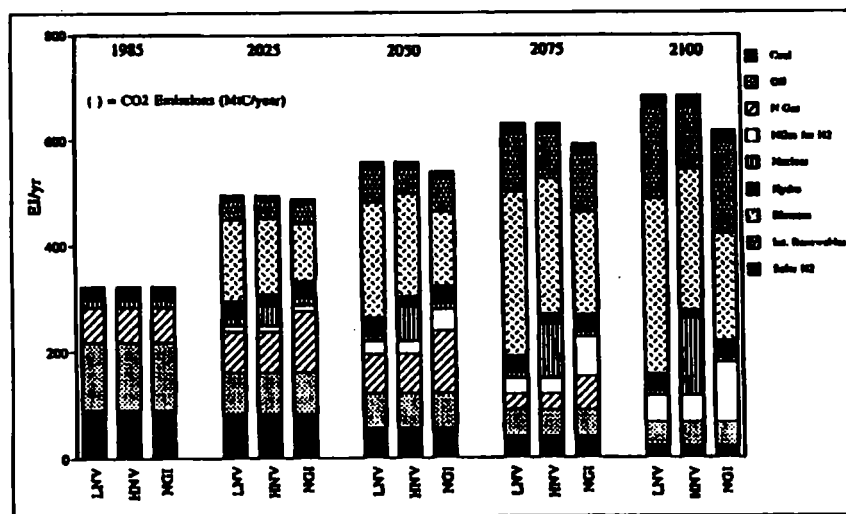


Figure 10. Global Primary Commercial Energy Use for Low Alternative LESS Variants

Notes

Low CO₂ emitting energy supply systems (LESS) are described that highlight alternative low-cost strategies for reducing emissions. However, it is not possible to identify a least-cost future energy system for the longer term, as the relative cost options depend on resource constraints that are imperfectly known and on actions to be taken by governments and the private sector. The LESS are therefore to be seen as indicative, not optimized systems. LESS = Low CO₂ Emissions Supply System; LNV = Low nuclear variant; HNV = High nuclear variant; and NGT = Natural gas intensive variant.

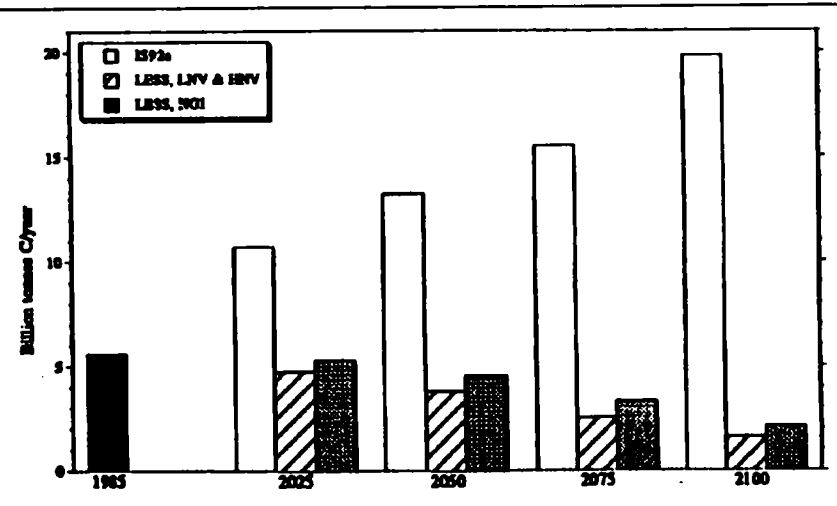


Figure 11. Global CO₂ Emissions from Fossil Fuel Burning for Alternative LESS Constructions, with a comparison to the IPCC IS92a Scenario.

1 Working Group II of IPCC has prepared Guidelines to assess the impacts of potential
 2 climate change and to evaluate appropriate adaptations. They reflect current knowl-
 3 edge and will be updated as improved methodologies are developed. The Guidelines
 4 outline a study framework which will allow comparable assessments to be made of
 5 impacts and adaptations in different regions/geographical areas, economic sectors and
 6 countries. The Guidelines are intended to help contracting parties meet, in part, their
 7 commitments under Article 4 of the UN Framework Convention on Climate Change.
 8
 9 Impact and adaptation assessments involve several steps:
 10
 11 • Definition of the problem
 12 • Selection of the methods
 13 • Testing the method
 14 • Selection of scenarios
 15 • Assessment of biophysical and socio-economic impacts.
 16 • Assessment of autonomous adjustments
 17 • Evaluation of adaptation strategies.
 18
 19 Definition of the problem includes identifying the specific goals of the assessment,
 20 the ecosystem(s), economic sector(s) and geographical area(s) of interest, the time
 21 horizon(s) of the study, the data needs and the wider context of the work.
 22
 23 The selection of analytical methods(s) depends upon the availability of resources,
 24 models and data. Impact assessment analyses can range from the qualitative and
 25 descriptive to the quantitative and prognostic. Testing the method(s), including
 26 model validation and sensitivity studies, before undertaking the full assessment is
 27 necessary to ensure credibility. Development of the scenarios requires, firstly, the
 28 projection of conditions expected to exist over the study period in the absence of
 29 climate change and, secondly, the projection of conditions associated with possible
 30 future changes in climate. Assessment of potential impacts on the sector(s) or
 31 area(s) of interest involves estimating the differences in environmental and socio-
 32 economic conditions projected to occur with and without climate change.
 33
 34 Assessment of autonomous adjustments implies the analysis of responses to cli-
 35 mate change that generally occur in an automatic or unconscious manner.
 36 Evaluation of adaptation strategies involves the analysis of different means of
 37 reducing damage costs. The methodologies outlined in the Guidelines for analyz-
 38 ing adaptation strategies are meant as a tool only to compare alternative adaptation
 39 strategies and thereby identify the most suitable strategies for minimizing the
 40 effects of climate change were they to occur.
 41
 42

6. METHODS FOR ASSESSING MITIGATION OPTIONS AND INVENTORY OF MITIGATION TECHNOLOGIES

Methods compiled by the IPCC to assess mitigation options are available to all
 countries. These draft methods may be used to develop strategies and to evaluate
 programs and projects that: (i) support national economic, social, and institutional
 development goals and (ii) can slow the rate of growth in greenhouse gas emis-
 sions. These methods, while involving analytical challenges, have been widely
 applied in both industrialized and developing countries. Moreover, the Global
 Environmental Facility, other international organizations, and bilateral programs
 provide resources to assist developing countries and countries with economies in
 transition in obtaining information on, testing, and using these methods. It is rec-
 ommended that all countries evaluate and use as appropriate these draft methods
 in the preparation of country studies and their national communications.

In the future, development and application of mitigation assessment methods will
 result in further improvements in the methods and the capabilities of countries to
 assess mitigation options. The IPCC, in coordination with other multilateral insti-
 tutions, could accelerate the dissemination of selected information on assessment
 methods through seminars, workshops and educational materials.

27 March, 1995

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IPCC SCIENTIFIC ASSESSMENT REPORT 1995

SUMMARY FOR POLICYMAKERS

Draft @ 24/3/95

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Executive Summary

This second scientific assessment of climate change by the IPCC scientific working group sets out the essential conclusions that follow from the group's earlier 1990 first assessment and updates in 1992 and 1994, along with a number of new conclusions reached during the second complete assessment process 1992-95. Overall we hold to our earlier conclusion that growth of greenhouse gas emissions will continue to alter the energy balance of the earth and that climate will change as a result. We also report a considerable body of evidence indicating that the climate is changing and that human activities are partly responsible.

Past trends in greenhouse gases and aerosols, and their radiative forcing of climate

Atmospheric concentrations of the major anthropogenic greenhouse gases are still increasing.

Concentrations of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) have increased since pre-industrial times by 27%, 145%, and 13% respectively. The increases, which have occurred particularly during the 20th Century, are mainly attributable to human activity. Current concentrations are the highest in at least the last 160,000 years. Other greenhouse gases not present in the pre-industrial atmosphere, in particular the halocarbons, have also been increasing in atmospheric concentrations. Although the atmospheric concentrations have been consistently increasing on a decadal scale, short term fluctuations in the growth rate have been observed. Notable are the fluctuations in carbon dioxide and methane during 1992/93.

Radiative forcing provides a simplified basis for comparing the importance of different climate-change agents Radiative forcing is the name given to the alteration of the energy balance of the Earth's surface and atmosphere arising from a change in greenhouse gas concentration, or from a change in any other factor driving climate change. Positive radiative forcing leads to climate warming, negative forcing leads to cooling.

The growth in atmospheric concentrations of anthropogenic greenhouse gases since pre-industrial times is believed to have caused a larger systematic radiative forcing of the climate system over the last several thousand years than any other change that has been identified. The radiative forcing due to increased carbon dioxide, methane, nitrous oxide and halocarbon concentrations since pre-industrial times is about 2.8 Wm⁻². In comparison the *average* radiative forcings due to volcanic eruptions or changes in solar output in the last century are much smaller, a few tenths of a Wm⁻². Stratospheric ozone depletion over the past 25 years has resulted in a small negative radiative forcing of about -0.1 Wm⁻².

Tropospheric aerosols and ozone, products of industrial activity, are important sources of radiative forcing. Aerosols (tiny airborne particles) can scatter incoming solar radiation, thereby increasing the Earth's albedo (the direct effect) and can also influence cloud droplet size and thus cloud albedo (the indirect effect). Tropospheric aerosols are relatively short-lived, with lifetimes of around a week, but arise from continuous emissions of surface pollutants. Together with a highly non-

uniform distribution of aerosol sources, this results in a highly non-uniform distribution of the climate forcing. The globally-averaged radiative forcing due to aerosols is now estimated as -0.5 Wm^{-2} (range: -0.25 to 1.0 Wm^{-2}) for direct forcing and between 0 and -1.5 Wm^{-2} for indirect forcing. The uncertainty is much greater than the corresponding uncertainty in the radiative forcing due to greenhouse gases. Tropospheric ozone perturbations are similarly short-lived and non-uniformly distributed. However tropospheric ozone trends lead to a positive forcing whose global average is estimated as $+0.4 \text{ Wm}^{-2}$ (range: $+0.2$ to $+0.6 \text{ Wm}^{-2}$).

New and revised values of Global Warming Potential (GWP) have been calculated. New direct and indirect GWPs are calculated for ozone depleting gases. Also, revised lifetimes for gases that are removed in the lower atmosphere (e.g. methane) have yielded new, lower GWPs for some species.

Trends in past climate

Measurements of surface temperature continue to indicate a net increase in global average temperature of 0.3 to 0.6°C since the late 19th century. The estimated warming has not significantly changed since the estimates in IPCC 1990 and IPCC 1992, although the data have been re-analysed, and more data are now available. The warming is evident in ocean and land surface temperatures. Urbanisation and desertification could have contributed, at most, only a small part of the observed warming. The warming has not been globally uniform. Some areas, such as the North Atlantic, have cooled. The recent increase in warmth has been greatest over the continents between 40°N and 70°N. The general tendency to reduced diurnal temperature range over land, noted in IPCC 1992, has been confirmed with more data (now more than 40% of the global land mass). Northern Hemisphere summer temperatures in recent decades have been the warmest since at least 1400 (which is as far back as hemispheric reconstructions go).

Surface temperatures cooled temporarily following the eruption of Mount Pinatubo. As discussed in IPCC 1994 relatively cool surface and tropospheric temperatures were observed in 1992 and 1993 due to a large, transient radiative forcing induced by aerosols arising from the mid-1991 eruption of Mt Pinatubo. This provides additional evidence that climate responds to radiative forcing. With the disappearance of the volcanic aerosols warmer surface temperatures reappeared in 1994 which, averaged globally, was among the warmest five years since 1860.

Precipitation has increased over land in the high latitudes of the Northern Hemisphere. These increases are mainly evident in the cold season. Some tropical land areas influenced by ENSO have been drier in recent years. There are insufficient data to establish global trends in precipitation.

Global sea level has risen by about 1 to 2.5 mm/year over the past 100 years. Warming and expansion of the oceans may account for 0.2 to 0.7 mm/year of this increase and melting of glaciers has also contributed.

Regionally, considerable evidence exists for changes in extremes and variability, often associated with the El Niño-Southern Oscillation (ENSO) phenomenon. The tendency for more frequent El Niño events since the late 1970's, noted in IPCC(1990), has continued and the prolonged 1990-95 El Niño is unprecedented in the record of the last 100 years.

Climate modelling

Climate models are the main tools with which to assess changes in the climate system due to the enhanced greenhouse effect. Because future anticipated radiative forcing is unprecedented, there are no good analogues for projecting future climate. Physically-based climate models have varying degrees of detail and complexity, and the most sophisticated include atmospheric and oceanic general circulation models (GCMs) as central components. These models incorporate numerous internal feedbacks which may amplify or diminish the response and they encapsulate in quantitative ways our understanding of the processes that are important. GCM calculations have provided plausible bounds on the possible future climate response in terms of global temperature, details of seasonal and latitudinal differences and time scales of change. To project the temporal and regional details that are important for impact assessment it is necessary to use coupled ocean-atmosphere GCMs. Simpler climate models that are computationally less intensive than the GCMs are used to explore a wider range of scenarios than is possible with the GCMs alone. Climate models at present incorporate only limited biogeochemical processes and feedbacks.

The likely equilibrium response of global temperature to a doubling of equivalent carbon dioxide concentration (the 'climate sensitivity') is in the range 1.5 to 4.5 °C. The First IPCC Scientific Assessment concluded that the 'best estimate' was 2.5°C. The three-fold range of the estimate arises from uncertainties in the climate models and in their internal feedbacks, particularly those concerning clouds and related processes. The 1990 estimate is unchanged by this report.

Detection of climate change

Though we are far from certain, on the basis of the best evidence we have at present it is likely that the effects of human activities on climate have been identified in the observations. (*Ben Santer to check this statement*).

Projections for the future

Atmospheric concentrations of greenhouse gases and aerosols will depend on future emissions.. Scenarios of future trends in society, industry and energy use generally imply increased emissions of the major greenhouse gases, aerosols and their precursors. However, the concentration of some greenhouse gases with long atmospheric lifetimes, particularly CO₂, would continue to increase even with emissions held constant at current levels. The concentrations of short-lived species such as tropospheric ozone, and aerosols, respond quickly to changes in emissions. Any future increases in subsonic and/or supersonic aircraft activity would be expected to increase upper tropospheric ozone. The radiative forcings due to aerosols and tropospheric ozone, which vary markedly from

region to region, cannot be considered as a simple offset to the radiative forcing due to the well-mixed greenhouse gases.

Climate change induced by the increasing concentrations of long-lived greenhouse gases will persist for centuries. Due to the long atmospheric residence times of many greenhouse gases and the inertia of the climate system climate change, once begun, will persist for hundreds of years.

Recent trends in stratospheric ozone are expected to slowly reverse. Stratospheric ozone depletion over the past 25 years has resulted in a negative radiative forcing. Implementation of the Montreal Protocol will result in a recovery of stratospheric ozone, and hence gradual removal of the associated radiative forcing, over the coming decades. Increasing use of substitutes for ozone-depleting gases is expected to result in increasing concentrations of hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) inducing a positive radiative forcing.

In simulations of future climate where both greenhouse gas and aerosol forcings are taken into account projected rates of warming over the next century are in the range a-b °C per decade versus about c-d °C per decade when only the greenhouse gases are included. This applies for the IS92a scenario. This rate of increase is still greater than seen over the past 10,000 years. The rise will not be steady because of the uncertain influence of other factors and it will not be uniform over the globe. Largest warming is still projected to occur over the high latitudes of the Northern Hemisphere.

Because the variability is largest on smaller scales, both the detection and the prediction of climate response are more difficult on regional scales than on the global scale. The regional patterns of climate change depend significantly on the history of the forcing. This is complicated by the fact that aerosol effects are likely to have a strong impact on regional climate. Confidence in regional climate predictions remains low.

The terrestrial biosphere may be a source or a sink of carbon, depending on time scale. Land-use change and deforestation produces a net source of CO₂ while CO₂-fertilisation produces a net sink in the short term. In the longer term, carbon input to the atmosphere due to deforestation and land use change will diminish but forest die-back and other ecosystem changes due to climate change are a potential source of very large amounts of atmospheric carbon dioxide. These factors add uncertainty to future projections of carbon dioxide concentrations in the atmosphere.

Sea level will continue to rise for centuries, even if greenhouse gas emissions are stabilised. Future sea level rise is less than estimated in the IPCC (1990) report because of the inclusion of scenarios for future atmospheric radiative forcings that incorporate aerosols. Sea level is likely to rise by between 10 and 30 cm by the year 2100 (compared to between x and y cm for a comparable emission scenario that does not include aerosols), and will continue to rise for several centuries thereafter.

27 March, 1995

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1. Introduction

The first IPCC Scientific Assessment in 1990 concluded that the increase in atmospheric concentrations of greenhouse gases since pre-industrial times had altered the energy balance of the earth and that some global warming would result, a conclusion based on well established science and largely beyond dispute. Further, there is good reason to believe that the main features of climate change resulting from anthropogenic greenhouse gases - its magnitude, rate and regional expression - are predictable. This is indicated by studies of the response of the climate to other changes in the distribution of the input of radiation (for instance those which resulted from changes in the earth's orbit during the ice ages or those resulting from volcanic eruptions).

In the 1990 report much attention focused on expected changes in mean global temperature because this was seen as a useful surrogate for the more complex changes expected in regional climate, and because it was likely to be a useful signal for the detection of climate change. However quantities expressed as a global average do have some important limitations:

(a) societal impacts of climate change will depend on change at the regional and local levels and not the global level.

(b) expressing quantities as a global average may be less meaningful when, for example, the factor driving climate change is spatially highly variable, e.g. ozone in the lower atmosphere derived from air pollution, or aerosols (airborne particles) derived from industrial emissions.

In the present report globally-averaged quantities are still used for the same reasons as before, but wherever possible this report explores the regional characteristics of climate change and, where appropriate, of the factors causing climate change. It should be remembered, however, that the signal arising from externally forced climate change is masked by the variability of climate occurring on all time and space scales - variability due to the climate being to some degree a 'chaotic' system. Because the variability is largest on smaller scales, both the prediction and the detection of climate response are more difficult on the regional scale than on the global.

For readers familiar with the United Nations Framework Convention on Climate Change (FCCC) an important distinction should be noted. In this report the term 'climate change' refers to change arising from any source, human or natural. Within the FCCC the term 'climate change' refers exclusively to change brought about by human activities. In many instances the two uses will, in effect, be the same but this basic distinction should be borne in mind.

Apart from the self-evident terms global and hemispheric, we also use the following terms for the description of spatial scales: 'continental' ($10^a - 10^b \text{ km}^2$), 'regional' ($10^c - 10^d \text{ km}^2$) and 'local' ($10^e - 10^f \text{ km}^2$).

Box 1

2. Greenhouse gases, aerosols and their radiative forcing

The material presented in this section was the subject of a recent IPCC report on the radiative forcing of climate change (IPCC (1994)). Here we restate the main unchanged conclusions from IPCC (1994) and present key new results.

As stated in IPCC (1994), there is clear evidence that the concentrations, distributions and life cycles of a number of radiatively active gases and aerosols are impacted by human activities.

2.1 Carbon dioxide

The growth of atmospheric CO₂ concentrations in 1994 was close to the average observed over the past decade (around 1.5 ppmv/yr). The low growth rate anomaly in the early 1990s discussed in IPCC (1994) has ended and, as best can be established, reflects a large but transient perturbation of the carbon system. While isotopic data show that it resulted from natural fluctuations in the ocean and terrestrial sinks, the mechanisms that caused the anomaly are not yet known.

Figure 2.1: showing CO₂ conc. against time and growth rate against time.

The increase in CO₂ since pre-industrial times (27%) has lead to a radiative forcing of 1.6 Wm⁻² (see figure 2.4 showing bar chart of radiative forcing for CO₂, CH₄ etc.).

The 1980's carbon budget remains unchanged from IPCC (1994) and is presented in Table 2.1.

The projected of CO₂ concentrations for the IS92 scenarios and the emissions which achieve stabilisation of CO₂ concentration at 450 and 650 ppmv have been recalculated using the IPCC (1994) budget and are not substantially different (at most a 10% change) from the calculations in IPCC (1994) which were based on an earlier carbon budget. In fact, the recalculated results fall within the uncertainty limits described in IPCC (1994).

For this assessment a sensitivity test was also carried out with respect to the size of the deforestation flux. The flux size was shown to have a substantial impact on emissions associated with concentration profiles leading to stabilisation (figures to be included here).

2.2 Methane

Methane is another naturally occurring greenhouse gas whose concentration in the atmosphere is growing as a result of human activities (rice paddies, animal husbandry, landfills, biomass burning and fossil fuel production and use)

The anomaly in the growth rate of the atmospheric methane abundance observed in 1992-93, and noted in IPCC (1994), was a short term fluctuation (see figure 2.2 showing methane growth rates). About mid-1992 methane concentrations stopped growing, but since 1993 the global growth rate has returned to about 8 ppbv/yr, close to the average global growth rate of 11 ppbv/yr observed between 1984 and 1991. There is clearly a long-term decline in the CH₄ growth rate: in the late

1 1970s it was about 20 ppbv/yr. Globally methane increase by 7% over the decade from 198?. Its
2 concentration in 1994 was 17XX ppbv.

3 The magnitude of the atmospheric increase of methane is well known, better than the
4 magnitudes of the sinks and, especially, the individual sources (Table 2.2). However, carbon
5 isotope measurements indicate that about 20% of the total annual methane emissions are related to
6 fossil fuel use (e.g., combustion, coal mines, natural gas production and distribution, and petroleum
7 industry operations). In total, anthropogenic activities are responsible for xx-yy% of current
8 methane emissions (Table 2.2). The direct radiative forcing due to the increase in methane
9 concentration since pre-industrial times is about 0.5 Wm^{-2} (Figure ?? showing bar chart of radiative
10 forcing for CO_2 , CH_4 etc.).

11
12 Figure 2.2 showing methane conc. against time and growth rate against time.

13
14 CH_4 has clearly identified chemical feedbacks. The main removal process for CH_4 is reaction
15 with the hydroxyl radical (OH). Addition of CH_4 to the atmosphere reduces the concentration of
16 tropospheric OH concentration which can subsequently feed back and reduce the rate of CH_4
17 removal.

18 The estimate for the atmospheric lifetime of CH_4 has been revised to 8.6 years. The revised
19 adjustment time for an added pulse of CH_4 is $12.2 (\pm 3)$ years. Two factors are responsible for these
20 changed lifetimes: (a) a new estimate for the chemical removal rate (11% faster) resulting from a
21 new calibration of CH_3CCl_3 ; and (b) inclusion of the soil loss in the calculation of the methane
22 lifetime. As in IPCC (1994), these effects are included in the calculation of the direct radiative
23 effect of a given emission of methane. The revised chemical removal rate implies that the global
24 losses are $560 (\pm 100) \text{ Tg}(\text{CH}_4)/\text{year}$, higher than the 1994 estimate. Our estimates of the methane
25 sources are unchanged: the new sink strength is consistent with the source strength reported in
26 IPCC (1994).

27
28 **Figure 2.2** showing methane conc. against time and growth rate against time.

29 **Table 2.2**

30 **2.3 Nitrous oxide**

31
32 There are many small sources of N_2O , both natural and anthropogenic, which are difficult to
33 quantify. The main anthropogenic sources are from agriculture (especially the development of
34 pasture in tropical regions), biomass burning, and a number of industrial processes (e.g., adipic acid
35 and nitric acid production). A best estimate of the current (1980s) anthropogenic emission of N_2O
36 is 3 to 8 $\text{Tg}(\text{N})/\text{yr}$. Natural sources are probably twice as large as anthropogenic ones. N_2O is
37 removed mainly by photolysis (breakdown by sunlight) in the stratosphere and has a long lifetime
38 (about 120 years).

39 Although sources/sinks cannot be well quantified, atmospheric measurements and evidence
40 from ice cores show that the atmospheric abundance of N_2O has increased since the pre-industrial
41 era, which is most likely due to human activities. The average growth rate over the past four

decades is about 0.25%/yr (0.8 ppbv/yr). In 1992 atmospheric levels of N₂O were 311 ppbv; pre-industrial levels were about 275 ppbv. Our understanding of the global nitrous oxide abundances and trends has not changed since they were reviewed in IPCC (1994). The 1993 growth rate (approximately 0.5 ppbv/yr) was lower than that observed in the global background atmosphere in the late 1980s and early 1990s, but these changes in growth rate are within the range of variability seen on decadal time scales. The radiative forcing due to the change in N₂O since pre-industrial times is about 0.1 Wm⁻² (Figure 2.4).

2.4 Halocarbons

Halocarbons containing fluorine, chlorine and bromine are significant greenhouse gases on a per-molecule basis. The chlorine and bromine containing species are also involved in the depletion of the ozone layer; the emissions of many such compounds are controlled by the Montreal Protocol and its subsequent amendments and adjustments.

Atmospheric measurements of methyl chloroform from 1978 to 1994 indicate that this gas increased steadily by about 4-5%/yr until mid-1990, levelled off in 1992 and dropped by 8% in 1994. As had been anticipated, this is the first reported global decrease in the concentrations of a halocarbon whose emissions are regulated by the Montreal Protocol. The rates of decrease are consistent with the reported decline in industrial emissions.

Measurements through mid-1994 indicate that the atmospheric growth rates of CFC-11 and -12 (other gases regulated by the Montreal Protocol) have further declined. For example, CFC-11 has stopped growing in the atmosphere.

With phase out dates for the production and consumption of CFCs and other ozone-depleting substances now fixed by international agreement, several hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) are being manufactured and used as substitutes. Global HCFC-22 levels have continued to grow at nearly linear rates in the background atmosphere. The mean mixing ratio in 1994 was approximately 110 pptv, with a constant growth rate (1992-1994) of about 5 pptv per year. Global abundances of HCFC-142b and -141b are still small, approximately 6 and 4 pptv respectively. However they show accelerating growth rates (21% and 67% increases respectively in 1994) presumably in response to their increasing use as CFC substitutes.

Perfluorocarbons and sulphur hexafluoride are removed slowly from the atmosphere with estimated lifetimes greater than 1000 years, and effectively all emissions accumulate in the atmosphere. The global abundance of sulphur hexafluoride was 3.2 pptv in 1994, rising at about 7 %/yr. This growth in SF₆ has a radiative forcing of about 0.5% of that due to the average current increase in CO₂.

The contribution to direct radiative forcing due to increases in the halocarbons since pre-industrial times is about 0.3 Wm⁻² (the largest contributions come from CFC-11, CFC-12 and CFC-113) (see figure showing bar chart of radiative forcings). As well as this positive direct effect, the halocarbon induced loss of ozone in the lower stratosphere represents an indirect radiative forcing which is negative (see Section 2.5). Prior to the onset of significant ozone depletion, the globally averaged radiative forcing caused by the increase in halocarbons was between 0.1 Wm⁻² and 0.2 Wm⁻².

Figure 2.3 (a) showing Montreal Protocol controlled gas against time (CH_3CCl_3)
(b) showing non-Montreal Protocol controlled gas against time (SF_6)

2.5 Ozone

Ozone is an important greenhouse gas present in both the stratosphere and troposphere. Changes in ozone can cause radiative forcing by influencing both solar and infrared radiation. The net radiative forcing is strongly dependent on the vertical distribution of ozone change and is particularly sensitive to changes around the tropopause level, at which height trends are difficult to estimate due to a lack of reliable observations. The patterns of both tropospheric and stratospheric ozone changes are not spatially uniform. Tropospheric ozone increases have occurred primarily in the Northern Hemisphere and may have varies within this region. Stratospheric ozone loss has occurred mainly in the mid-latitude and polar regions of both hemispheres. Estimation of the radiative forcing due to changes in ozone is thus more complex than for the well-mixed greenhouse gases.

Table 2.3- redundant?

2.5 Ozone

Ozone is an important greenhouse gas present in both the stratosphere and troposphere. Changes in ozone can cause radiative forcing by influencing both solar and infrared radiation. The net radiative forcing is strongly dependent on the vertical distribution of ozone change and is particularly sensitive to changes around the tropopause level, at which height trends are difficult to estimate due to a lack of reliable observations. The patterns of both tropospheric and stratospheric ozone changes are not spatially uniform. Tropospheric ozone increases have occurred primarily in the Northern Hemisphere and may have varies within this region. Stratospheric ozone loss has occurred mainly in the mid-latitude and polar regions of both hemispheres. Estimation of the radiative forcing due to changes in ozone is thus more complex than for the well-mixed greenhouse gases.

2.5.1 Stratospheric Ozone

Decreases in stratospheric ozone have occurred since the 1970s. The most obvious feature is the annual appearance of the Antarctic ozone hole in September and October. The October average total ozone values over Antarctica are 50–70% lower than those observed in the 1960s. The ozone loss occurs at altitudes between about 14 and 24 km and is caused by the chlorine and bromine compounds released in the stratospheric decomposition of halocarbons (principally CFCs and halons).

Statistically significant losses in total ozone have also been observed in the mid-latitudes of both hemispheres. In the Northern Hemisphere the trends in the 1980s are larger in local winter and spring than in summer or autumn, while in the Southern Hemisphere the trends show little seasonal variation. At Northern mid-latitudes in winter and spring the ozone losses amount to about a 10% decrease since around 1970. The weight of recent scientific evidence strengthens the conclusion

that the mid-latitude ozone loss is due largely to anthropogenic chlorine and bromine compounds. Little or no downward trend in ozone has been observed in the tropics (20°N–20°S).

Since the stratospheric abundances of halocarbon compounds are expected to continue to grow for a few more years (see Section 5), continuing global ozone losses are expected for the remainder of the decade (other things being equal), with a gradual recovery throughout the first half of the 21st century.

A loss of ozone in the lower stratosphere over the past 15 to 20 years has led to a globally averaged radiative forcing of about -0.1 Wm^{-2} . This negative radiative forcing represents an indirect effect of CFCs and halons (the compounds thought to be largely responsible for the ozone loss) which, over the last 15 to 20 years, may have partially offset their direct warming effect.

2.5.2 Tropospheric Ozone

In the troposphere ozone is produced from various short-lived precursor gases (carbon monoxide (CO), nitrogen oxides (NO_x) and non-methane hydrocarbons (NMHC)) and as a result of chemical feedbacks involving CH₄. Ozone can also be transported into the troposphere from the stratosphere. Changes in tropospheric ozone concentration are highly spatially variable, both regionally and vertically, making assessment of global long-term trends extremely difficult. Observations show that free tropospheric ozone has increased above many locations in the Northern Hemisphere over the last 30 years. There is also some evidence (from measurements made at high mountain sites in Europe) that levels have increased in the Northern Hemisphere since the early 1900s. Over the last decade, trends were small or non-existent. Model simulations and the limited observations together suggest that tropospheric ozone may have doubled in the Northern Hemisphere since pre-industrial times, an increase of around 25 ppbv. In the Southern Hemisphere, a decrease has been observed since the mid-1980s at the South Pole; in the hemisphere as a whole there are insufficient data to draw strong inferences.

Such changes in ozone have potentially important consequences for radiative forcing. Although detailed quantification is not possible, due to uncertainties in the size and distribution of the ozone change since pre-industrial times, the estimate of radiative forcing is $0.4 (\pm 0.2) \text{ Wm}^{-2}$.

Limited observations and model simulations suggest that tropospheric ozone in the Northern Hemisphere has increased since pre-industrial times resulting in a global average radiative forcing of $0.4 (\pm 0.2) \text{ Wm}^{-2}$. Since the 1960s concentrations of tropospheric ozone have almost certainly increased over large parts of the Northern Hemisphere. Trends during the 1980s were small and of variable sign. *Could go to ES ??*

2.6 Tropospheric aerosols

Aerosols are suspensions of particles (diameter range 10^{-3} to $10 \mu\text{m}$) in the atmosphere.

Tropospheric aerosols are formed by dispersal of material from the surface (e.g., soil dust), by direct

emissions of material into the atmosphere (e.g., smoke) and by chemical reactions in the troposphere which convert gases (such as sulphur dioxide) into particles. The release of sulphur dioxide from fossil fuel combustion, and organic and elemental carbon, mainly from biomass burning, are the main anthropogenic sources of aerosols.

The addition of anthropogenic aerosols to the troposphere can influence the radiative balance of the Earth in two major ways: (i) through absorption and through scattering of solar radiation back to space, known as the *direct* effect and (ii) by acting as nuclei on which cloud droplets form, aerosols can influence the formation, lifetime and radiative properties of clouds (e.g., increase the amount of solar radiation they reflect): the *indirect* effect.

There are many uncertainties associated with estimating the climatic influence of aerosols. Aerosols are highly variable regionally, in both concentration and chemical composition, and observations of their spatial distribution in the atmosphere (currently and in the past) are lacking. Both the direct radiative effect of aerosols and their ability to modify cloud properties are strongly influenced by particle size and composition. As a result, the radiative effects of the anthropogenic component of aerosols cannot be related to aerosol mass loading in a simple way. The radiative effects of anthropogenic aerosols are relatively large compared with their mass contribution because most anthropogenic aerosols are in the size range which is most radiatively active.

More confidence can be placed on the calculations of direct aerosol forcing, as a result of revisions to the models used to derive the geographic distribution of aerosol particles. The calculations have been extended to include the distribution of anthropogenic soot aerosol. Uncertainties remain concerning the optical properties of the aerosol particles.

The reduction of sulphate aerosol sources in North America and western Europe accompanied by increases in Asia are likely to result in changes in the geographic distribution of the radiative forcing.

The total direct forcing due to aerosol particles (sulphate aerosols, fossil-fuel soot and aerosols from biomass burning) is estimated to be -0.5 Wm^{-2} (with a factor of two uncertainty). This estimate is less than that given in IPCC (1994) owing to revised aerosol spatial distributions (as noted above) and inclusion of soot aerosol for the first time. The uncertainty in the direct forcing due to sulphate aerosols resulting from fossil fuel emissions and smelting has been slightly reduced since IPCC (1994); the radiative forcing since pre-industrial times is estimated to be -0.4 Wm^{-2} (with a factor of two uncertainty). The first estimates of the impact of soot in aerosols from fossil fuel sources have been made; significant uncertainty remains but an estimate of $+0.1 \text{ Wm}^{-2}$ (with at least a factor of three uncertainty) is proposed. The direct radiative forcing since 1850 of particles associated with biomass burning remains unchanged from IPCC (1994) at -0.2 Wm^{-2} (with a factor of three uncertainty).

The range of estimates for the radiative forcing due to changes in cloud properties caused by aerosols arising from human activity from IPCC (1994) is unchanged at between 0 and -1.5 Wm^{-2} . Several new studies confirm that it may have caused a substantial negative radiative forcing since pre-industrial times, but it remains very difficult to quantify, more so than the direct effect. While no best estimate of the indirect forcing can currently be made, values of 0.0 and -0.8 Wm^{-2} are used in the scenario calculations described in Section 6.1.

2.7 Summary of radiative forcing

Figure 2.4 - bar chart showing radiative forcing (updated from IPCC(1994))

The use of global-mean radiative forcing remains a useful concept for giving a first-order estimate of the potential climatic importance of various forcing mechanisms. However, as was emphasised in IPCC (1994), there are limits to its utility. In particular, the spatial patterns of forcing due to the well-mixed greenhouse gases and tropospheric aerosols are very different, and a comparison of the global-mean radiative forcings does not give a complete picture of their possible climatic impact.

Estimates of the radiative forcings from changes in greenhouse gas concentrations since pre-industrial times remain unchanged from IPCC (1994) (see Figure 2.4). These are $+2.4 \text{ Wm}^{-2}$ (with an estimated uncertainty of 15%) for the direct effect of the well-mixed greenhouse gases (CO_2 , CH_4 , N_2O and the halocarbons), $0.4 (\pm 0.2) \text{ Wm}^{-2}$ for tropospheric ozone and -0.1 Wm^{-2} (with a factor of two uncertainty) for stratospheric ozone.

There are no significant changes since the IPCC (1994) assessment of the radiative forcing due to changes in solar output or from changes in stratospheric aerosol loading due to volcanic eruptions. The long-term radiative forcing due to solar variabilities remains much smaller than that resulting from human activity. The radiative forcing due to volcanic aerosols lasts for only a few years. However, the transient variations in both these forcings may be important in explaining some of the observed climate variations on decadal values.

2.8 Global Warming Potential (GWP)

Policymakers need some measure of possible future commitment to global warming resulting from current anthropogenic emissions. The GWP is an attempt to provide such a measure. The index is defined as the cumulative radiative forcing between the present and some chosen later time "horizon" caused by a unit mass of gas emitted now, expressed relative to some reference gas (here CO_2 is used). The future global warming commitment of a greenhouse gas over the reference time horizon is the appropriate GWP multiplied by the amount of gas emitted. For example, GWPs could be used to calculate the effect of reducing CO_2 emissions by a certain amount compared with reducing CH_4 emissions, for a specified time horizon.

Derivation of GWPs requires knowledge of the fate of the emitted gas (typically not well understood) and the radiative forcing due to the amount remaining in the atmosphere (reasonably well understood). Consequently, GWPs encompass the uncertainty associated with all the topics discussed in this report. Additionally the choice of time horizon will depend on policy considerations.

The net Global Warming Potentials (GWPs), which include the direct 'warming' and indirect 'cooling' effects, have now been estimated for the ozone-depleting gases. In IPCC (1994), only the

direct GWPs were presented. The net GWPs of the chlorofluorocarbons (CFCs) tend to be positive, while those of the halons tend to be negative.

Updates or new GWPs are given for a number of key species, based on improved or new estimates of atmospheric lifetimes or molecular radiative forcing factors. Revised lifetimes for gases destroyed by chemical reactions in the lower atmosphere (particularly methane and the CFC substitutes) are based upon a recent reference gas re calibration, resulting in GWPs that are lower than those cited in IPCC (1994). Three new gases have been added to the suite of GWPs presented.

See Table 2.4 which summarises GWP values.

Table 2.4

3. Observed trends and patterns in climate and sea-level

3.1 Is the climate warming?

Global surface temperatures have increased by about 0.3° to 0.6°C since the late 19th century, and by about 0.2° to 0.3°C over the last 40 years (the period with most reliable data) (see Fig. 3.1 showing annual global surface temp). The estimate of warming since the late 19th century has not significantly changed since the IPCC 1990 and 1992 reports. Urbanisation and desertification could have contributed at most only a small part of the warming, as evidenced by the increase in both sea surface and land-based surface temperatures. Indirect indicators such as borehole temperatures, snow cover, and glacier recession data, provide independent support for the observed warming, re-confirming the IPCC 1990 and 1992 findings. (Section 3.2.2.3)

The observed warming has not been globally uniform. A few areas, such as the North Atlantic (north of 30°N), have cooled. The recent warmth has been greatest over the continents between 40°N and 70°N. (Fig. 3.2 showing post-1977 temperature anomalies) (Section 3.2.2.3)

As predicted in IPCC (1992) and discussed in IPCC (1994), relatively cool surface and tropospheric temperatures and a relatively warmer lower stratosphere, were observed in 1992 and 1993, following the 1991 eruption of Mt Pinatubo. Warmer surface and lower tropospheric temperatures reappeared in 1994 following the dispersal of the stratospheric aerosols from Mt Pinatubo. Surface temperatures in 1994, averaged globally, were in the warmest 5% of all years since 1860. (some in Section 3.2.6)

The general tendency toward reduced diurnal temperature range over land, at least since the middle of the 20th century, noted in IPCC 1992, has been confirmed with more data (now greater than 40% of the global land mass). One likely explanation is the increase in cloud cover which has been observed in many of the areas with reduced diurnal temperature range. An increase in cloud reduces diurnal temperature range both by obstructing daytime sunshine, and by preventing the escape of terrestrial radiation at night. Anthropogenic aerosols may also have an influence on diurnal temperature range, but this is as yet uncertain. (Sections 3.2.2.4, 3.3.8.1, ref for aerosol relationship ???)

Measurements of lower tropospheric temperature, from both weather balloons and from satellites, show slight overall cooling since 1979, whereas global surface temperature has warmed

slightly over the same period. The transient effects of volcanic aerosols and El Niño strongly influence trends calculated from short periods and furthermore, their influence on tropospheric and surface temperatures is different. Therefore, given the short period of the record and the occurrence of volcanic eruptions and El Niño events, the surface and tropospheric measurements are not inconsistent. Over the longer period since 1950, when tropospheric measurements with weather balloons began, the troposphere and surface show consistent warming (around 0.1°C per decade).

(Section 3.2.3.2)

Cooling of the lower stratosphere has been observed since 1979 by both satellites and weather balloons (as noted in IPCC (1992) and IPCC(1994)). Cooling of the lower stratosphere is expected due to ozone depletion and CO₂ increases. (Section 3.2.3.3, ref for ozone, CO₂ bit)??

In order to establish whether the recent warming is part of the natural variability of the climate system or a response to anthropogenic forcing, we need information on climate variability on relevant timescales. The last 1000 years or so is the most relevant to defining "current" natural variability principally because of data availability (recently from instrumental records and in the more distant past from palaeo data). For the Northern Hemisphere summer, recent decades appear to be the warmest since about 1400 at least (Fig. 3.3 showing post 1400 temps), and the warming since the late 19th century is unprecedented over the last 600 years. Prior to 1400 data are insufficient to provide hemispheric temperature estimates. Ice core data suggest that the 20th century has been warm in many parts of the globe, but also that the significance of the warming varies geographically, when viewed in the context of climate variations of the last 1000 years. In some areas the 20th century has seen the warmest decades of the last 1000 years. (Section 3.6.2)

3.2 Is the climate getting wetter or drier?

For land areas as a whole there has probably been little or no trend in precipitation averaged over the 20th century. However, precipitation has increased over land in high latitudes of the northern hemisphere, especially during the cold season, concomitant with temperature increases (Fig. 3.5, showing precipitation. variations 30-85°N and 30°S-30°N). This increase is qualitatively consistent with model simulations of warmer-world climates (see section ???). A step-like decrease of precipitation occurred after the 1960s over the subtropics and tropics from Africa to Indonesia, as temperatures increased. We are confident that these changes are real because they are consistent with changes in streamflow, lake levels, and soil moisture (where data are available and have been analysed). (Section 3.3.2.1, 3.3.3, 3.3.5.1, 3.3.5.2, 3.3.5.3)

There is evidence to suggest increased precipitation over the central equatorial Pacific Ocean, in recent decades, with decreases to the north and south. These are consistent with the recent increased frequency of El Niño episodes. Lack of data prevents us from reaching firm conclusions about precipitation changes elsewhere over the ocean. (Section 3.3.2.2)

Estimated evaporation appears to have increased over the tropical oceans (although not everywhere), qualitatively consistent with increased atmospheric water vapour in the tropics, at least since 1973. (Section 3.3.6.2, 3.3.7)

Snow cover extent has consistently remained below average since 1987, continuing the trend noted in IPCC 1992. Snow-radiation feedback has amplified springtime warming over mid- to high-latitude Northern Hemisphere land areas. (Section 3.3.4)

A summary of observed changes and our confidence in these changes are shown in the figure (Fig. 3.6 showing schematic of observed temp/precipitation changes).

3.3 Have rapid changes in climate occurred in the past?

Observations in the climate record of very rapid climate changes can provide information about the sensitivity and stability of the climate system, including the potential for climate surprises.

Large and rapid climatic changes during the last glacial period (10,000 to 120,000 years ago), evident in ice-core records, were probably linked to changes in the oceanic circulation in the North Atlantic (see also section 6.2.4). On a regional scale, changes of about 5°C occurred over a few decades, at least in Greenland and the North Atlantic (Fig. 3.7 showing large changes over last 50000 years in Greenland and North Atlantic). Data from a recently analysed Greenland ice core suggest rapid changes during the previous interglacial (*state dates*), suggesting that the more stable conditions during the last 10,000 years may not be typical. However, these data have not been confirmed. (Section 3.6.3)

The existence of these rapid climate changes suggest that the climate response to changes in incoming solar radiation could be highly non-linear (i.e., a large change in climate might occur as the result of a small radiative forcing) at least in the North Atlantic and adjacent continents, under the conditions which prevailed during the last glacial. The relevance of these rapid climate changes to future climate is discussed in section ?? (Section ???)

Temperatures have been less variable during the last 10,000 years. There is no evidence of global temperature increases, on the century time scale, of 1C or greater through this period. Thus the projected change of 1-3°C over the next century as a result of human activity would be unprecedented over the last 10,000 years(*perhaps this sentence better in section 6?*). (Section ???)

3.4 Is sea-level rising?

Over the last 100 years global sea level has risen by about 1 to 2.5 mm/yr, based on analyses of tide-gauge records. The major source of uncertainty in estimating the rate of rise is the influence of vertical land movements, which are included in sea level measurements made by tide gauges. Since IPCC 1990, improved methods for filtering out the effects of long-term vertical land movements, as well as greater reliance on the longest tide-gauge records for estimating trends, have provide greater confidence that the volume of the ocean has, in fact, been increasing and causing sea level to rise within the indicated range. Recent technological developments in measuring sea level changes directly from satellites will provide future near-global sea level change measurements. (Section 7.2)

It is likely that the rise in sea level has been related to the concurrent rise in the global temperature over the last 100 years. On this time scale, the warming and consequent expansion of the oceans may account for about 0.2-0.7 mm/yr of the observed rise in sea level, while the retreat of glaciers may account for about 0.2-0.4 mm/yr. Additional contributions may have come from the

huge ice sheets of Antarctica and Greenland, but it is not clear from observational evidence whether the ice sheets are currently expanding, contracting or in balance. The ice sheets remain the major source of uncertainty regarding both past and future changes in sea level. (Section 7.3, 7.4)

3.5 Is the climate becoming more variable and/or extreme?

There is evidence of changes in variability or extremes in certain regions, for instance:

- A decrease in severe tropical cyclone activity in the North Atlantic Ocean since 1970. (Section 3.5.3.1)
- Fewer frosts in several wide-spread areas, consistent with the observed increase of mean minimum temperatures. (Section 3.5.3.4)
- Reduced day-to-day temperature variability in North America and Asia, but not Australia (the only areas analysed). (Section 3.5.2.1)
- Increased rainfall intensity over the contiguous United States. (Section 3.5.3.3)
- There is some evidence of recent (since 1988) increases in extreme extra tropical cyclones over the North Atlantic. However, records from some other regions do not exhibit any trends towards increased storminess. Elsewhere, a lack of adequate data makes analysis difficult. (Section 3.5.3.2)
- A rather abrupt change in the El Niño - Southern Oscillation (a major cause of interannual climate variability) behaviour, around 1976/77, was noted in IPCC 1990 and the new regime has persisted. There have been relatively more frequent El Niño episodes, with only rare excursions into the other extreme (La Niña episodes) of the phenomenon. This behaviour, and especially the persistent El Niño between 1990 and 1995, is highly unusual in the context of the last 120 years (i.e., since records began). Changes in precipitation over the tropical Pacific and some other regions are related to this change in the El Niño - Southern Oscillation, which has also affected the pattern and magnitude of surface temperatures. (Section 3.4.2)

Widespread changes in flood frequency or extreme high temperature events have not been observed.

There is no evidence that globally average climate variability or extreme events have increased over the 20th century. However, such analysis is made difficult by a lack of adequate data and a dearth of analyses.

(Section 3.5, 3.5.4)

Box 2

4 Modelling climate and climate change

Detailed understanding of future climate change, rely heavily on physically-based models of the atmosphere, ocean, and parts of the cryosphere, known as climate models. For climate prediction, we are mostly dependent on coupled ocean-atmosphere models (see Box 2 on the tools used to predict future climate). How much confidence should we have in the model predictions?

4.1 The basis for confidence in climate models

There remains considerable scope for improving climate models. However, it is equally important to acknowledge that substantial progress has been made in model development and performance over the last five years and also to realise that a model does not have to be 'perfect' to be of value in simulating the perturbations which arise from anthropogenic climate forcing (see box 2).

In order to assess the value of a model for such climate prediction, its simulated climate can be compared with known features of the observed recent climate and, to a less satisfactory degree, with the more limited information from significantly different past climate states. The main factors which give us confidence in the ability of models to predict anthropogenic climate change are:

- The models include the most important relevant physics and dynamics (see box 2)
- Climate models are able to simulate the important large-scale features of the components of the climate system well, both for the mean state and as they vary through the seasons - see, for example, the figure 4.1 which present illustrations of this for temperature and precipitation. (Section 5.3.3)

Fig 4.1 (a), (b) and (c) Observed and modelled surface air temperature in December to February from x coupled models and inter model standard deviation. (d), (e) and (f) Observed and modelled precipitation in June to August from x coupled models and inter model standard deviation.

- Atmospheric models with prescribed sea surface temperatures can reproduce with moderate to good skill several regional climate variations, especially, for instance, in some parts of the sub-tropics. (Section 5.2.1.2.3, 5.2.1.2.4)
- A useful test was provided by the stratospheric aerosols resulting from the eruption of Mount Pinatubo in June 1991. This gave rise to a short-lived negative global mean radiative forcing of the troposphere, peaking at -3.5 Wm^{-2} a few months after the eruption, a magnitude considerably greater than the enhanced greenhouse forcing so far. The radiative forcing had virtually disappeared by about the end of 1994. A coupled model with a mixed layer ocean (the only model run so far) has simulated surprisingly well the observed global surface air temperature variations between the time of the eruption and the end of 1994. Noteworthy was the very good simulation of the phase and magnitude of the reduction of ocean surface air temperatures (0.4°C) and land surface air temperatures (0.8°C), both in late 1992. Although other large-scale natural variations in the climate system occurred during this period, the global effect of the volcanic eruption on temperature is believed to have been the dominant influence. (some in Section 3.2.6)

- Previous reports demonstrated the ability of models to simulate some known features of palaeoclimate. More recently, only modest progress has been made in testing the ability of

models to simulate these past climates, mainly because of the paucity of reliable data with which to compare. (Section 5.4.2)

- The models exhibit 'natural' variability on a wide range of time and space scales which appear comparable with the observed variability. For instance the simulated interannual standard deviation of annual surface air temperature (based on three models) for the current climate is moderately realistic (Figure 4.2 showing surface temperature standard deviation observed and modelled). The observed small values over the oceans, mainly between 0.2°C and 0.5°C and the larger values over the continental interiors, typically at least 1°C, are quite well captured. The main deficiency is a lack of adequate interannual variability of tropical East Pacific Ocean temperatures associated with the El Niño-Southern Oscillation (ENSO) phenomenon. No current coupled model provides a fully realistic simulation of ENSO events, though the best models simulate ENSO sufficiently well to reproduce some of the observed interannual variations in the atmosphere associated with these events. (Section 5.3.4)

Fig 4.2 Observed and modelled decadal surface air temperature over land and sea surface

In addition to the problems of adequately describing certain crucial climate processes (see section 4.2) the main remaining difficulties with climate models are:

- that of the systematic adjustments (the so-called flux corrections) that are used in some models at the atmosphere-ocean interface in order to bring the simulated climate closer to the observed state. These corrections are needed to compensate for model errors involving, for example, the representation of clouds and too coarse model resolution. Although the flux correction values can be quite large in some models, their use does not appear to affect many of the qualitative large-scale features of the response of the models to anthropogenic climate forcing, as is evidenced by the comparable results obtained from models with and without such adjustments. However, there are indications that some non-linear processes could be affected along with some quantitative aspects of climate sensitivity. (Section 5.3.2.2, 6.2.3)

- that the comparatively coarse resolution of climate models, plus greater natural variability on regional scales, means that their simulations differ significantly at the regional level. (Section 6.5.1)

- The models include the most important relevant physics and dynamics (see box 2)

- Climate models are able to simulate the important large-scale features of the components of the climate system well, both for the mean state and as they vary through the seasons - see, for example, the figure 4.1 which present illustrations of this for temperature and precipitation.

(Section 5.3.3)

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- Previous reports demonstrated the ability of models to simulate some known features of palaeoclimate. More recently, only modest progress has been made in testing the ability of models to simulate these past climates, mainly because of the paucity of reliable data with which to compare. (Section 5.4.2)
- The models exhibit 'natural' variability on a wide range of time and space scales which appear comparable with the observed variability. For instance the simulated interannual standard deviation of annual surface air temperature (based on three models) for the current climate is moderately realistic (Figure 4.2 showing surface temperature standard deviation observed and modelled). The observed small values over the oceans, mainly between 0.2°C and 0.5°C and the larger values over the continental interiors, typically at least 1°C , are quite well captured. The main deficiency is a lack of adequate interannual variability of tropical East Pacific Ocean temperatures associated with the El Niño-Southern Oscillation (ENSO) phenomenon. No current coupled model provides a fully realistic simulation of ENSO events, though the best models simulate ENSO sufficiently well to reproduce some of the observed interannual variations in the atmosphere associated with these events. (Section 5.3.4)

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- that the comparatively coarse resolution of climate models, plus greater natural variability on regional scales, means that their simulations differ significantly at the regional level. (Section 6.5.1)

4.2 Climate feedbacks

The response of the atmosphere to a radiative forcing (e.g., surface and lower tropospheric warming due to an increase in greenhouse gas concentrations), will be modified by climate feedbacks which may either amplify (a positive feedback) or damp (a negative feedback) the initial response. Much of the uncertainty in the detailed prediction of climate change is associated with our understanding and ability to model such feedbacks. Modelling is made difficult because many of the climate processes involved in such feedbacks are, by and large, processes that involve the hydrological cycle and which occur on spatial scales too small to be resolved by global models and so must be described in terms of larger scale features.

Water vapour feedback.

An increase in the temperature of the atmosphere is expected to be accompanied by an increase in the amount of water vapour in the atmosphere. Since water vapour is a powerful greenhouse gas, the increased water vapour would in turn lead to a further enhancement of the greenhouse effect (a positive feedback).

The processes determining the distribution of upper tropospheric water vapour are poorly understood and modelled with little confidence. However, as stated in IPCC (1992), there is not compelling evidence that the water vapour feedback is anything but the positive feedback it has generally been considered to be.

Cloud/radiative feedback

This is more complicated than the water vapour feedback as several processes are involved. Clouds can both reflect solar radiation (which cools the surface) and absorb and emit longwave radiation

(which warms the surface). The balance of these two effects is controlled by cloud height and cloud radiative properties. The radiative properties of clouds depend on the evolution of atmospheric water in its vapour, liquid and ice phases and are problematic and a major source of error. Current cloud descriptions in climate models give a wide range of radiative feedback depending on a variety of processes. If clouds are kept fixed according to their observed distributions and properties, climate models would all report global temperature of sensitivities for doubled CO₂ in the range of 2-3°.

Modellers have shown for various assumptions that physically plausible changes in cloud distribution could either as much as double the warming expected for fixed clouds or, on the other hand, substantially reduce it. Thus, the sensitivity range for a doubling of CO₂ of 1.5° to 4.5° is largely dictated by our inability to confidently include clouds in climate models. Considerable progress has been made since IPCC 1990 in describing what cloud processes are most important for determining radiative and hence temperature changes.

Ocean circulation

The oceans are likely to have an important influence on future climate change mainly because of their role in poleward heat transport and their large heat capacity. When attempting to predict the details of future climate change, particularly timing and regional distribution, it is necessary to couple together atmospheric and oceanic GCMs (see Box 2).

Ocean GCMs must adequately represent processes of small scale mixing, convection in high latitudes. They should be able to reproduce the large-scale annual cycle and interannual variability in the tropics in response to current atmospheric forcing.

Ice/albedo feedback

An ice or snow covered surface has a high albedo (i.e., it strongly reflects solar radiation). As some ice melts at the warmer surface, less solar radiation is reflected leading to further increased warming (a positive feedback).

The simplest sea ice components of GCMs consists of a motionless ice-layer governed by thermodynamics. More realistic models incorporate snow on top of the ice layer and the effects of salinity and the especially important process of sea-ice dynamics where the ice moves and responds to momentum as well as thermodynamic forcing. There is recent evidence that including sea-ice dynamics may reduce modelled climate sensitivity to increased greenhouse gases. (Section 5.2.4)

Land surface/atmosphere interactions

The changes which might occur as a result of anthropogenic climate change (increased temperature, changes in precipitation, changes in net radiative heating) will influence the state of the land surface (soil moisture, albedo, roughness, vegetation). In turn, the altered land surface can feedback and alter the overlying atmosphere (precipitation, water vapour, clouds, latent and sensible heating).

Land models have also substantially improved since the 1990 IPCC Assessment but there is not yet general agreement as to which processes over land need to be included in a climate model,

current data sets are inadequate, and for the most part the currently more realistic treatments have not yet been incorporated into the models used for greenhouse warming scenarios.

Land surface schemes used in the coupled GCMs on which future predictions of climate change are based do not as yet include interactive vegetation so the effect of changes in vegetation on the release of carbon dioxide and on the physical properties of the land surface are not included (these feedbacks are discussed in the section below).

Feedbacks from the marine or terrestrial biosphere.

Attempts to model the effect of climate feedbacks on the carbon cycle are only just beginning and are not included in most carbon cycle models. It seems likely that terrestrial carbon storage will change with changes in climate and atmospheric CO₂ concentration. Estimates depend on land use changes (e.g. deforestation). In the short term (yr to decades) increased carbon storage (1-2 Gt/yr) is expected, but in the intermediate term (decades to centuries) climate-induced change in vegetation structure will generally lead to a decrease in terrestrial carbon storage. There is potential loss of 100s of Gt carbon, that will only be reclaimed on the long term (centuries to millennia), as ecosystems adapt to a new equilibrium. Ecosystems may reorganise in two ways, by shifts in the dominance of existing species (fast) and by migration (slow). Both mechanisms will be important. Though nitrogen deposition in precipitation results in increased carbon storage initially, chronic nitrogen deposition can indirectly cause forest die-back and a net flux of carbon from land to atmosphere.

The oceanic uptake of CO₂ by phytoplankton in the open ocean will not increase with increasing atmospheric CO₂ unless climate/environmental change results in increased nutrient availability in the surface ocean, due to changes in ocean circulation, coastal runoff input or atmospheric deposition.

It is not likely that iron fertilisation can be used to draw down atmospheric CO₂ by increasing CO₂ uptake by phytoplankton in nutrient-rich regions because natural resupply rates have time scales of a few years, so massive seeding would be required for decades. Input of nutrients and organic carbon to the continental shelves from human activity has already made them increasingly eutrophic. Low oxygen conditions lead to denitrification and outgassing of N₂ and N₂O. Both provide potential feedback: the former would reduce the uptake of CO₂ by reducing the nitrate required by phytoplankton, and the latter would increase the atmospheric concentration of the greenhouse gas N₂O. At present denitrification appears to be a minor effect.

5. Detection of Climate Change

Since the 1990 IPCC Report we have made considerable progress towards the detection of an anthropogenic effect on climate. We now have more relevant model simulations for defining an anthropogenic climate change signal and for estimating the background noise of natural climatic variability. We also have more powerful statistical tools for detection studies. By looking at *patterns* of change rather than global-mean changes alone, we are starting to address the vital issue of attribution - the process of establishing a causal link between changes in anthropogenic emissions and changes in climate.

Detection studies using global-mean data only have shown that the change in global-mean annually-averaged temperature over the last century is unlikely to be due to natural variability of the climate system, although this explanation cannot be ruled out completely. It is difficult to achieve attribution using global mean changes alone. However, such studies do yield the important conclusion that GCM-based estimates of the climate system's sensitivity to radiative forcing can be reconciled with the observations of past temperature rise when the likely cooling effect of sulphate aerosols on climate is accounted for. Figure showing temperature change for CO₂ only and for CO₂ and aerosols (these may already be included in section 6). (Section 8.4.1)

Further, recent pattern-based work suggests that the regional-scale features of an anthropogenic climate change signal (including the effects of both greenhouse gases and sulphate aerosols) can be identified in the observations. Confidence in these results will be improved as our estimates of the expected anthropogenic climate change signal become increasingly realistic and as our understanding of the natural variability of the climate system advances. (Section 8.4.2)

Claims of unambiguous detection that are based solely on complex statistical methods or on a single variable are likely to be controversial unless they are supported by a broad range of qualitative evidence. As in the quantitative studies, caution is needed in assessing consistency because the expected climate signal due to human activities is still uncertain, and has changed as our ability to model the climate system has improved. To date, most of our information on this signal comes from experiments with greenhouse gases only. (Section 8.5)

Nevertheless, there are broad areas of qualitative agreement between observations and those model predictions that either include aerosol effects or do not depend critically on their inclusion. In addition to the surface warming, the model and observed commonalities in which we have most confidence include lower stratospheric cooling, reduction in diurnal temperature range, sea-level rise, high-latitude precipitation increase, and water vapour and evaporation increase over the tropical oceans (show summary figures of observed and modelled climate changes). There is also some agreement between modelled and observed variability changes, including a decrease in daily temperature variability, and an increase in extreme rainfall in certain areas (e.g., USA, Australia). (Section 8.5)

For some climate variables, model-based estimates of changes due to anthropogenic activities do not agree with observed changes (e.g., evaporation over land). One apparent inconsistency that has received considerable attention recently is the slight cooling in the lower troposphere since 1979 (see section 3.1). However, this disagreement might be expected, given the short period of the observed trend and our knowledge of natural variability on decadal time scales (see section 3.1). For a variety of important climatic phenomena, such as tropical cyclones and ENSO, we are unable at present to assess model-observed consistency, partly due to limitations associated with coarse model resolution. (Section 8.5)

Though we are far from certain, on the basis of the best evidence we have at present it is likely that the effects of human activities on climate have been identified in the observations. (*Ben Santer to check this statement*).

6 What are the prospects for climate over the next century?

6.1 Models and forcing scenarios

Climate projections from both complex coupled GCMs of the atmosphere and oceans and from more simple box-diffusion energy balance models (see box on page ...) are presented here. GCMs represent the most comprehensive approach, however GCM simulations are expensive in terms of computer resources, and typically only one or two extended runs from a particular model are available. The range of concentration scenarios that have been used to drive GCMs is consequently rather small, most often a 1% (compound) increase per year of equivalent CO₂ concentration is used. To study the effect of aerosol forcing only two GCM experiments have been performed so far, which have not yet been fully evaluated. To complement the GCM results, which are discussed in sections 6.2.1 and 6.3 below, and to explore the sensitivity of the climate system in a broader context, computationally less expensive energy-balance upwelling-diffusion box models have been run using a much wider range of scenarios. The specific scenarios and sensitivity studies presented below are provisional. They are intended as illustrative of possible effects. Consistency with the more detailed models and observations of trace gases and aerosol trends and climate responses will be required for completion of the study.

from SPM94: (must be adapted to: other GHGs, updates from Ch 2, discussion of radiative f.)

Six greenhouse gas emission scenarios were described in IPCC (1992), based on a wide range of assumptions regarding future economic, demographic and policy factors. The anthropogenic CO₂ emissions for these scenarios are shown in Figure 6.1. IS92c, which has the lowest CO₂ emissions, assumes low population growth, low economic growth and severe constraints on fossil fuel supplies. The highest emission scenario (IS92e) assumes moderate population growth, high economic growth, high fossil fuel availability and a phase out of nuclear power. Figure 6.2 shows the resulting concentrations of CO₂, CH₄ and N₂O. All show increases in concentration well above pre-industrial levels by 2100 (75 to 220% higher). None of the scenarios show a stabilisation of concentration before 2100, although IS92c produces slow growth in CO₂ concentration. IS92a, b, e and f all produce a doubling of the pre-industrial CO₂ concentration before 2070 with rapid rates of concentration growth. Neither IS92c nor d results in doubled pre-industrial CO₂ concentrations by 2100.

<add other GHGs and tables>

<possible update from Ch. 2>

<radiative forcings from Wigley>

Figure 6.1

(a) IS92 scenarios: emissions of CO₂, CH₄ and N₂O.

(b) IS92 scenarios: emissions of halocarbons

(c) IS92 scenarios: emissions of aerosols (sulphate and biomass burning?).

<Wigley + Ch 2 authors>

Figure 6.2:

(a) CO₂, CH₄ and N₂O concentrations resulting from IS92 emissions scenarios.

(b) halocarbon concentrations resulting from IS92 emissions scenarios..

(c) aerosol concentrations resulting from IS92 emissions scenarios..

<Wigley>

Figure 6.3:

(a) Radiative forcing 1990-2100 resulting from the IS92a for all gases, CO₂, net CH₄, net CFCs.

(b) Radiative forcing 1990-2100 resulting from the IS92a for aerosols

(c) Total radiative forcing (without aerosols) for all IS92 scenarios 1990-2100

(d) Total radiative forcing (including aerosols) for all IS92 scenarios 1990-2100

<Wigley>

6.2 Globally averaged climate change**6.2.1 GCM response**

The increase of global mean temperature over the last 130 years can be simulated, within the limits of natural variability. Under scenario IS92a, the projected rate of warming over the next century is about 0.3°K/decade, reduced to 0.2°K/decade in simulations allowing for the effects of sulphate aerosols, assuming a middle estimate of the climate sensitivity. Figure 6.4 shows the global mean temperature response of two GCMs .

All models produce an increase in global mean precipitation of about 2%/K warming. If aerosol forcing is taken into account, the increase in global precipitation is smaller, as would be expected with the smaller warming. (Section 6.2.2)

Figure 6.4: Global mean temperature changes between 1860 and 2100, both with and without the effects of sulphate aerosol taken into account, as simulated by two GCMs. <Mitchell, Cubasch>

6.2.2 Global mean climate response to IS92 emission scenarios

In order to investigate the climate system's average global temperature response to a wide range of greenhouse gas scenarios much simpler models than the computationally expensive coupled Ocean-Atmosphere GCMs are used. These 'Energy-Balance/Upwelling-Diffusion models' are constructed to give similar results to the GCMs (see box 2).

<global temperature response from Wigley Figure 6.5>

Figure 6.5: Global mean temperature changes for the IS92 scenarios.

(a) All IS92 scenarios, no aerosol, climate sensitivity 2.5°C, 1860-2100

(b) All IS92 scenarios, with aerosol, climate sensitivity 2.5°C, 1860-2100

(c) IS92a showing all gases, no aerosol; all gases constant 1990 aerosol; CO₂ only constant 1990 aerosol, all gases with aerosol; climate sensitivity 2.5°C

(d) Figure showing range using highest emissions scenario and highest sensitivity; lowest emissions scenario and lowest sensitivity.

<Wigley>

Changes in sea-level

Projections of future changes in sea level as a consequence of global warming (see Chapter 6) were made for each of the six IPCC IS92 forcing scenarios for the period 1990 to 2100 (Figure 6.6a). In addition, high, middle and low estimates, using a range parameter values based on uncertainties in climate and sea level modelling, were made for IS92a (the forcing scenario most comparable to the IPCC 1990 Scenario A - Figure 6.6b). The results showed that:

- for forcing scenarios IS92a-f, sea level is projected to be <new values to appear> cm higher than today by the year 2050, using the 'best-estimate' model parameters. By the year 2100, the sea level rise for the six scenarios ranges from <new values to appear> cm.
- for scenario IS92a at the year 2050, the projected rise in sea level is <new values to appear> cm, with a range of uncertainty of <new values to appear> cm. By the year 2100, the rise is <new values to appear> cm, with a range of uncertainty of <new values to appear> cm.
- Most of the projected rise in sea level is due to thermal expansion, followed by increased melting of glaciers and ice caps.

A major source of uncertainty concerns the polar ice sheets. Not only is there a lack of understanding of the current mass balance, but there is considerable uncertainty regarding the possible dynamic responses on the time-scale of century.

Overall, the estimates of global sea level rise presented here are lower than those presented in IPCC (1990). However, about four-fifths of the difference is due to reductions in the estimates in global *temperature* change which drive the projections of sea level rise – not to our basic understanding of the climate-sea level connections. (Section 7.5)

Figure 6.6: Global mean sea level changes for IS92 scenarios.

(a) All IS92 scenarios, no aerosol, climate sensitivity 2.5°C, 1860-2100

(b) All IS92 scenarios, with aerosol, climate sensitivity 2.5°C, 1860-2100

(c) IS92a showing all gases, no aerosol; all gases constant 1990 aerosol; CO₂ only constant 1990 aerosol, all gases with aerosol; climate sensitivity 2.5°C

(d) Figure showing range using highest emissions scenario and highest sensitivity; lowest emissions scenario and lowest sensitivity.

<Wigley>

6.3 Spatial patterns of projected climate change and sea-level.

6.3.1 Continental scale patterns

Temperature.

With increasing greenhouse gases, the land warms faster than the oceans, as in equilibrium simulations. There is a minimum warming around Antarctica and in the northern North Atlantic

(Figure 6.7). which is associated with deep oceanic mixing in those areas. The maximum annual mean warming occurs in high northern latitudes associated with reduced sea-ice cover. The warming here is largest in winter, but becomes negligible for a short period in summer. There is little seasonal variation of the warming in low latitudes or over the southern circumpolar ocean. The diurnal range of land temperature is reduced in most seasons and most regions.

Including the effects of aerosols in simulations of future climate leads to a much reduced warming in middle latitudes of the northern hemisphere and the maximum winter warming in high northern latitudes is less extensive.(Figure 6.8). The simulated warming patterns to date correlate more closely with the observed changes when aerosol effects are included.

Figure 6.7: 2 x CO₂ warming pattern of transient coupled model run. <Mitchell >.

Figure 6.8: Warming pattern of transient coupled model run at CO₂ doubling when both CO₂ and aerosol concentration increases are taken into account. <Mitchell to supply>.

Precipitation

Precipitation increases in high latitudes in winter and in most cases the increases extend well into mid-latitudes. In the tropics, the patterns of change vary from model to model, with shifts or changes in intensity of the main rainfall maxima. In general, changes in the dry subtropics are small. However, most models produce more rainfall over India and/or Southeast Asia. Including aerosol effects tends to reduce monsoon precipitation.

Soil moisture.

Though soil moisture parametrisations are among the weaker components of climate models, all models produce predominantly increased soil moisture in high northern latitudes in winter. Most models produce a drier surface in summer in northern mid-latitudes. This occurs most consistently over southern Europe and N America. Soil moisture in northern mid-latitudes increases when aerosol effects are included, relative to present climate, presumably because of the reduced warming and its effect on evaporation.

Ocean circulation

There is some evidence for a decrease in the strength of the northern North Atlantic oceanic circulation further reducing the strength of the warming around the North Atlantic. The increase in precipitation in high latitudes decreases the surface salinity, inhibiting the sinking of water at high latitudes.

Sea-level

Global sea-level will rise between .. and .. cm at the time of CO₂ doubling, due to thermal expansion of the sea water and due to glacier melt. However changes in future sea level will not occur uniformly around the globe. Recent coupled ocean-atmosphere GCM experiments suggest

that the regional responses could differ by a factor of 2-3, due to regional differences in heating and circulation changes. In addition, geological and geophysical processes cause vertical land movements and thus affect relative sea levels on local and regional scales. (Section 7.6)

ENSO

Several coupled models show greater increases of mean SSTs in the eastern than the western Pacific, and a corresponding reduction of the east-west SST gradient in the tropical Pacific. This is associated with a mean change of precipitation patterns in the tropical Pacific that resembles present-day observed ENSO precipitation, wind and ocean current anomalies. (Section 6.2.3, 6.2.4)

6.3.2 Subcontinental scale patterns

The uncertainties in present day simulations of regional climate change and the inter-model variability in the simulated regional changes are still too large to yield a high level of confidence in simulated change scenarios. This is complicated by the fact that aerosol effects are likely to have a strong impact on regional climate. Changes in soil moisture are the least reliable, and changes in precipitation are less certain than changes in temperature. This conclusion essentially does not modify that of the 1990 Report and 1992 Update. In addition, the limited number of experiments available with statistical down scaling techniques and nested regional models show that complex topographical features, large lake systems and narrow land masses not resolved at the resolution of current GCMs significantly affect the simulated regional and local change scenarios, both for precipitation and (to a lesser extent) temperature. This adds a further degree of uncertainty in the use of GCM-produced scenarios for impact assessment.

Regional changes can be very different from the globally averaged changes. The simulated changes in temperature and precipitation are shown for 7 regions (the 5 regions that were discussed in IPCC 1990, plus 'Northern Europe' and 'East Asia') are shown in Fig. 6.9.

(Section 6.5.2)

Figure 6.9: Regional GCM results (temperature and precipitation) for 6(?) regions, including 5 IPCC (1990) regions. <Giorgi>

6.3.3 Changes in Variability and extremes

Variability is defined as a measure of the deviations from some mean value. Small changes in the mean climate or climate variability can produce relatively large changes in the frequency of extreme events; a small change in the variability has a stronger effect than a similar change in the mean.

Temperature

A general warming tends to lead to an increase in extreme temperature events and a decrease in winter days below 0°C. (Section 6.4.5)

Hydrology

Many models suggest an increase in the probability of heavy precipitation events in a warmer climate. In some simulations in some areas, there is also an increase in the probability of dry days and the length of dry spells (consecutive days without precipitation). Where mean precipitation decreases, the likelihood of drought may increase markedly. (Section 6.7.6)

Warming leads to an increase in potential evapotranspiration (i.e., when soil moisture is available, evaporation tends to increase) in all models, in regions that are currently prone to droughts, droughts may become longer lasting and more severe. (Section 6.2.?)

Storms/storm tracks

There is little agreement between models on the changes in storminess that might occur in a warmer world. Conclusions regarding extreme storm events, are obviously even more uncertain.

(Section 6.4.4)

Hurricanes/Tropical cyclones

Changes of global tropical cyclone frequency may be negligible in comparison to the observed natural variability. There may be some potential for changes of cyclone intensity in regions where SST is between 26 and 29°C. (Section 6.4.4)

ENSO

Several global coupled models indicate that the ENSO-like variability they simulate continues with increased CO₂ with either little change or somewhat of a decrease of SST variability in the tropical Pacific.

Associated with the mean increase of tropical SSTs, there could be enhanced precipitation variability associated with ENSO events in the increased CO₂ climate, especially over the tropical continents. (Section 6.3.3)

Monsoon

Several models indicate that there could be enhanced variability of area-averaged south Asian monsoon rainfall. Recent coupled models (with increased CO₂ only) agree with earlier model results that mean south Asian monsoon rainfall could intensify due to the enhanced moisture source from the warmer oceans and faster warming of the south Asian land surface compared to the Indian Ocean (increasing the land-sea temperature contrast). Runs with current projections of aerosol show a reduction in monsoon precipitation relative to the current climate. When aerosol effects are included, a weak increase in variability of area-averaged south Asian monsoon rainfall is found.

(Section 6.3.3)

Extreme sea level events

Tides, waves and storm surges could be affected by regional climate changes and are, at present, highly uncertain. (Section 7.6.3)

6.4 Stabilisation

Stabilisation of current global emissions of CO₂ **does not** lead to stabilisation of CO₂ concentration by 2100. CO₂ concentrations reach about 500 ppmv by the end of the 21st century and calculations show that concentrations continue to increase slowly for several hundred years.
from SPM94:

In the context of the ultimate objective of the UN Framework Convention on Climate Change (quoted in the preface to Part I of this report), it is important to investigate, for all the greenhouse gases, the emission profiles which would lead to stabilisation of their concentration in the atmosphere. In this section CO₂ is considered; because of the complex nature of the lifetime of atmospheric CO₂, the calculations for CO₂ are relatively complex and therefore require considerable explanation. The stabilisation of other greenhouse gases, CH₄ and N₂O, for which the calculations are simpler, are considered in later sections.

Carbon cycle models have been used to calculate the emissions of CO₂ which would lead to stabilisation at a number of different concentration levels (i.e., the inverse of the type of calculation considered in Section xxx). These calculations are designed to illustrate the relationship between CO₂ concentration and emissions. Concentration profiles have been devised (Figure 6.10) which stabilise at CO₂ concentrations from 350 to 750 ppmv (for comparison, the pre-industrial CO₂ concentration was close to 280 ppmv and the 1993 concentration was 356 ppmv).

The calculations which have been made so far are necessarily limited in their scope and ranges. They are designed to illustrate the relationship between CO₂ concentration and emissions. The selection of the range of concentrations from 350 ppmv to 750 ppmv was arbitrary and should not be construed as having any policy implications. Many different stabilisation levels, time-scales for achieving these levels, and routes to stabilisation could have been chosen. Those in Figure 6.10 give a smooth transition from the current rate of CO₂ concentration increase to stabilisation. As a result, the year of stabilisation differs with stabilisation level from around 2150 for 350 ppmv to 2250 for 750 ppmv.

<add other GHGs, tables and graphs>

<possible update from Ch. 2>

<radiative forcings (figure 6.12) and global temperature response (figure 6.13) Wigley>

Figure 6.10: Stabilisation concentration scenarios. <Wigley + Chapter 2>

Figure 6.11: Stabilisation emission scenarios. <Wigley + Chapter 2>

Figure 6.12: Radiative forcings for stabilisation scenarios.

Figure 6.13: Climate response to stabilisation scenarios <Wigley>

Sea-level

If greenhouse gas concentrations were stabilised, sea level would continue to rise, but at a slowly declining rate, for many centuries after greenhouse gases and temperature stabilise. Figure 6.14 shows the sea level response to(section 7.6)

Figure 6.14: Sea-level response to stabilisation scenario <Wigley + Warrick>

6.5 Might there be surprises?

As the climate system is non-linear, its response to gradual forcing changes may be quite irregular. Moreover unforced surprises, such as volcano eruptions also occur. Abrupt significant changes in the atmospheric circulation involving the North Pacific which began about 1976 were described in IPCC (1990). A related example is the change in the recent behaviour of El Niño, with warm conditions prevailing since 1990, which surprised researchers and modellers.

Another example is the possibility that the West Antarctic Ice Sheet might "surge", causing a rapid rise in sea level. The probability of a major sea level excursion by the year 2100 due to the collapse of the West Antarctic Ice Sheet is relatively remote, but not zero. Our ignorance of the specific circumstances under which West Antarctica might collapse limits the ability to quantify the risk of such a calamity occurring, either in total or in part, by the year 2100. (Section 7.7.3)

The meridional overturning of the oceans, driven by deep convection in the northern North Atlantic Ocean, the thermohaline circulation, which keeps the northern North Atlantic Ocean several °C warmer than it would otherwise be, is weakening in several transient warming simulations with coupled models. Observations suggest that in recent decades the deep convection in the northern North Atlantic, that drives the thermohaline circulation, may have diminished or shifted. Both the study of palaeoclimate from sediment records and ice cores and modelling studies with coupled climate models and ocean GCMs can be interpreted to suggest that the present-day ocean circulation has multiple modes of operation under present forcing, which could give rise to sudden (both in the observations and in the ocean models, transitions occur on a time-scale of decades) changes in the (regional, North Atlantic, Western Europe) climate. Whether or not such a sudden change can actually be realised in response to global warming and how strong a perturbation is required to cause a transition between these modes are still the subject of much debate. (Section 5.??)

7 Advancing our understanding

The most urgent scientific problems requiring attention relate to:

- The factors controlling the distribution of clouds and their radiative and hydrological characteristics - in order to improve understanding of the magnitude of possible climate change.
- Improved capabilities for long-term monitoring of important climate variables - in order to make possible the detection and attribution of climate change.
- Coupling between the atmosphere and ocean, and ocean circulation - in order to better understand the rate and timing of possible climate change.
- Development of climate models that include biological, ecological and chemical effects - in order to better understand the climatic impact of different choices relating to future human activities.

- 1 • The factors controlling the atmospheric abundance of carbon dioxide and other greenhouse
- 2 gases - in order to inform choices regarding the reduction of anthropogenic radiative forcing.

Box 1: What drives changes in climate?

The Earth absorbs radiation from the Sun, mainly at the surface. This energy is then redistributed by the atmospheric and oceanic circulation and re-radiated to space at longer ('thermal', 'terrestrial' or 'infrared') wavelengths. On average, for the Earth as a whole, the incoming solar energy is balanced by outgoing terrestrial radiation.

Any factor which alters the radiation received from the Sun or lost to space, or which alters the redistribution of energy within the atmosphere, and between the atmosphere, land and ocean, can affect climate. A change in the energy available to the global Earth/atmosphere system is termed here, and in previous IPCC reports, a *radiative forcing*.

Increases in the concentration of greenhouse gases will reduce the efficiency with which the Earth cools to space, by increasing the absorption of outgoing terrestrial radiation and re-emitting it at a higher altitude and colder temperature. This results in a positive radiative forcing which will tend to warm the lower atmosphere and surface. This is the *enhanced* greenhouse effect - an enhancement of an effect which has operated in the Earth's atmosphere for millions of years due to the naturally occurring greenhouse gases: water vapour, CO₂, methane and N₂O. In common usage, the 'enhanced greenhouse effect' has come to be termed simply the 'greenhouse effect'. The amount of warming depends on the size of the increase in concentration of each greenhouse gas, the radiative properties of the gases involved, and the concentration of other greenhouse gases already present in the atmosphere.

Aerosols (small particles) in the troposphere, derived from the emission of sulphates from fossil fuel burning, and derived from other sources, can absorb and reflect solar radiation. In addition, changes in aerosol concentrations can alter cloud reflectivity through their effect on cloud properties. In most cases tropospheric aerosols tend to produce a negative radiative forcing and cool climate. In general, they have a much shorter lifetime than greenhouse gases so their concentrations respond much more quickly to changes in emissions.

Volcanic activity can inject large amounts of aerosol into the stratosphere, producing a large, but transitory negative radiative forcing, tending to cool the climate.

The Sun's output of energy is known to change by small amounts (0.1%) over an 11-year cycle, and variations over longer periods may occur. On time-scales of tens to thousands of years, slow variations in the Earth's orbit, which are well understood, have led to changes in the seasonal and latitudinal distribution of solar radiation; these changes have played an important part in controlling the variations of climate in the distant past, such as the glacial cycles.

Any changes in the radiative balance of the Earth, including those due to an increase in greenhouse gases or in aerosols, will tend to alter atmospheric and oceanic temperatures and the associated circulation and weather patterns. Changes in the hydrological cycle (for example, altered cloud distributions or changes in rainfall and evaporation regimes) will accompany changes in greenhouse gas and aerosol concentrations.

Any human-induced changes in climate will be superimposed on a background of natural climatic variations which occur on a whole range of space and time-scales, from days to centuries. To distinguish man-made climate variations from natural changes, it is necessary to identify the

man-made 'signal' against the background 'noise' of natural climate variability. Natural climate variability can occur as a result of changes in the forcing of the climate system, for example as a result of the dust thrown up by volcanic eruptions. They can also occur in the absence of a change in external forcing, as a result of complex interactions between components of the climate system, such as the atmosphere and ocean, for example the El Niño - Southern Oscillation phenomenon.

Box 2: What tools do we use to predict future climate and how do we use them?

We project future climate using climate models. The most highly developed global climate models are atmospheric and oceanic general circulation models (GCMs), as well as representations of land surface processes, sea-ice and all other complex processes involved in the climate system. GCMs are based upon physical laws and their depiction as mathematical equations that describe the atmospheric and oceanic dynamics and physics. These equations are solved numerically with computers using a three dimensional grid over the globe. For climate, typical resolutions are about 250 km in the horizontal and 1 km in the vertical in atmospheric GCMs. Many physical processes, such as clouds, take place on much smaller spatial scales and therefore cannot be properly resolved and modelled explicitly, but their average effects must be included in a simple way by taking advantage of relationships with the larger scale variables (called parametrisation) that are physically based.

Useful weather forecasts can be made using atmospheric GCMs for periods up to about ten days, beyond which time detailed predictability is lost, because the weather systems arise mainly from instabilities within the atmosphere. Such forecasts determine the detailed evolution of weather systems and describe the associated weather. For climate prediction, only the conditions averaged over many weather systems, for several months or more, are considered reliable, although the predicted quantities may include measures of variability as well as mean conditions.

When a model is employed for climate prediction it is first run for many simulated decades without any changes in external forcing in the system. The quality of the simulation can then be assessed by comparing the mean, the annual cycle and the variability statistics on different time scales with observations of the current climate. In this way the model is evaluated. The model is then run with changes in external forcing, for instance with a change in greenhouse gas concentrations based on various assumptions regarding future profiles of greenhouse gas concentrations. The differences between the two climates provide an estimate of the consequent climate change.

This strategy has the considerable advantage that systematic errors which occur in both simulations are removed when differences are taken. Consequently, it is not necessary to have a perfect model to achieve credible results.

Comprehensive climate models are very complex and take large computer resources to run. To explore all the possible scenarios and the effects of assumptions or approximations in parameters in

1 the model more thoroughly, simpler models are also widely used and are constructed to give similar
2 results to the GCMs when globally averaged. The simplifications may involve coarser resolution,
3 and simplified geography, physical processes, and/or dynamics. An example is the box-upwelling
4 diffusion model which uses boxes, to represent, for example, the land and ocean areas in each
5 hemisphere, and vertical diffusion and upwelling to model heat transport within the ocean.

6
7 A long-term change in global mean surface air temperature arising from a doubling of carbon
8 dioxide is often used as a benchmark to compare models, and as an indication of the climate
9 sensitivity of the models. The range of results is typically 1.5 to 4.5°C. However, such equilibrium
10 results will not be realised in practice because the concentrations of greenhouse gases will not level
11 off at doubling. The regional patterns of climate change depend significantly on the time
12 dependence of the change in forcing. It is important, therefore, to make future projections using
13 plausible evolving scenarios of anthropogenic forcing so that the response of the climate to the
14 forcing is properly simulated. These climate simulations are often called "transient experiments".

15
16 Climate models are imperfect but are the best tools for quantitatively predicting future climate.
17 There are substantial uncertainties that arise from difficulties in adequately depicting many
18 processes, including biogeochemical processes. The complexity and variety of clouds and their
19 rapid evolution in time makes it especially difficult to properly represent their effects on radiation
20 and in producing rainfall. Another challenge is the proper coupling of the atmosphere with the land
21 and oceans that is so important in climate.

Table 2.1: Annual average anthropogenic carbon budget for 1980 to 1989.
CO₂ sources, sinks and storage in the atmosphere are expressed in GtC/yr.

CO₂ sources

(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 regrowth	0.5 ± 0.5
(7) Additional terrestrial sinks (CO ₂ fertilisation, nitrogen fertilisation, climatic effects) = [(1)+(2)]-[(4)+(5)+(6)]	1.4 ± 1.5

Table 2.2 (to be updated with latest figures): Estimated sources and sinks of methane for 1980 to 1990. All figures are in Tg[†](CH₄)/yr). Current global burden is 4850 Tg(CH₄).

(a) Observed atmospheric increase, estimated sinks and sources derived to balance the budget .

	Individual estimates	Total
Atmospheric increase		37 (35–40)
Sinks of atmospheric CH ₄		
tropospheric OH	445 (360–530)	
stratosphere	40 (32–48)	
soils	30 (15–45)	
Total atmospheric sinks		515 (430–600)
Implied sources (sinks + atmospheric increase)		552 (465–640)

(b) Inventory of identified sources.

	Individual estimates	Total
Natural sources		160 (110–210)
Anthropogenic sources:		
Fossil fuel related	100 (70–120)	
Total biospheric	275 (200–350)	
Total anthropogenic sources		375 (300–450)
Total identified sources		535 (410–660)

† 1 Tg = 1 million million grams which is equivalent to 1 million tonnes.

Table 2.3 (to be updated with latest figures): A summary of key greenhouse gases affected by human activities.

	CO ₂	CH ₄	N ₂ O	CFC-12	HCFC-22 (a CFC substitute)	CF ₄ (a perfluoro- carbon)
Pre-industrial concentration	280 ppmv	700 ppbv	275 ppbv	zero	zero	zero
Concentration in 1992	355 ppmv	1,714 ppbv	311 ppbv	503 pptv [†]	105 pptv	70 pptv
Recent rate of concentration change per year (over 1980s)	1.5 ppmv/yr 0.4%/yr	13 ppbv/yr 0.8%/yr	0.75 ppbv/yr 0.25%/yr	18–20 pptv/yr 4%/yr	7–8 pptv/yr 7%/yr	1.1–1.3 pptv/yr 2%/yr
Atmospheric lifetime (years)	(50–200) ^{††}	(12–17) ^{†††}	120	102	13.3	50,000

† 1 pptv = 1 part per trillion (million million) by volume.

†† No single lifetime for CO₂ can be defined because of the different rates of uptake by different sink processes.

††† This has been defined as an adjustment time which takes into account the indirect effect of methane on its own lifetime.

Table 2.4: Global Warming Potentials, referenced to the absolute GWP for CO₂. The typical uncertainty is ±35% relative to the CO₂ reference.

Species	Chemical Formula	Lifetime (yr)	Global Warming Potential (Time Horizon)		
			20 years	100 years	500 years
Methane [†]	CH ₄				
Nitrous oxide	N ₂ O				
CFCs					
CFC-11	CFCl ₃				
CFC-12	CF ₂ Cl ₂				
CFC-13	CClF ₃				
CFC-113	C ₂ F ₃ Cl ₃				
CFC-114	C ₂ F ₄ Cl ₂				
CFC-115	C ₂ F ₅ Cl				
HCFCs, etc.					
HCFC-22	CF ₂ HCl				
HCFC-123	C ₂ F ₃ HCl ₂				
HCFC-124	C ₂ F ₄ HCl				
HCFC-141b	C ₂ FH ₃ Cl ₂				
HCFC-142b	C ₂ F ₂ H ₃ Cl				
HCFC-225ca	C ₃ F ₅ HCl ₂				
HCFC-225cb	C ₃ F ₅ HCl ₂				
Carbon tetrachloride	CCl ₄				
Methylchloroform	CH ₃ CCl ₃				
Bromocarbons					
H-1301	CF ₃ Br				
Other					
HFC-23	CHF ₃				
HFC-32	CH ₂ F ₂				
HFC-43-10mee	C ₅ H ₂ F ₁₀				
HFC-125	C ₂ HF ₅				
HFC-134 _i	CHF ₂ CHF ₂				
HFC-134a	CH ₂ FCF ₃				
HFC-152a	C ₂ H ₄ F ₂				
HFC-143	CHF ₂ CH ₂ F				
HFC-143a	CF ₃ CH ₃				

HFC-227ea	C_3HF_7
HFC-236fa	$C_3H_2F_6$
HFC-245ca	$C_3H_3F_5$
Chloroform	$CHCl_3$
Methylene chloride	CH_2Cl_2
Sulphur hexafluoride	SF_6
Perfluoromethane	CF_4
Perfluoroethane	C_2F_6
Perfluorocyclo-butane	$c-C_4F_8$
Perfluorohexane	C_6F_{14}

1

2 † The methane GWP includes the direct effect and those indirect effects due to the production of tropospheric ozone and
3 stratospheric water vapour. The indirect effect due to the production of CO_2 is not included.

4 †† For methane the adjustment time is given, rather than the lifetime - see Section xxx

5

Figure Captions

Figure 2.1: CO₂ concentration against time, CO₂ growth rate against time.

Figure 2.2: CH₄ concentration against time, CH₄ growth rate against time.

Figure 2.3: (a) Montreal Protocol controlled gas against time, (b) Non-Montreal Protocol controlled gas against time

Figure 2.4: Summary of radiative forcing due to changes in greenhouse gases, aerosols, solar activity etc changes since pre-industrial times.

Figure 3.1: Global, annual mean surface temperature record for 20th century.

Figure 3.2: Spatial distribution of recent surface temperature anomalies. (Not yet available)

Figure 3.3: Temperature record for the last 1000 years.

Figure 3.4: Temperature estimates from ice cores in several widespread locations. In the tropics and subtropics the warming this century appears to be unprecedented in the last 1000 years. The polar cores, however, show little evidence of any recent anomalous warming.

Figure 3.5: Precipitation variations, 30-85°N and 30°S-30°N. (Not yet available)

Figure 3.6 Chapter 3 summary figure which shows observed changes in temperature and hydrological cycle with confidence indication.

Figure 3.7 Figure showing rapid changes over the last 50,000 years in Greenland and North Atlantic.

Figure 4.1

a. Mean modelled surface air temperature in December to February from x coupled models.

b. Mean difference from the observed surface air temperature.

c. Inter model standard deviation.

d. Mean modelled precipitation in June to August from x coupled models

e. Mean observed precipitation.

f. Inter model standard deviation.

Figure 4.2 (Not yet available)

- a. Mean standard deviation of modelled decadal surface air temperature over land and sea surface temperature.
- b. Mean standard deviation of observed decadal surface air temperature over land and sea surface temperature.
- c. Inter model standard deviation.

(THESE DIAGRAMS DO NOT EXIST IN EXACTLY THIS FORM YET IN CHAPTER 5)

Figure 5.1 Global temperature from simple model with CO₂ only and with CO₂+aerosols.

Figure 5.2 Chapter 6 summary figure which shows modelled changes in temperature and hydrological cycle with confidence indication.

Figure 6.1

- a. IS92 scenarios: emissions of CO₂, CH₄ and NO₂.
 - b. IS92 scenarios: emissions of halocarbons
 - c. IS92 scenarios: emissions of aerosols (sulphate and biomass burning?).
- <Wigley + Ch 2 authors>

Figure 6.2:

- a. CO₂, CH₄ and NO₂ concentrations resulting from IS92 emissions scenarios.
 - b. halocarbon concentrations resulting from IS92 emissions scenarios..
 - c. aerosol concentrations resulting from IS92 emissions scenarios..
- <Wigley>

Figure 6.3:

- a. Radiative forcing 1990-2100 resulting from the IS92a for all gases, CO₂, net CH₄, net CFCs.
 - b. Radiative forcing 1990-2100 resulting from the IS92a for aerosols
 - c. Total radiative forcing (without aerosols) for all IS92 scenarios 1990-2100
 - d. Total radiative forcing (including aerosols) for all IS92 scenarios 1990-2100
- <Wigley>

Figure 6.4: Global mean temperature changes between 1860 and 2100, both with and without the effects of sulphate aerosol taken into account, as simulated by two GCMs. <Mitchell, Cubasch>

Figure 6.5: Global mean temperature changes for the IS92 scenarios.

- a. All IS92 scenarios, no aerosol, climate sensitivity 2.5°C, 1860-2100
- b. All IS92 scenarios, with aerosol, climate sensitivity 2.5°C, 1860-2100
- c. IS92a showing all gases, no aerosol; all gases constant 1990 aerosol; CO₂ only constant 1990 aerosol, all gases with aerosol; climate sensitivity 2.5°C
- d. Figure showing range using highest emissions scenario and highest sensitivity; lowest emissions scenario and lowest sensitivity.

1 <Wigley>

2
3 **Figure 6.6:** Global mean sea level changes for IS92 scenarios.

4 **a** All IS92 scenarios, no aerosol, climate sensitivity 2.5°C, 1860-2100

5 **b.** All IS92 scenarios, with aerosol, climate sensitivity 2.5°C, 1860-2100

6 **c.** IS92a showing all gases, no aerosol; all gases constant 1990 aerosol; CO₂ only constant 1990
7 aerosol, all gases with aerosol; climate sensitivity 2.5°C

8 **d.** Figure showing range using highest emissions scenario and highest sensitivity; lowest emissions
9 scenario and lowest sensitivity.

10 <Wigley>

11
12 **Figure 6.7:** 2 x CO₂ warming pattern of transient coupled model run. <Mitchell >.

13
14 **Figure 6.8:** Warming pattern of transient coupled model run at CO₂ doubling when both CO₂ and
15 aerosol concentration increases are taken into account. <Mitchell to supply>.

16
17 **Figure 6.9:** Regional GCM results (temperature and precipitation) for 6(7?) regions, including 5
18 IPCC (1990) regions. <Giorgi>

19
20 **Figure 6.10:** Stabilisation concentration scenarios. <Wigley + Chapter 2>

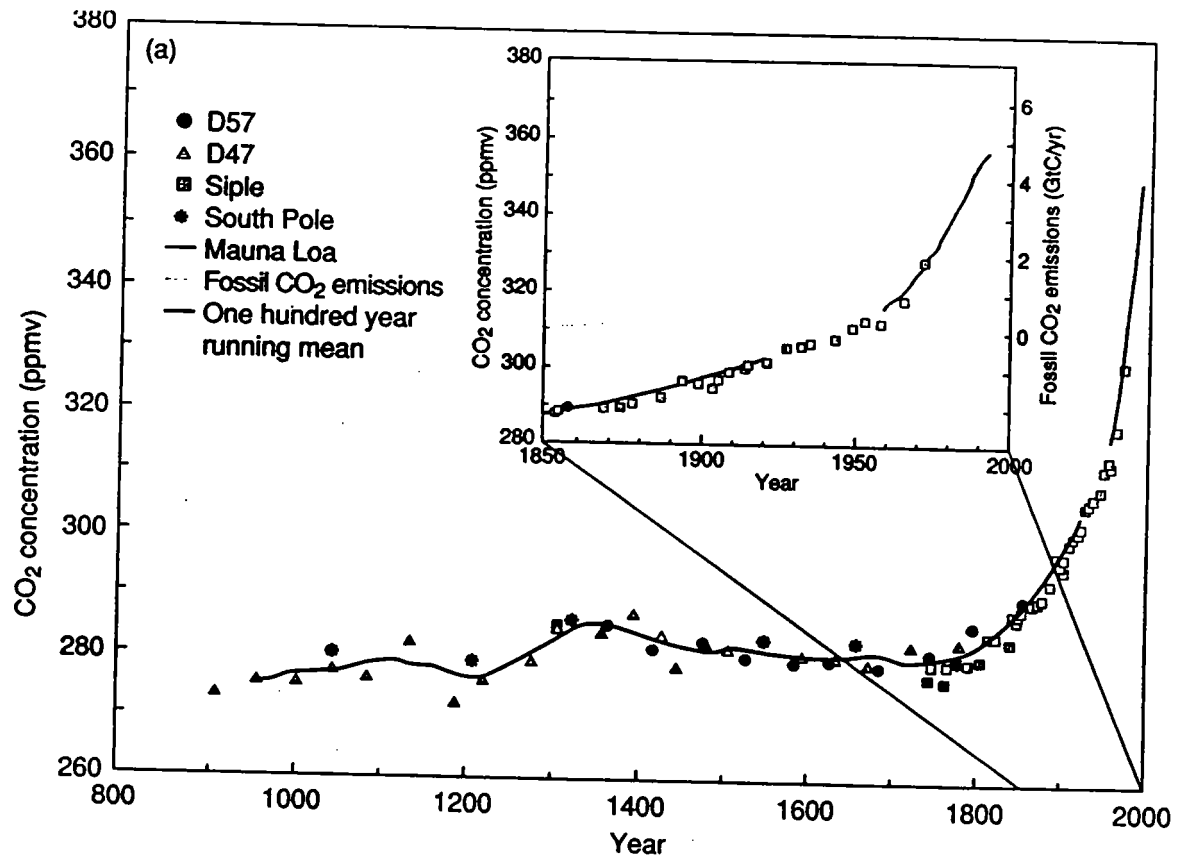
21
22 **Figure 6.11:** Stabilisation emission scenarios. <Wigley + Chapter 2>

23
24 **Figure 6.12:** Radiative forcing for stabilisation scenarios.

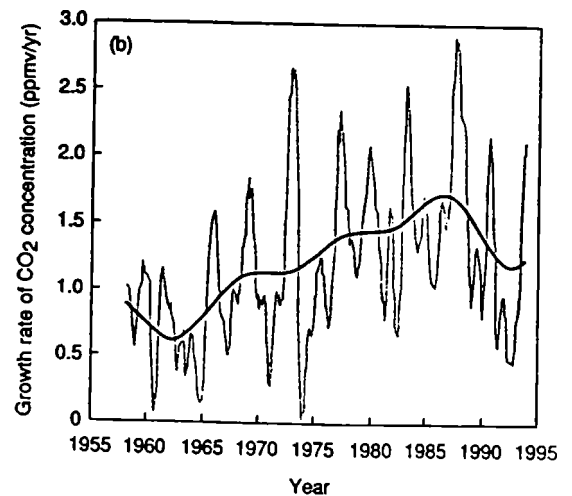
25
26 **Figure 6.13:** Climate response to stabilisation scenarios <Wigley>

27
28 **Figure 6.14:** Sea-level response to stabilisation scenario <Wigley + Warrick>

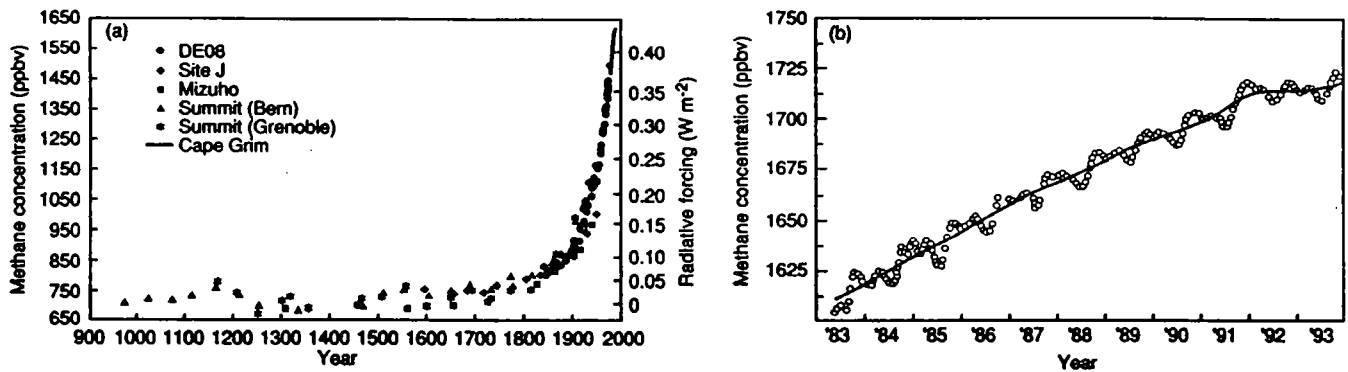
Figure 2.1



(a) CO₂ concentrations over the past 1000 years from ice-core records (D47, D57, Siple and South Pole) and (since 1958) from the Mauna Loa, Hawaii measurement site. The smooth curve is based on a hundred year running mean. The rapid increase in CO₂ concentration since the onset of industrialisation is evident and has followed closely the increase in CO₂ emissions from fossil fuels (see inset of period from 1850 onwards). (b) Growth rate of CO₂ concentration since 1958 in ppmv/yr at the Mauna Loa station showing the high growth rates of the late 1980s, the decrease in growth rates of the early 1990s, and the recent increase. The smooth curve shows the same data but filtered to suppress any variations on time-scales less than approximately 10 years.



These figures will be updated.

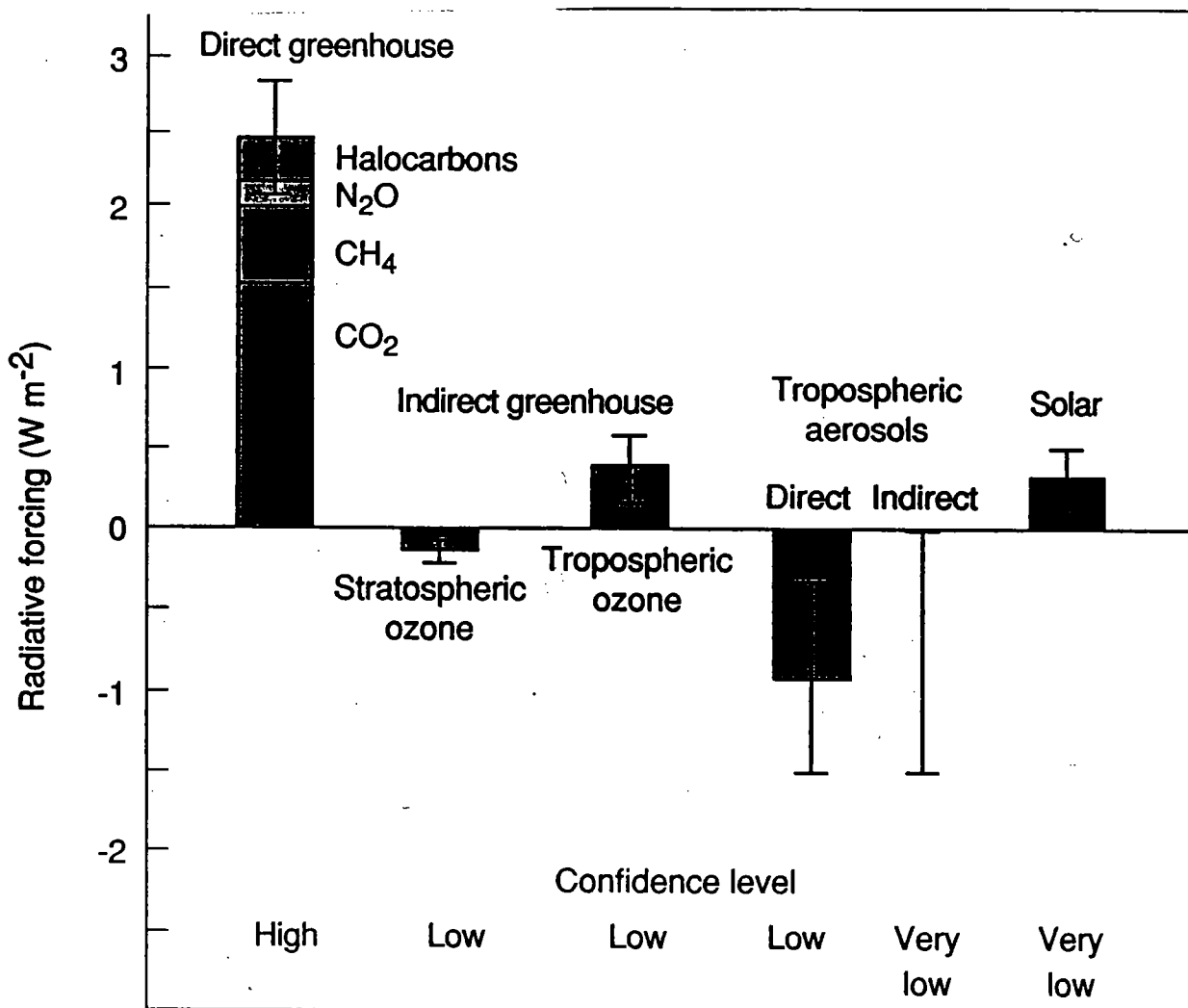


(a) CH_4 concentration derived from Antarctic ice cores over the past 1000 years. Direct observations of CH_4 concentration from Cape Grim, Tasmania, are included to demonstrate the smooth transition from ice core to atmospheric measurements. The radiative forcing resulting from increases in CH_4 relative to the pre-industrial period are indicated on the right-hand axis. The effect of overlap with N_2O is accounted for according to IPCC (1990). (b) Globally averaged CH_4 concentration for 1983 to 1993 showing the low growth rates during 1992 and 1993.

These figures will be updated

Figure 2.2

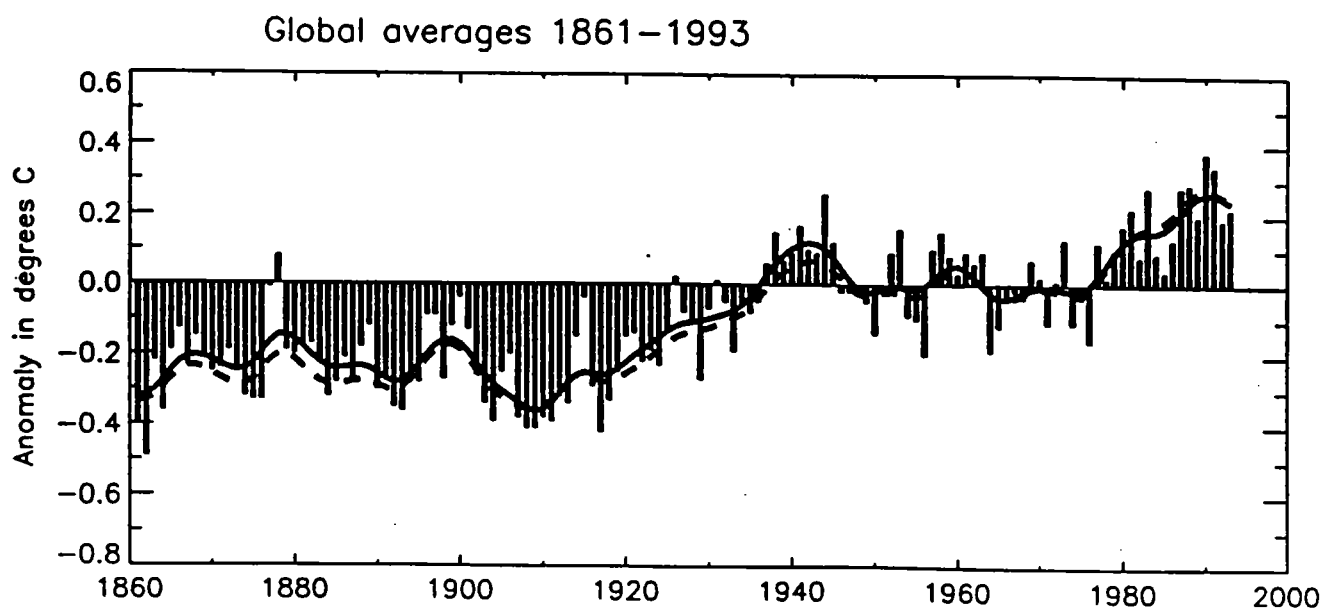
figure 2.4



Estimates of the globally averaged radiative forcing due to changes in greenhouse gases and aerosols from pre-industrial times to the present day and changes in solar variability from 1850 to the present day. The height of the bar indicates a mid-range estimate of the forcing whilst the lines show the possible range of values. An indication of relative confidence in the estimates is given below each bar. The contributions of individual greenhouse gases are indicated on the first bar for direct greenhouse gas forcing. The major indirect effects are a depletion of stratospheric ozone (caused by the CFCs and other halocarbons) and an increase in the concentration of tropospheric ozone. The negative values for aerosols should not necessarily be regarded as an offset against the greenhouse gas forcing because of doubts over the applicability of global mean radiative forcing in the case of non-homogeneously distributed species such as aerosols and ozone (see Section 1 and Section 7).

This figure will be updated

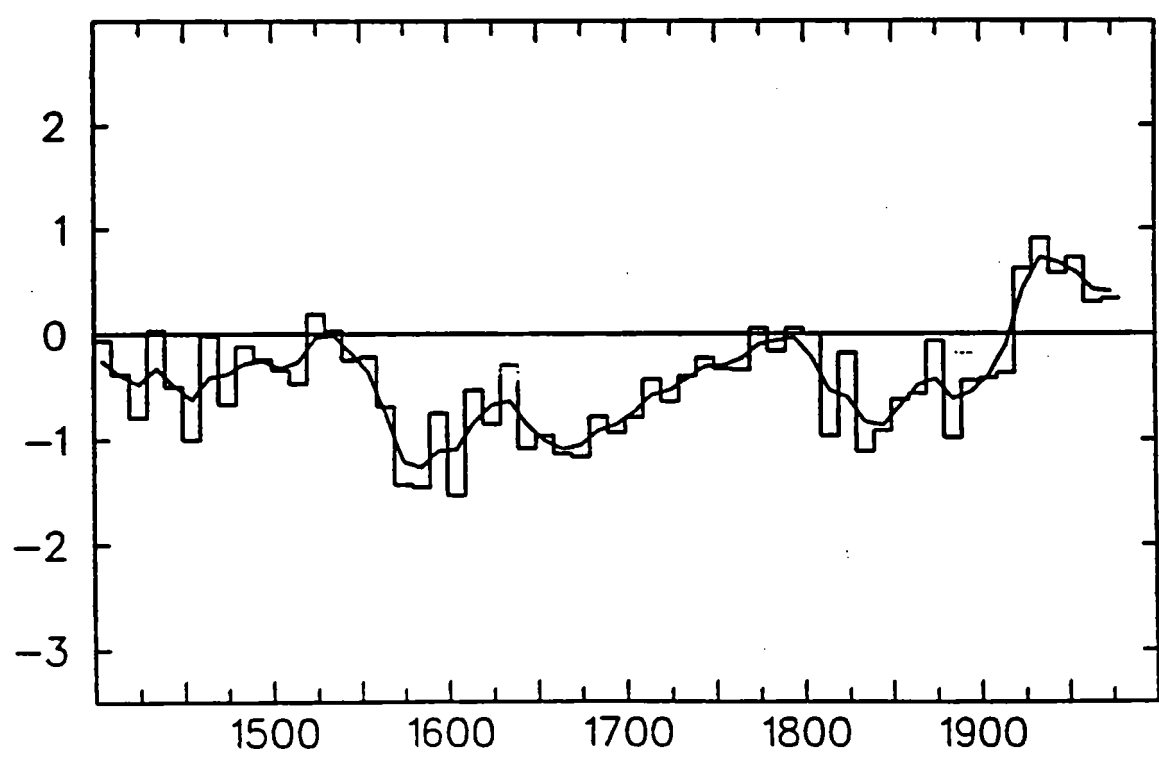
Figure 3.1



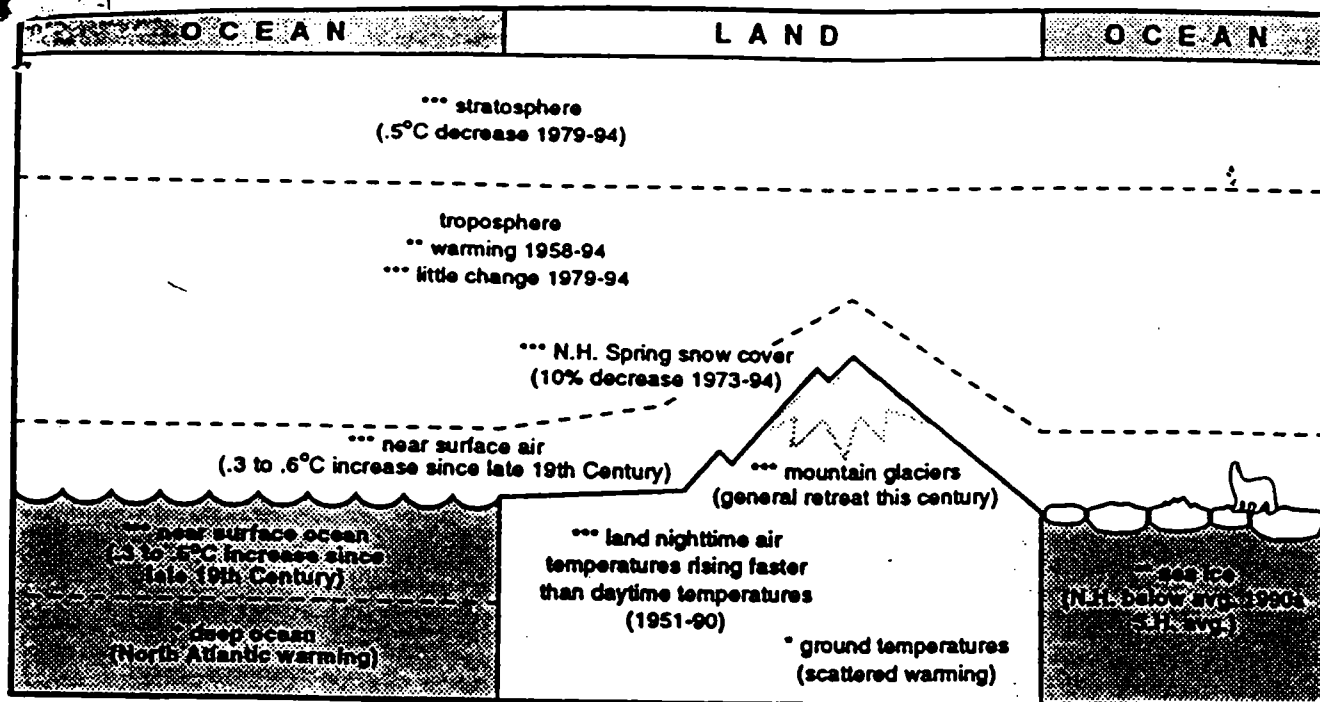
map of observed temperature
anomalies for the period 1977 - 93.
Annual mean (from chapter 3)

Figure 3.2

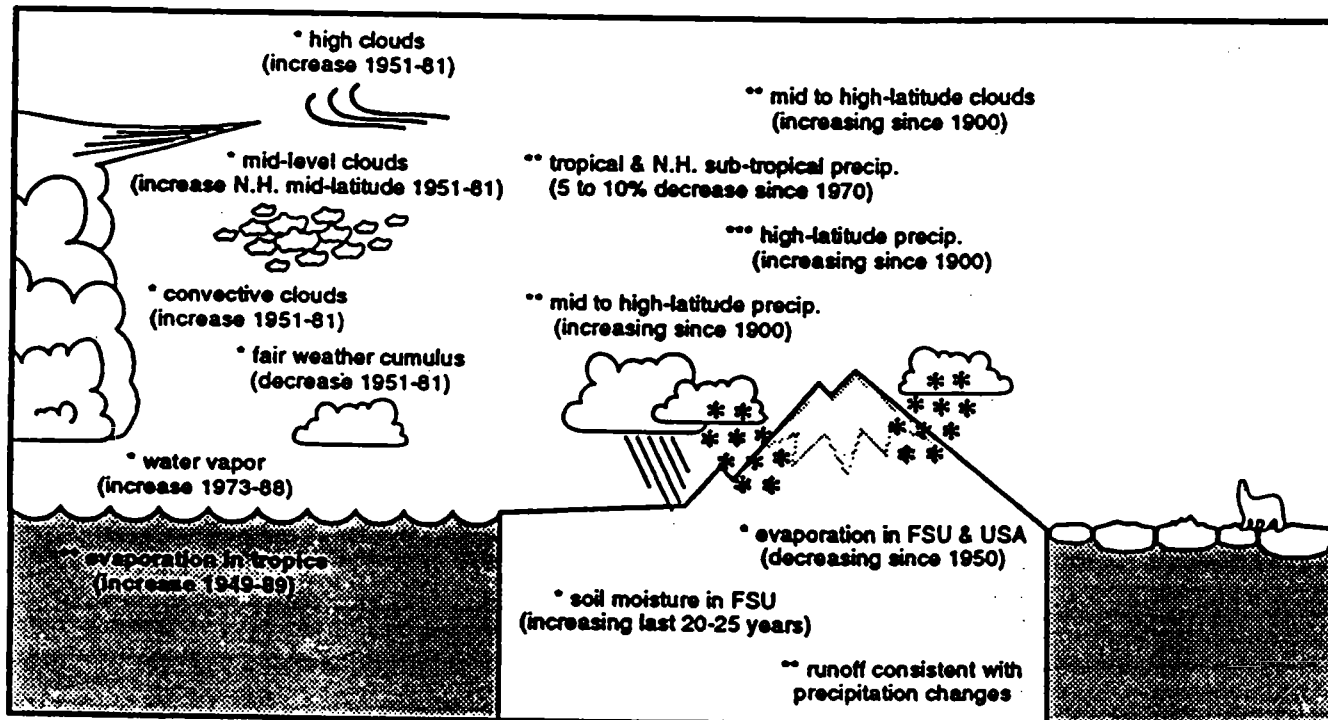
Figure 3.3



Temperature Indicators



Hydrologic Indicators



Asterisk indicates Confidence Level (i.e. assessment) : *** high, ** medium, * low

Figure 3.6

Figure 3.7

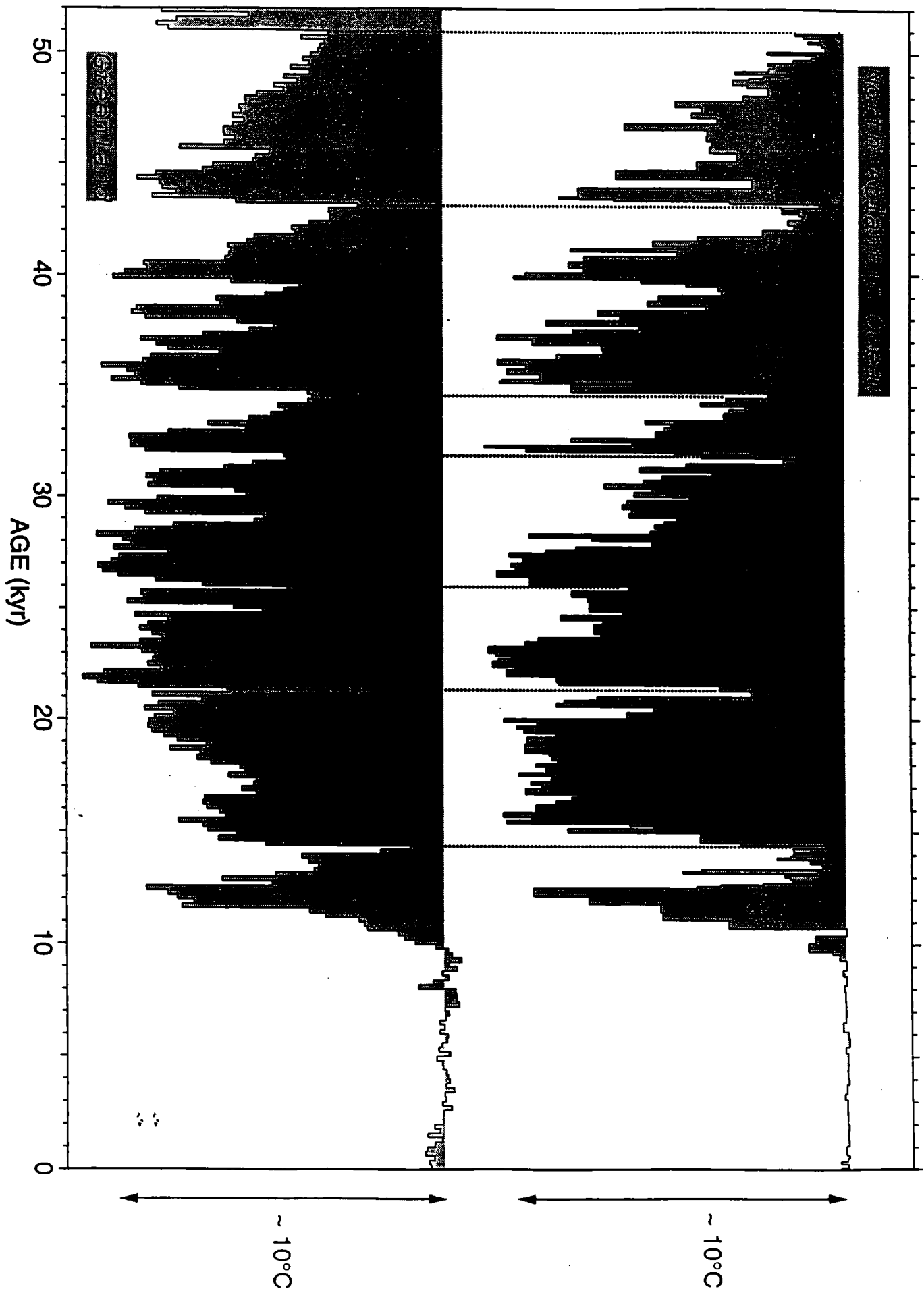
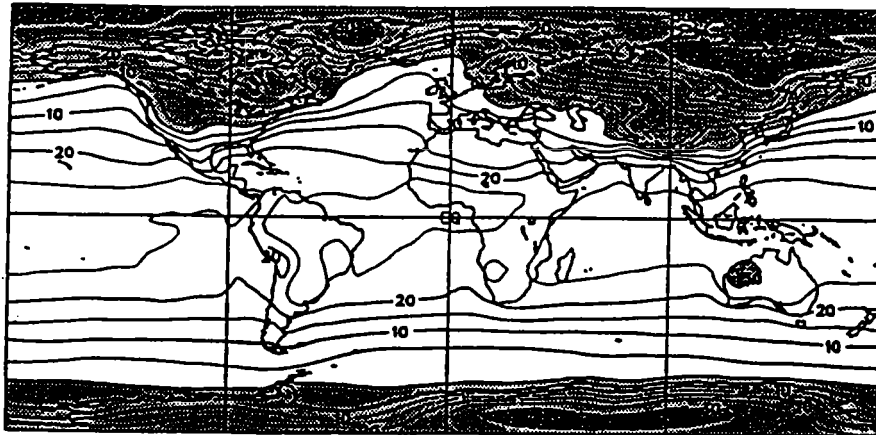


Figure 41

December-February Surface Air Temperature ($^{\circ}\text{C}$)

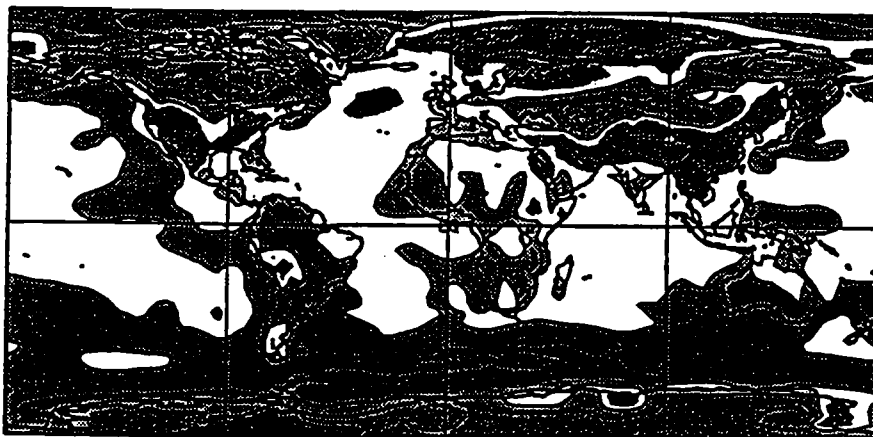
Model Average

a



Difference of Model Average from Observed

b



Intermodel Standard Deviation

c

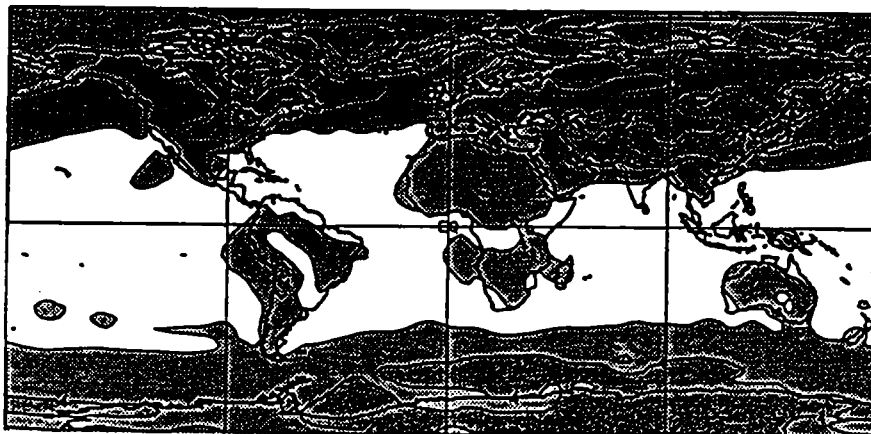
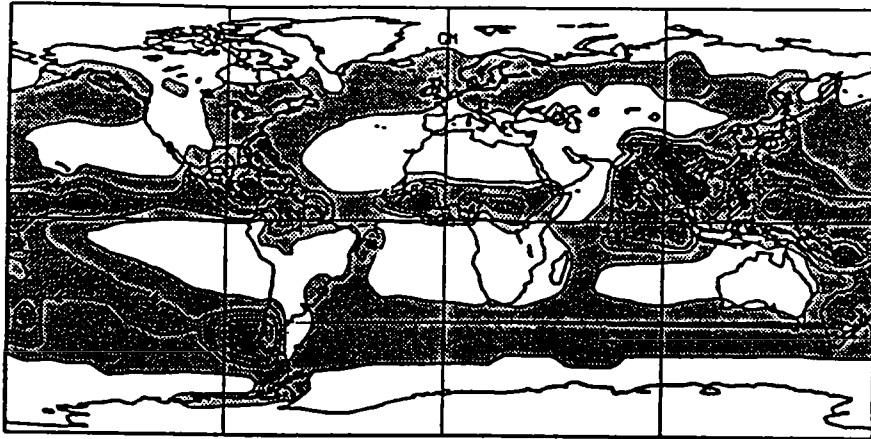


Figure 4.1

June-August Precipitation Rate

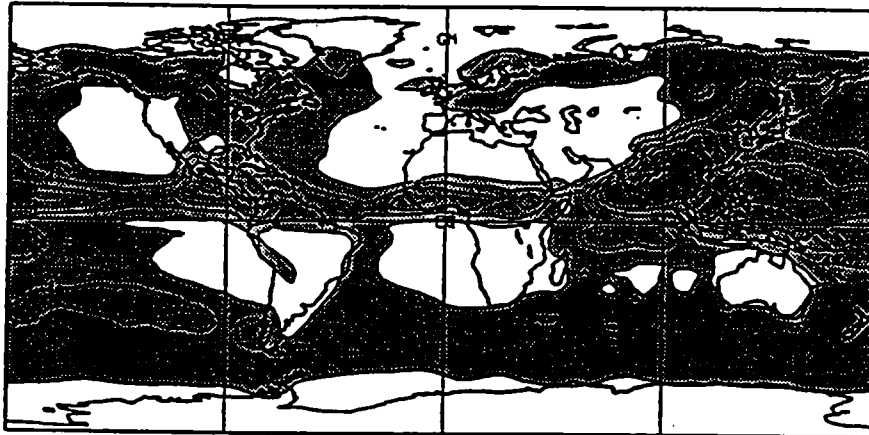
Observed

d



Model Average

e



Intermodel Standard Deviation

f

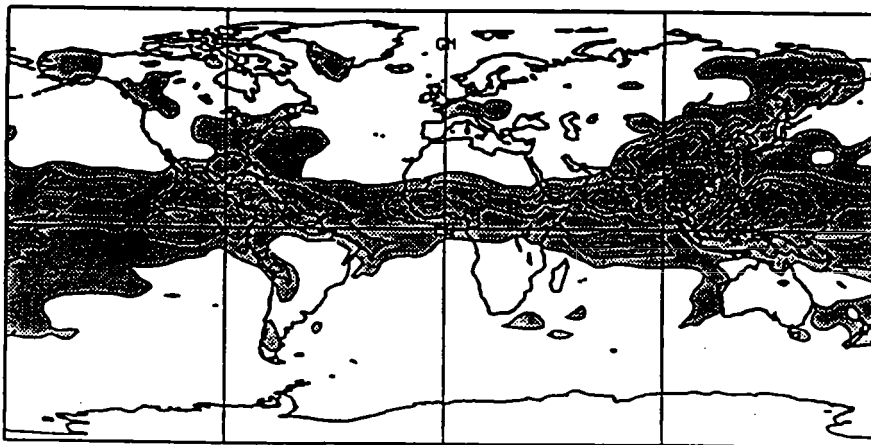
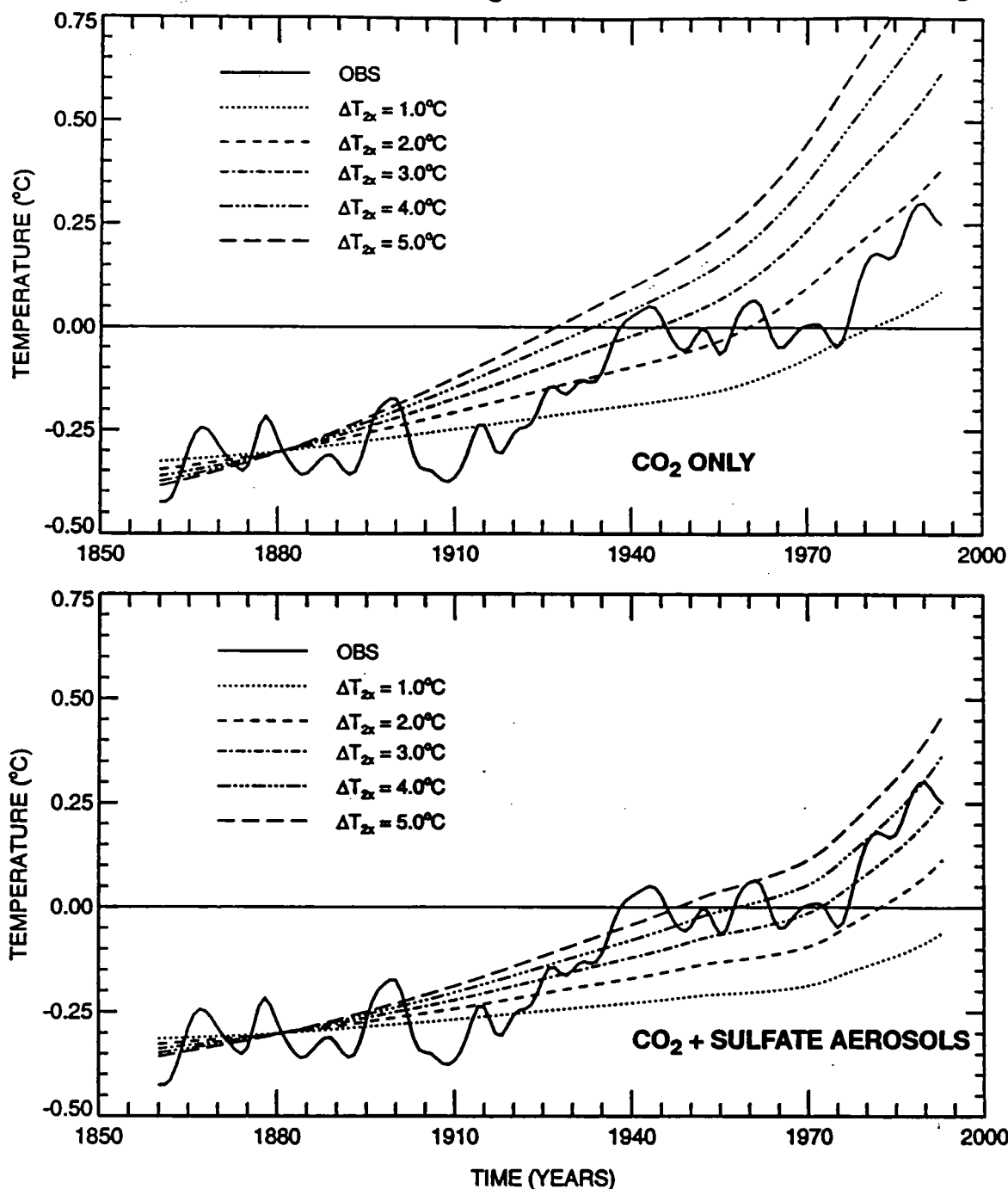


Figure 5.1

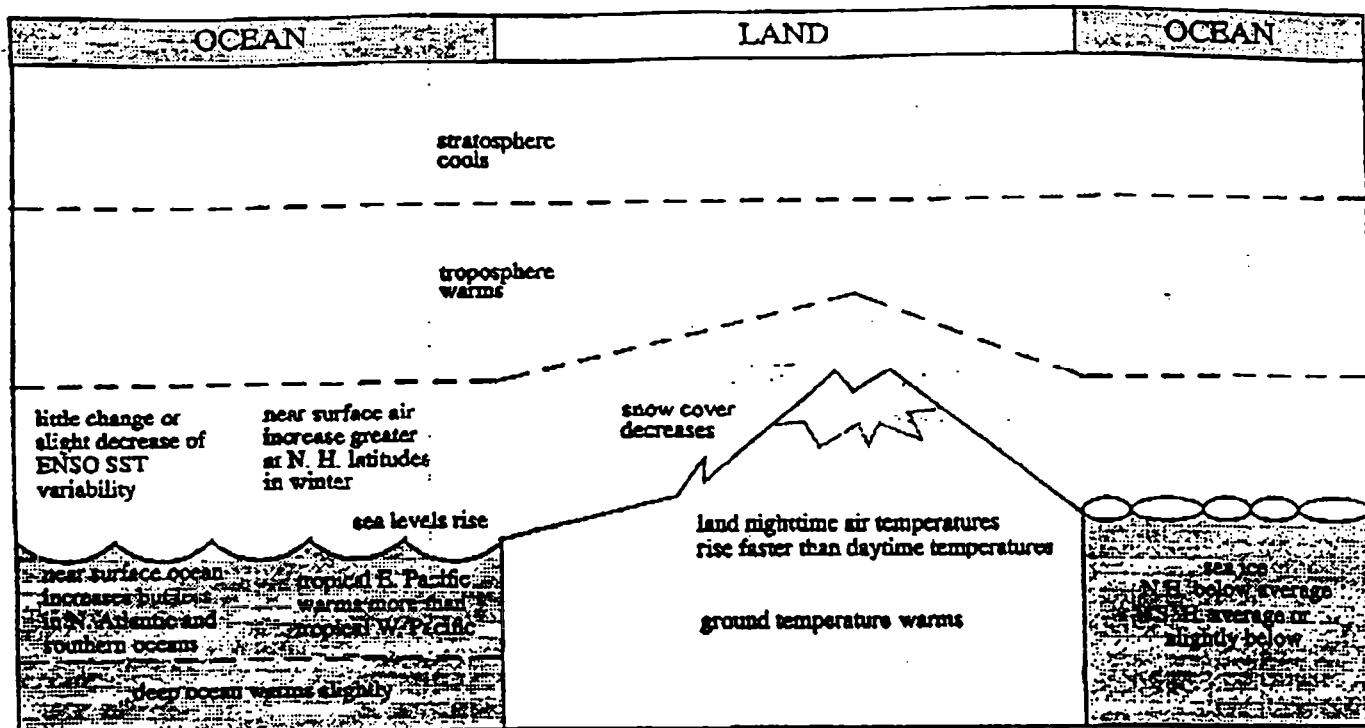
Show simplified version of this in the SPM - just using 2.5°C climate sensitivity (?).



Comparison of modelled and observed global-mean temperature changes. The modelled curves (dashed lines) are from the upwelling-diffusion energy-balance model of Wigley and Raper (1992), the same model that was used in the 1990 IPCC Report. Results are shown for values of the climate sensitivity (ΔT_{2x}) of 1, 2, 3, 4 and 5°C and best-guess values of the other model parameters, as specified in Wigley and Raper (1992). The observed data are smoothed annual-mean values from the land-plus-marine data set of Jones et al. (1991), updated to 1993. The observed data are anomalies relative to the 1951-1980 mean. Modelled results, which have an arbitrary reference period, have been adjusted to have the same mean as the observed data over 1861-1900. The upper panel shows model results for greenhouse-gas forcing alone, while the lower panel shows results for both greenhouse-gas and sulfate aerosol forcing (reducing the total forcing from around 2.3 W/m^2 to 1.5 W/m^2).

TEMPERATURE INDICATORS

MODELLED RESULTS



HYDROLOGIC INDICATORS

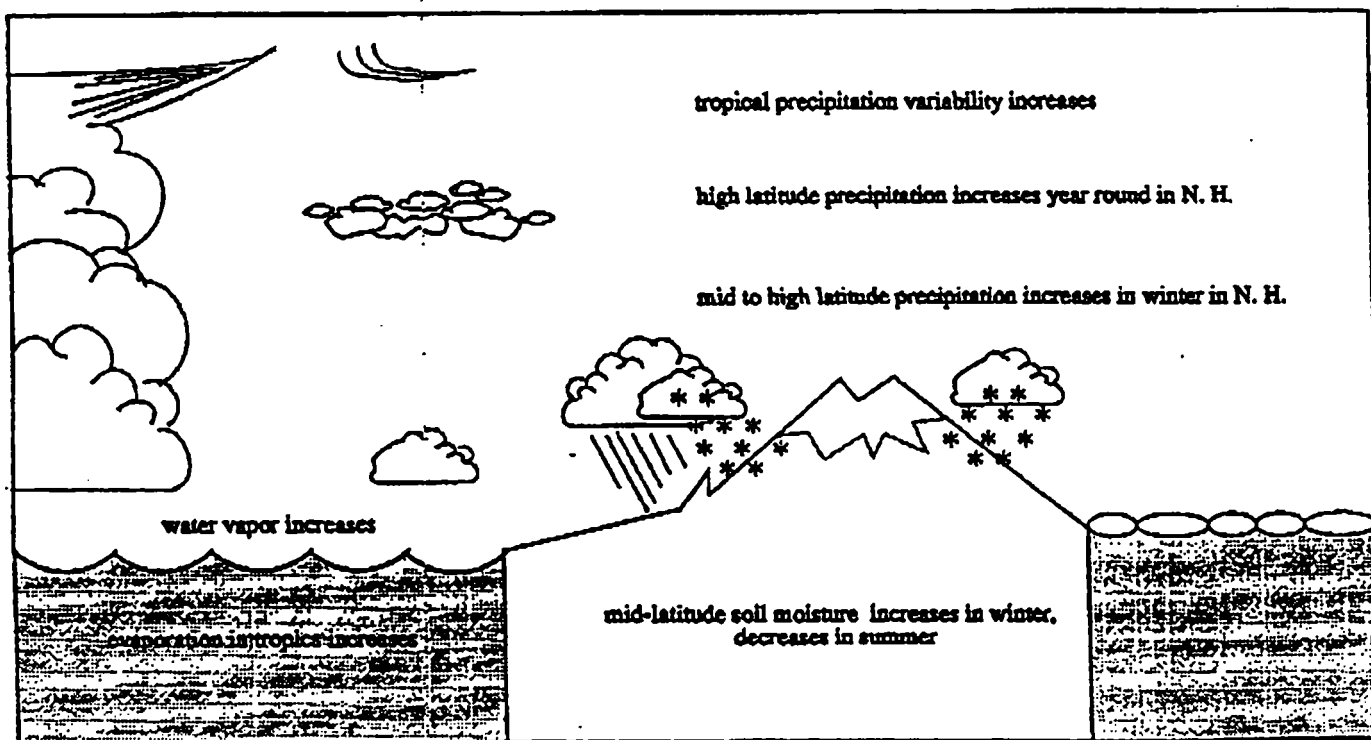


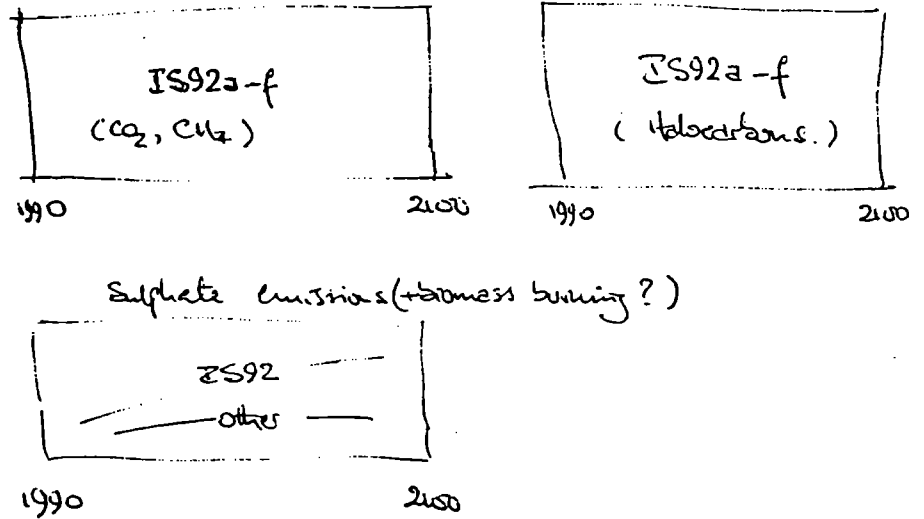
Figure 5.2

Proposals for presentation of Temperature & Sea level results in SRM.

Emissions

IS92 emission scenarios

Figure 6.1



Concentrations

Figure 6.2

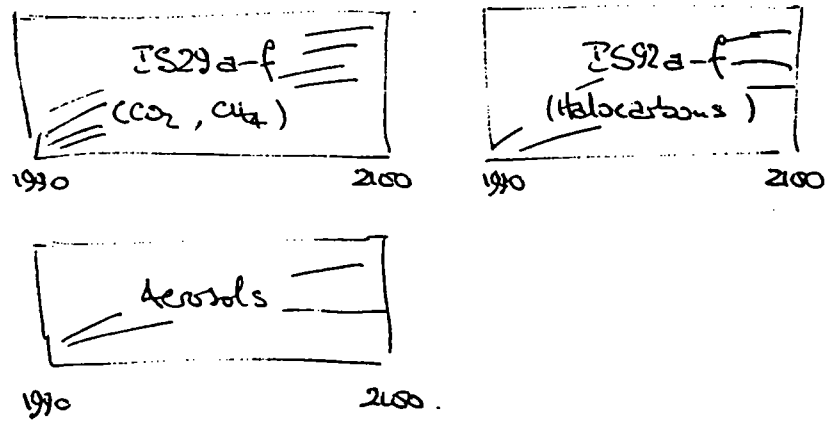
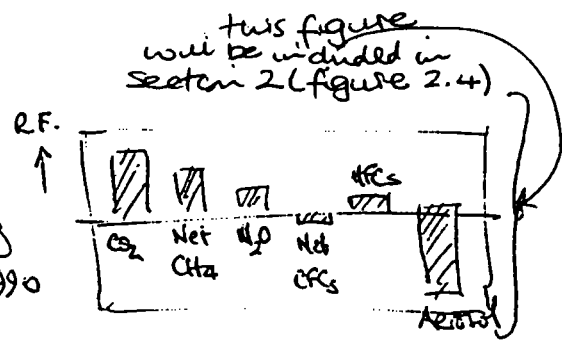


Figure 6.3

Radiative forcing

History of radiative forcing
- change of r.f. 1860 - 1990



Radiative forcing
1990 - 2100

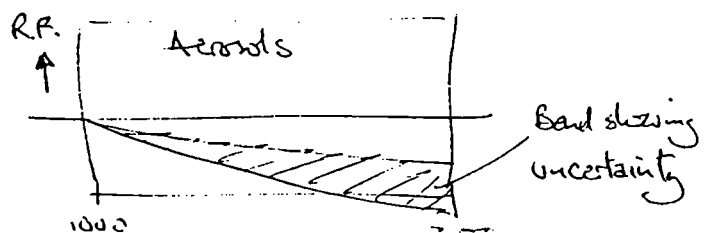
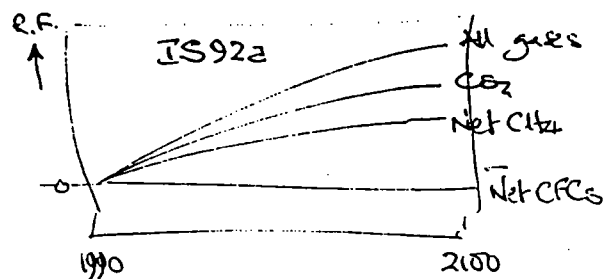
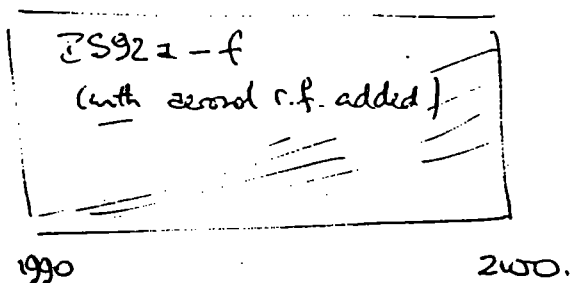
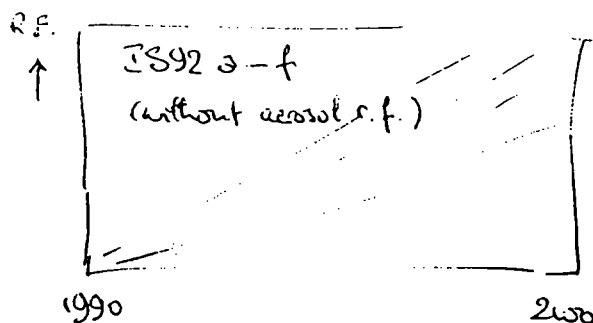


Figure 6.3 (contd) Radiative forcing
1990 - 2100

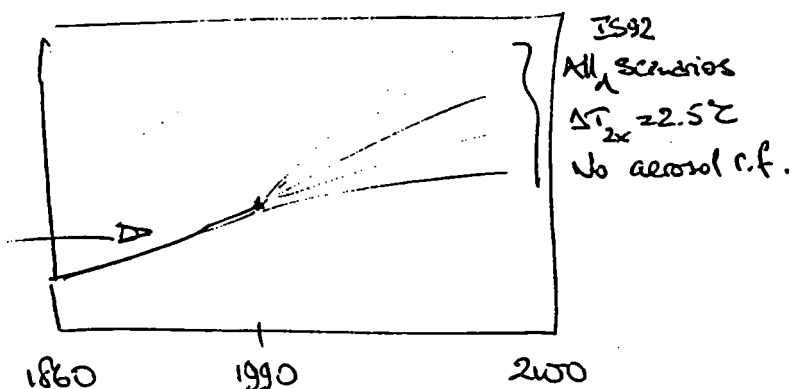
Figure 6.3
Continued



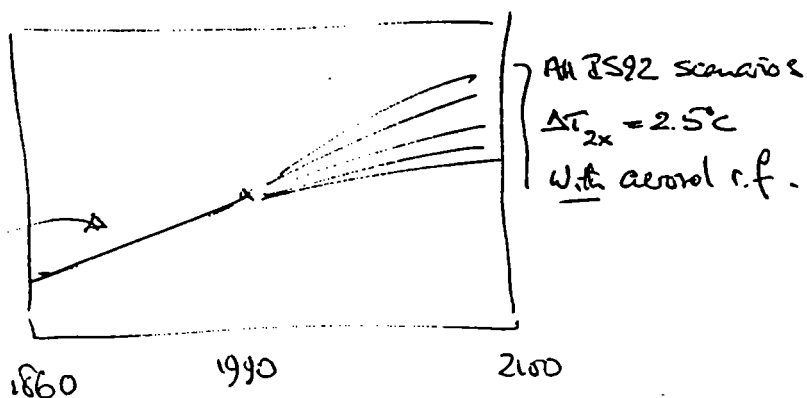
Temperature & Sea level (Figures 6.5 and 6.6)

Calculation
based on
best estimate of
ghg's at aerosol.

$$\frac{\Delta T}{\Delta s.l.}$$

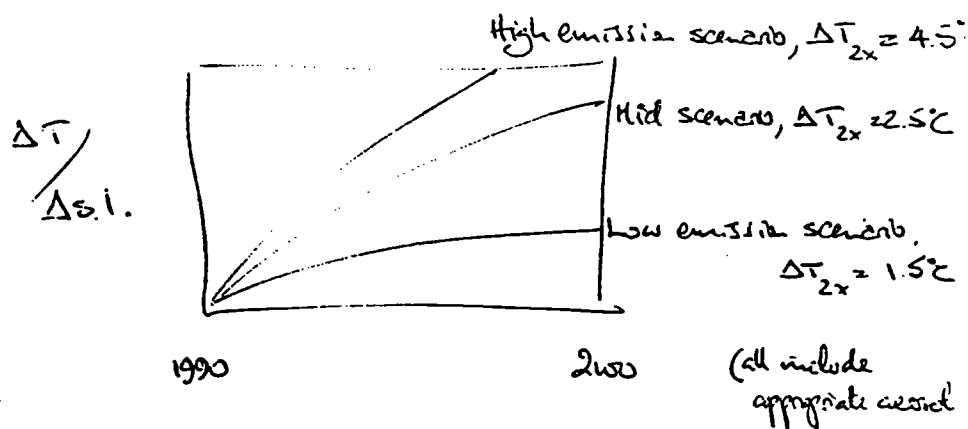
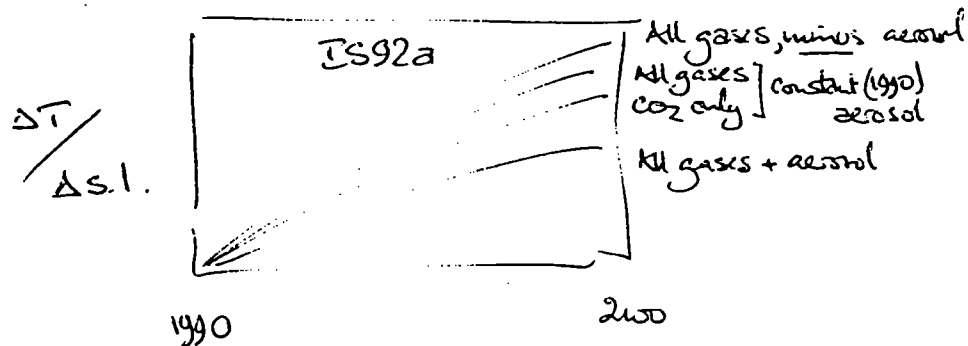


$$\frac{\Delta T}{\Delta s.l.}$$



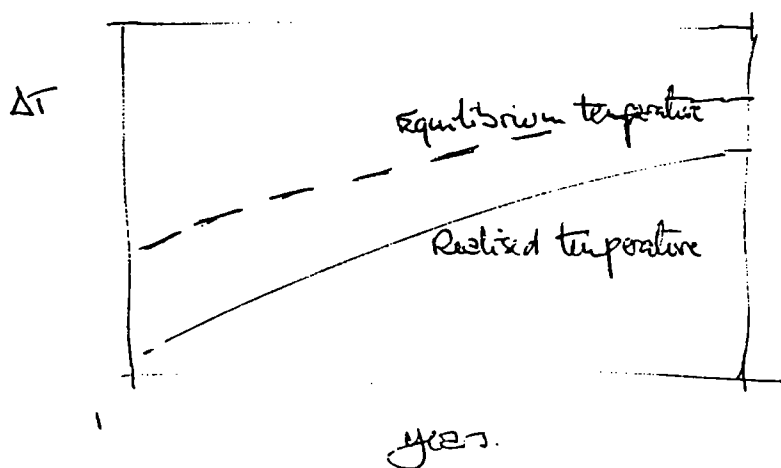
Figures 6.5 & 6.6

(contd) Temperature & Sea Level



Finally - we also need a device for showing that even if concentrations are stabilised, global temperature and sea level will still tend towards their equilibrium values.

Possibilities



Coupled model aerosol runs

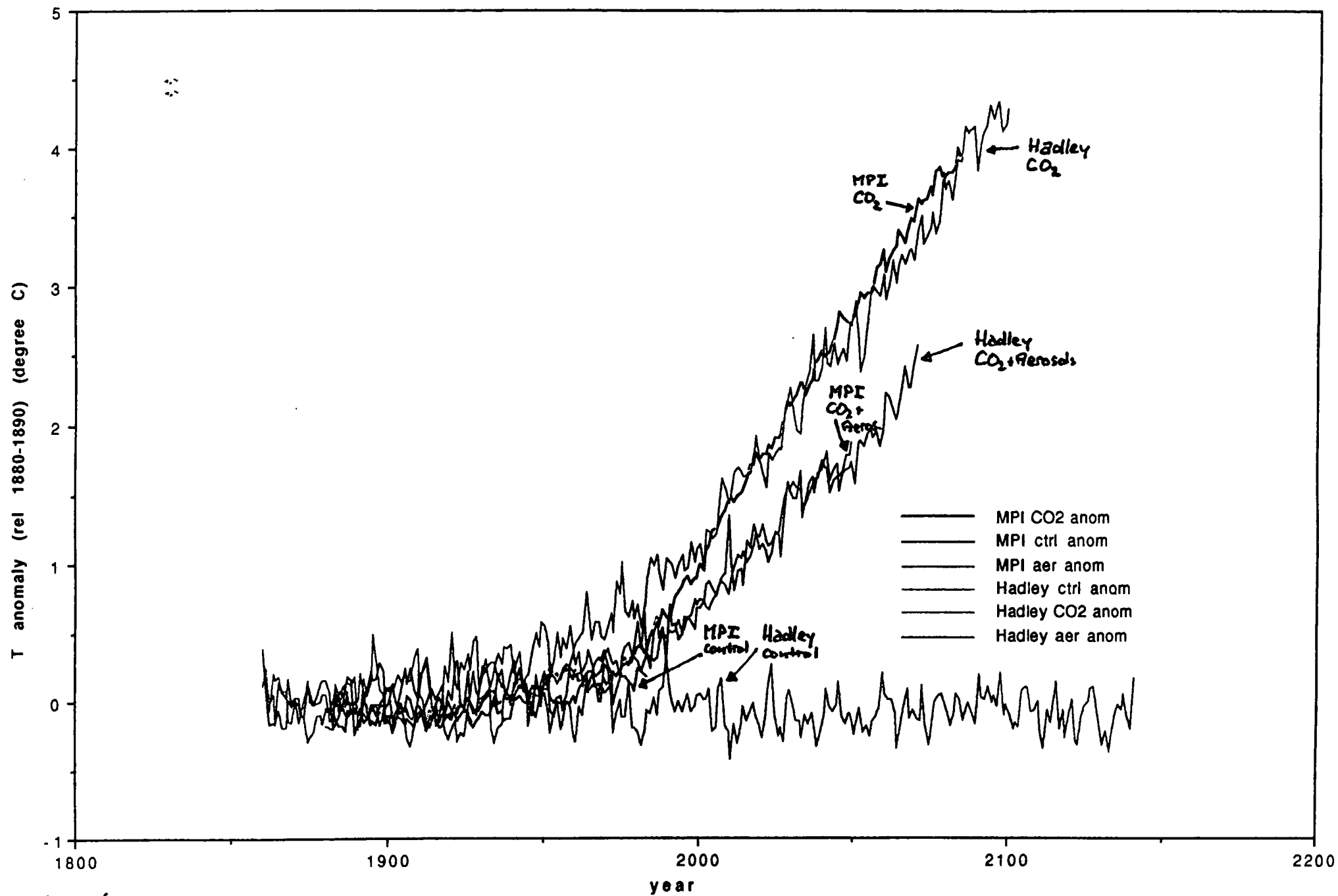
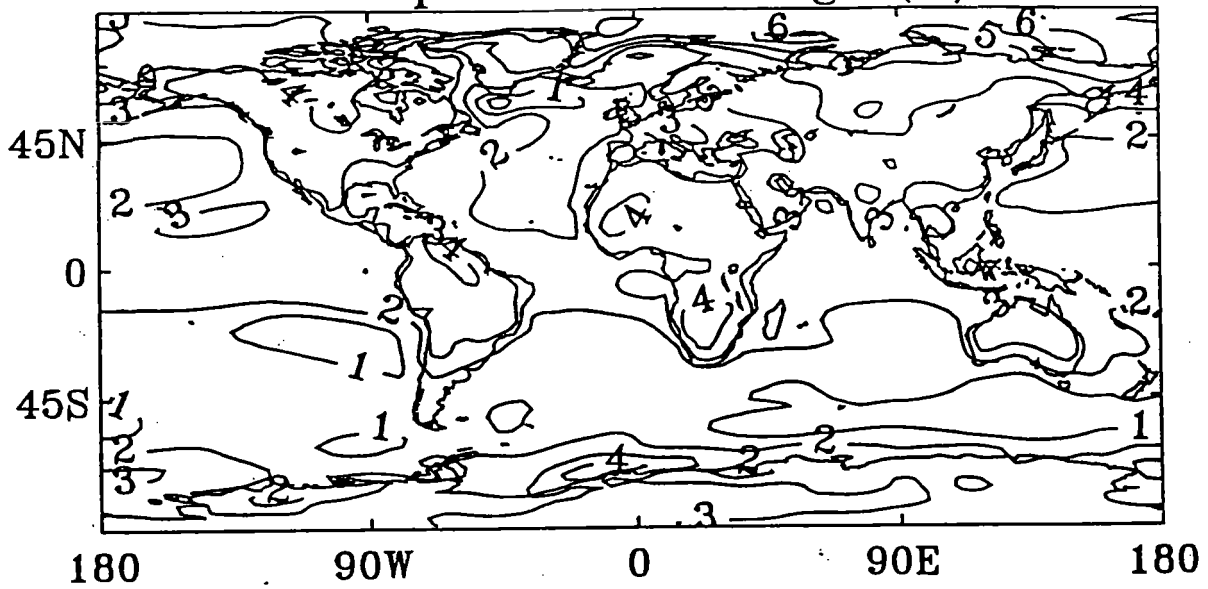


Figure 6.4

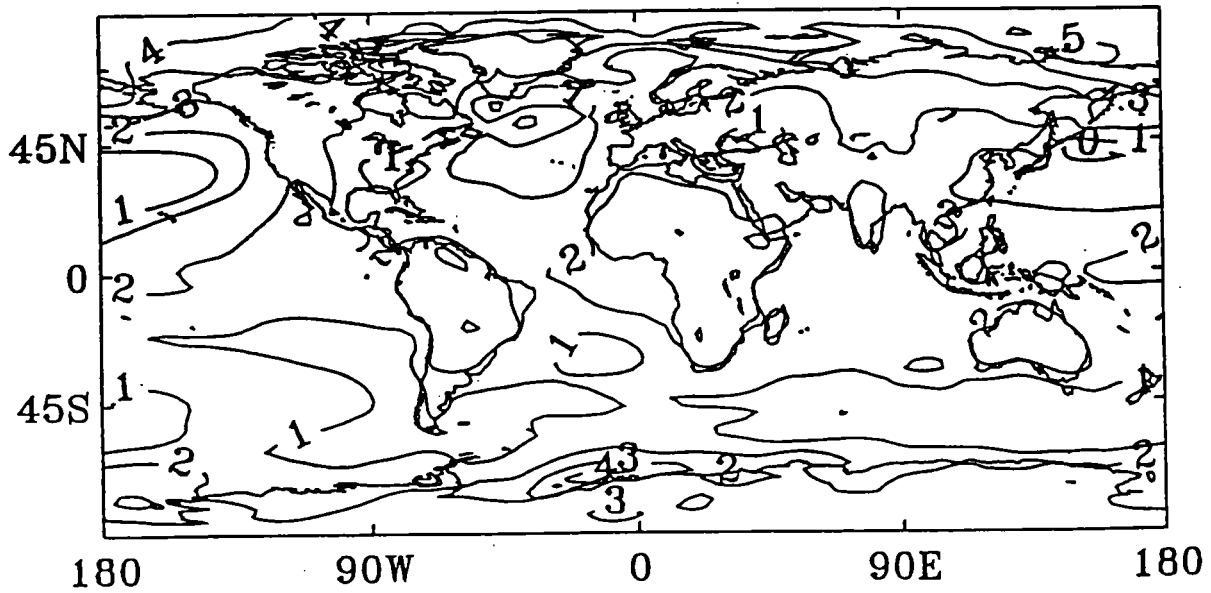
Fig. 6.4

867

Temperature Change (K)

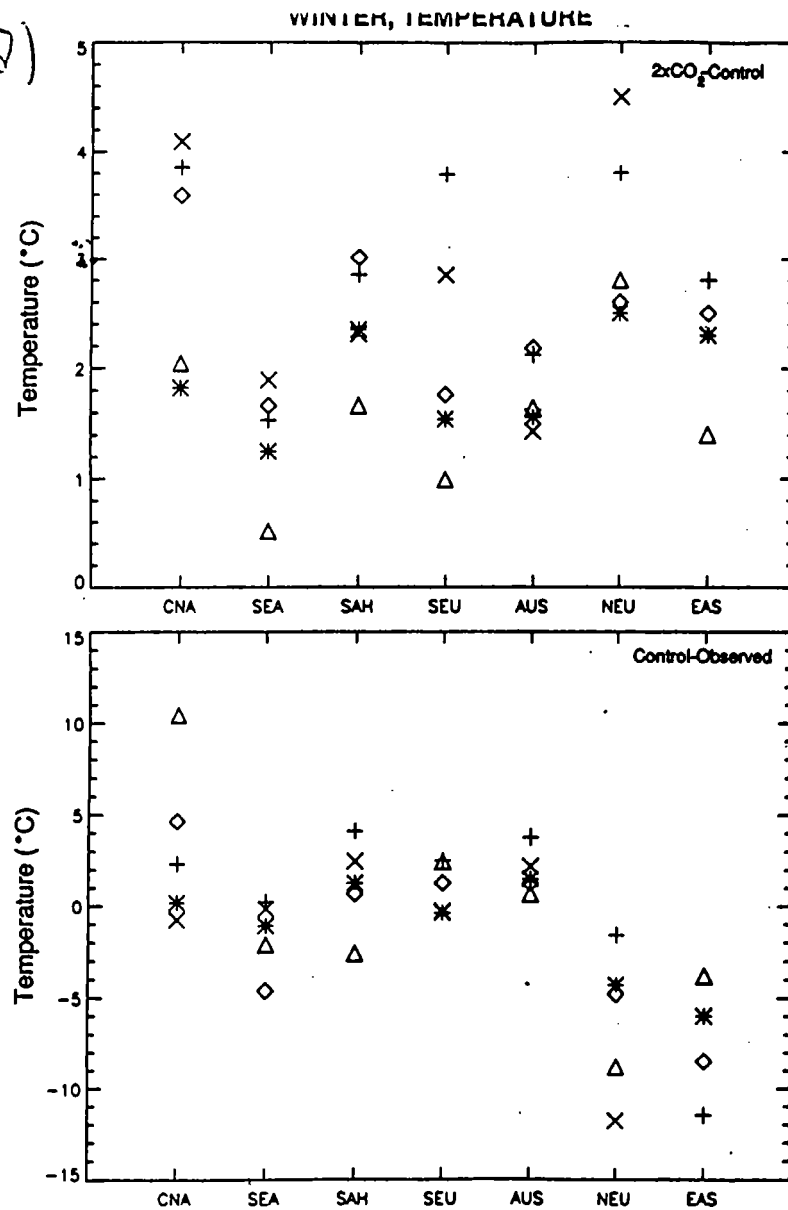


868



869

(a)

SUMMER, TEMPERATURE

Temperature (°C)

2xCO₂-Control

Control-Observed

CNA SEA SAH SEU AUS NEU EAS

(b)

figure 6.9

Temperature

Difference between averages at time of CO₂ doubling and control run averages (2CO₂-Control) and difference between control run averages and observed averages (Control-Observed) as simulated by five coupled model runs over seven regions (see text). (a) Temperature, winter; (b) Temperature, summer; (c) Precipitation, winter; (d) Precipitation, summer. Units are °C for temperature and percentage of control run, or observed, averages for precipitation. CNA = Central North America, SEA = South East Asia, SAH = Sahel, SEU = Southern Europe, AUS = Australia, NEU = Northern Europe, EAS = East Asia.

- + GFDL
- * DKRZ/OPYC
- ⊗ DKRZ/LSG
- △ NCAR
- × UKMO

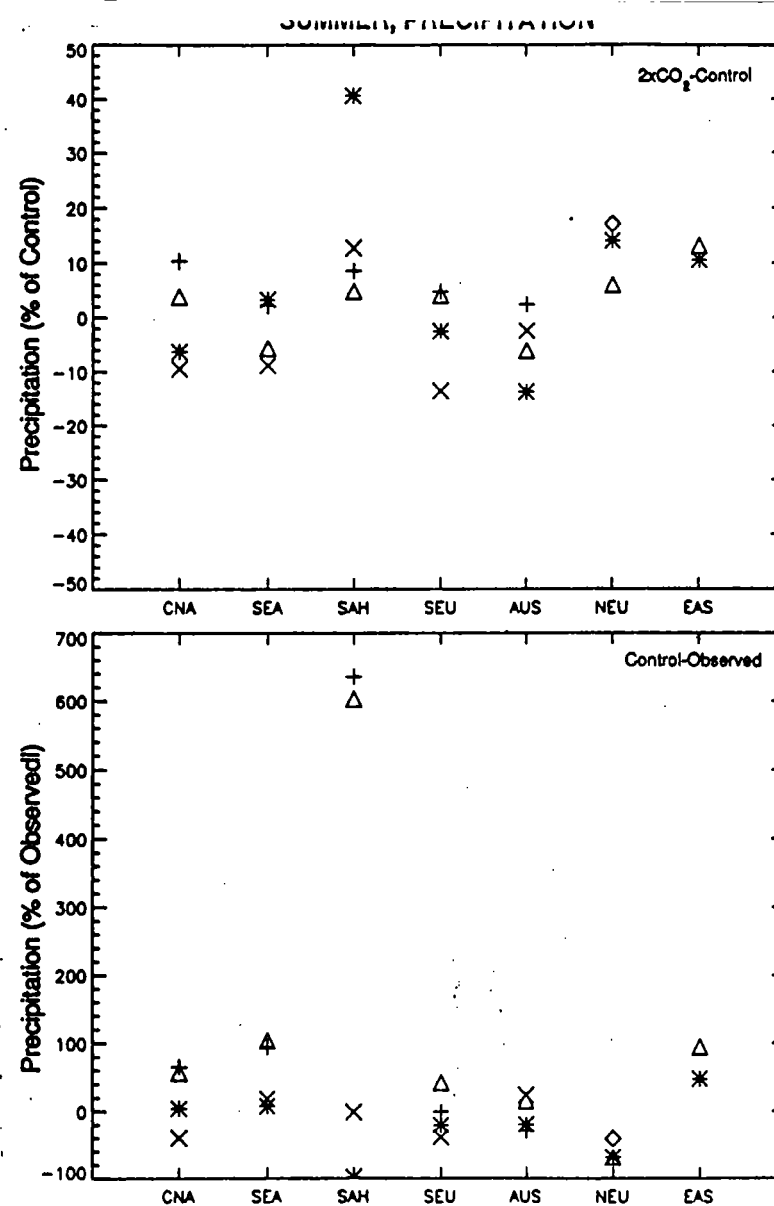
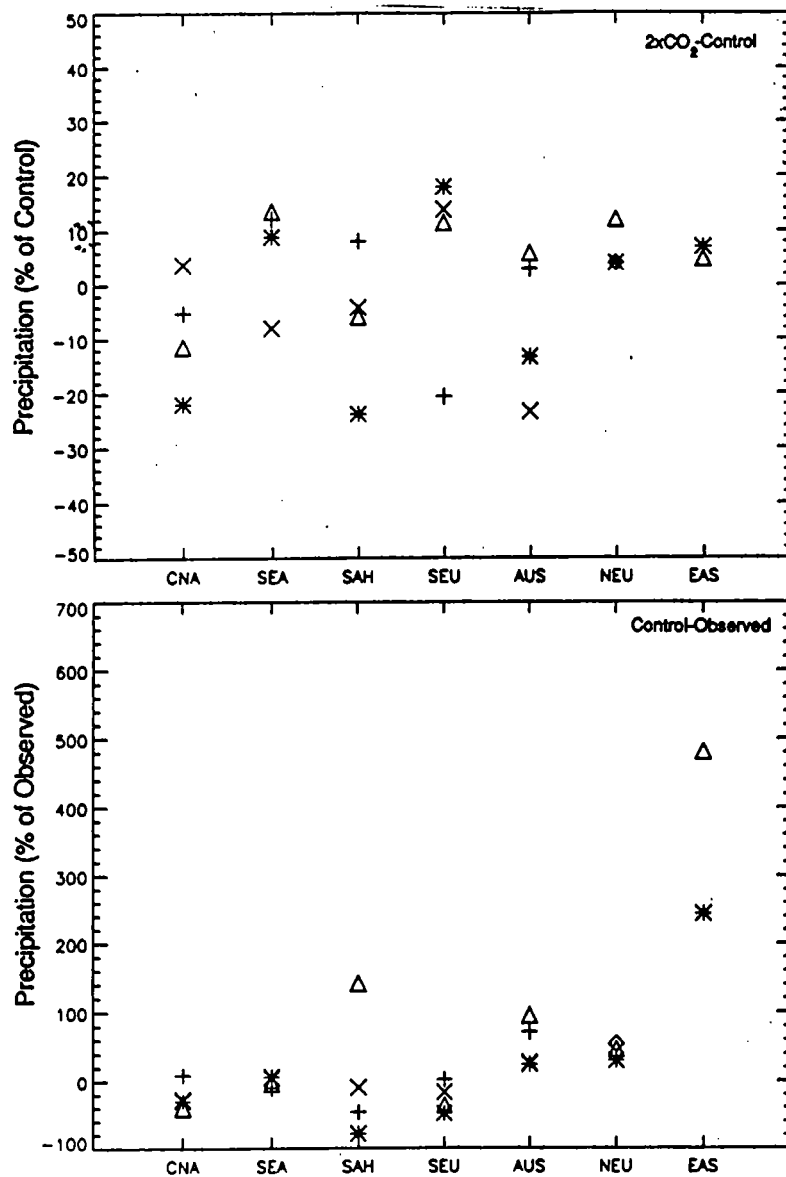


Figure 6.9 Precipitation

Difference between averages at time of CO₂ doubling and control run averages (2CO₂-Control) and difference between control run averages and observed averages (Control-Observed) as simulated by five coupled model runs over seven regions (see text). (a) Temperature, winter; (b) Temperature, summer; (c) Precipitation, winter; (d) Precipitation, summer. Units are °C for temperature and percentage of control run, or observed, averages for precipitation. CNA = Central North America, SEA = South East Asia, SAH = Sahel, SEU = Southern Europe, AUS = Australia, NEU = Northern Europe, EAS = East Asia.

+ GFDL
 * DKRZ/OPYC
 ◇ DKRZ/LSG
 △ NCAR
 X UKMO

Environ 1P CC

Policy Makers Summary

p. 1 I agree with the first two priorities listed, but believe the third priority may be misinterpreted: the chapters of the report call for expansion of the commitments to the less developed countries, but do not call for stronger commitments on the part of the developed countries *at the current time*. The various chapters emphasize the high returns from research.

Concerning the first priority: my impression is that the most recent research puts greater emphasis on methane.

I would add, as an expansion on the first point, or a new "third" point: the development of policies at the international and national levels that will enhance the possibility and likelihood that emission reductions will be conducted in an efficient way. Such policies include the elimination of subsidies, the creation of appropriate institutions, and the dissemination of information.

p. 3. The argument that a "lower peak" in the *emissions profile* is more likely to avoid damage from climate change seems inconsistent with the earlier statement that cumulative emissions are more important than the pattern of annual emissions. I agree with the latter statement, not the former.

The argument that a lower peak is likely to be preferred from an economic perspective is not made in the chapters of the report; and in fact is contravened in some of the economics literature. This sentence should be deleted.

p. 4. I do not think that the statement that "Ethical considerations or scientific information may argue for limiting atmospheric concentrations below a particular level regardless of cost" has any support in the chapters of the report. On the contrary, arguments to that effect are criticized. This paragraph needs extensive rewriting.

The sentence that "Some people object..." is factually correct, but the economics and risk assessment literature argues forcefully that those objections are without much merit. The sentence should be deleted.

p. 5: On costs and benefits

You need to stress two robust findings of the studies:

1. Efficient strategies--such as those involving tradeable permits or carbon taxes--have significantly lower costs than inefficient strategies for emission reductions.

2. Stabilizing atmospheric concentrations may be achieved at much lower costs by devoting more near-term resources to R & D. Setting

arbitrary near-term emission reduction standards may unnecessarily increase, by a substantial amount, the costs of achieving given targets for atmospheric concentration.¹

p. 5 You say that relatively little information is available. I'm not sure that most of the authors would agree with that conclusion. At best, they might agree with a sentence to the effect that "Relatively little hard information...." A similar remark applies to the concluding par. on p. 6

I would prefer a statement explaining some of the reasons that it is difficult to calculate global costs: (a) Some countries are likely to be better off, even as other countries suffer; (b) Direct economic impacts are likely to be greatest in agriculture, which will be accounting for a shrinking fraction of the world GDP; (c) Impacts depend greatly on the time provided for adjustment; with long adjustment times, crops suitable to the changed climate can be planted, and adjustments in capital stock can be undertaken.

"Estimates of the extra damage done by CO2 emitted now..." The marginal cost of the damage of current emissions cannot be estimated without knowing future responses, particularly since losses are likely to be non-linear in temperature.

I think you should separate out issues where *precision* is an issue (uncertainty about parameters) and where there is controversy about evaluation (the discount rate.)

¹This is related to the point made on p. 3 that cumulative emissions are more important than the pattern of annual emissions.

Minor comments

p. 1 following priorities if the objective
(the priorities do not relate just to the next decade)

p. 1 bottom of mpage. Few countries can be confident that they
will ...

p. 2 The sentence beginning, "Costs of abatement..." should be
deleted

incidence of damages cannot be *as easily* controlled

You give as targets "the level and date at which concentrations
are to be stabilized" Why is the date important?

The robustness of the near term strategy to a *wide range of targets*
is...

Dear Erik,

I have at last had a chance to take a look at the policy makers summary. I enclose a set of comments. The copy I received did not have figures.

THE WHITE HOUSE
WASHINGTON

*Enclosure -
pesticides*

FAX COVER SHEET

TO: BO CUTTER (6-1605)
BILL GALSTON (6-2878)
JOE STIGLITZ (5-6958)
GREG FRAZIER (720-0591)
KIM SCHNOOR (720-5437)
KATIE MCGINTY (6-2710)
KEITH COLLINS (690-4915)
BARBARA CHOW (6-2604)
MARK WEATHERLY (5-4941)
PETER YU
MARION BERRY
MIKE DAVIS (6-2710)
ROB INNES (5-6853)

FROM: BRIAN BURKE

COMMENT: ATTACHED PLEASE FIND THE REVISED MEMO ON PESTICIDES
REGULATION -- 1 PAGE ATTACHED

DRAFT-2/21/95

1995 FARM BILL-- PESTICIDES REGULATION

ISSUE

Whether the 1995 Farm Bill should include all or part of the Administration's proposal for FIFRA and FFDCA reform.

1994 PESTICIDES PACKAGE

In 1994, the Administration proposed legislation to amend the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and the Federal Food, Drug and Cosmetic Act (FFDCA). The legislation included the following reforms: registration sunset, streamlined procedures for label changes, incentives for reduced risk pesticides, support for IPM, export restrictions, assistance for minor use pesticides, streamlined cancellation and suspension procedures, special provisions for infants and children in tolerance settings, additional fees to support re-registration, and expanded enforcement authorities.

CORE PRINCIPLES FROM THE 1994 PESTICIDES PACKAGE

- Modernize DeLaney to represent modern scientific assessment and risk standards, replacing the zero-risk Delaney standard with a more flexible and less costly uniform public health based standard.
- Establish mechanisms based on the best and most recent science to better protect children's and infants' distinctive diet.
- Place the pesticide regulatory system on sound financial and administrative footing to meet the challenge of sustainable pest control into the next century.
- Promote economic efficiency, environmental sustainability, and market innovation in pesticide regulation by applying cost-benefit criteria to registration decisions, by reviewing all pesticide regulations to ensure that they meet the most current scientific standards, and by expediting the registration process for reduced risk and minor use pesticides.
- Promote market-based incentives in regulating pesticides.

RECOMMENDATIONS FOR 1995 FARM BILL

- Include the core principles from the 1994 pesticides package (above) in the Administration's 1995 Farm Bill.
- If requested by Congress, introduce a "small package" of reforms which includes issues of greatest concern to the Administration, Congress and stakeholders (e.g., DeLaney, children, minor use, food safety and registration sunset).

Environment IPCC

Ray Sqrter
301-913-0252

MEMORANDUM FOR JIM BRUCE, CHAIRMAN IPCC WG3

FROM: Joseph E. Stiglitz

SUBJECT: Comments on Synthesis Report: Draft Outline (7 April) and Draft Report (20 April)

I am sorry I cannot join you in Athens; pressing business keeps me away. Thank you nonetheless for the opportunity to comment on the drafts.

The draft and outline are a good start, especially on the physical science side. It does not yet contain many of the important insights from economics or decision science, which is where I will focus my suggestions.

I suggest a section that would go between "2. What is projected to happen...?" and "3. What options are available...?" in the 7 April outline. The new section would explain how to think about climate change from the point of view of a decision maker. This approach allows many of the important economic insights to be included. Let me lay out my view of this section, showing how it connects to the sections before and after it in the current draft, and how it allows a coherent discussion of many of the major economic insights from the Working Group III report.

To explain the general idea of decision making under uncertainty, it may be helpful to refer to Pascal's wager. In discussing the existence or nonexistence of God, Pascal proposed (to put his argument in the language of modern decision analysis) two possible states of the world (either there is a God or there is not), and two possible actions (I can ^{act} as if there is a God, said Pascal, or as if there is no God). If there is a God, and I act as if there is, or if there is no God, and I act as if there is not, said Pascal, there is no problem. If there is no God and I act as if there is, I will have wasted a certain amount of time and energy. But if there is a God and I act as if there is not, then I will suffer terrible consequences--at least according to the theology of the 17th Century.

Suppose that the (simplified) choice facing the world today is to take aggressive and costly action, to take moderate (and moderately costly) action, or to take no action. For simplicity, suppose we can only make this decision once, and thereafter are bound by the consequences of our choice. And suppose that in ~~50 years~~²⁰⁴⁰ the current uncertainties in climate change science will have been resolved and we will know either that climate change is a big problem, or that it is not a big problem. What should we decide, given the information available today? That will depend on the costs of being wrong in either direction, and the probabilities that the uncertainty will be resolved

either up (no problem) or down (big problem). Figure 1 shows the simple decision tree for this problem.

The decision problem we actually face is of course far more complex. First, rather than one decision to be made now, there will be many decisions to be made over many years. Second, the uncertainties will not be resolved all at once, but rather one by one over many decades. Figure 2 shows a more complex decision tree. An initial decision is to be made in 1998. One important uncertainty is resolved in 2010 (e.g., the cost of climate change mitigation programs). Learning from this new information, another decision is made in 2020, with the final uncertainty (e.g., the cost of climate change damages) resolved in 2040. We need a decision process that is sequential, can respond to new information with mid-course corrections, and can include, insurance, hedging, and the option value of alternative courses of action.

? || The actual problem facing governments is complicated by several other factors: the long time lags between emissions and effects, the potential for irreversible damages or costs, the global nature of the problem (which means that international trade considerations are crucial, and many conclusions of traditional economic analysis do not apply), wide regional variations, and multiple greenhouse gases of concern. ?

[The next group of conclusions may fall later in the outline, as they do not fall directly out of the discussion of decision making under uncertainty.]

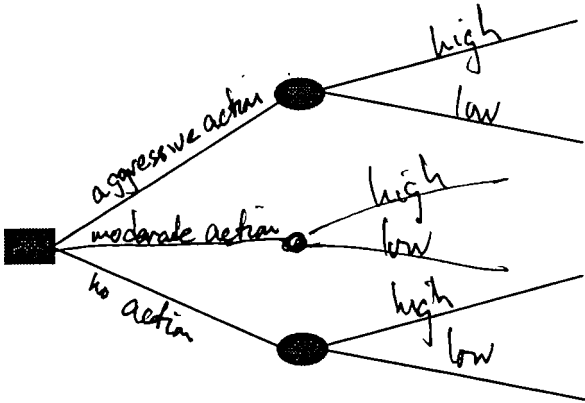
✓ Even in the presence of these complications, several general conclusions apply. First, a well-chosen portfolio of policies will yield greater benefits for a given cost than any one option undertaken by itself. Striking the appropriate balance requires taking into account costs, benefits, and risks. Second, in an interrelated global system, an attempt to reduce greenhouse gas emissions in one region or one sector of the economy might be offset by increases in other regions or sectors. Third, efficiency requires that efficiency reductions occur where their cost is lowest, irrespective of who bears the financial responsibility. C.H. '81/M

Given the state of knowledge about climate change, what decisions are consistent with our preferences and resources? Irrespective of the possible consequences of climate change, policies that mitigate against or assist adaptation to climate change and have zero or negative net costs ("no regrets" policies) are clearly justified. If the evidence suggests that damages can be expected from climate change, then the expectation of damages provides a rationale for going beyond "no regrets" policies to those that incur positive net costs. The principles of risk aversion and portfolio balancing provide a rationale for further steps.

[The following point is also important and should be inserted in the outline where appropriate.]

The atmosphere is an international public good, in that all countries benefit from each country's reductions in greenhouse gas emissions.

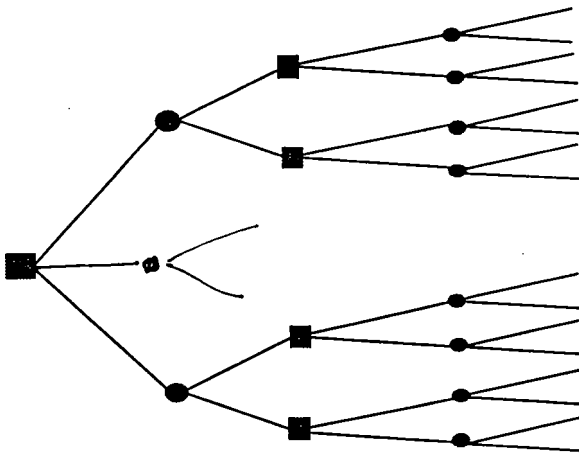
Simple Decision



Decision	Uncertainty
1998	Resolved
2005	2005
2040	2040

damages from climate change

Sequential Decisions



Decision 1	Uncertainty 1	Decision 2	Uncertainty 2
1998	2005	2010	2020
1995	2010	2020	2040

IPCC Synthesis Report Draft Outline -- 7 Apr 95

from Sally Kane
4.28

how do we interpret current information

Executive Summary

1. Why do we care about climate? -- why are we concerned?

- a) Socio-economic systems (agriculture, forestry, and water), ecological systems, and human health are sensitive to climate change.
(Spend about one to two pages discussing how things people care about may be affected by changes in climate)

direct effects

- b) Atmospheric concentrations of GHGs and climate have changed over the past 100 years.

(Spend about two pages summarizing how GHGs, aerosols, and climate have changed over the past 100 years, and to what degree these changes can be ascribed to human activities)

2. What is projected to happen in the absence of climate-change policies?

- a) Projected changes in climate

(This section will relate projected changes in emissions, to changes in concentrations, to changes in radiative forcing, to changes in global climate, to changes in regional climate, using a series of figures and a relatively small amount of text)

a)

- b) Projected impacts of climate change on:

ecosystems
human health
water supplies
food fiber
coastal zones

mostly qualitative

(This section will project impacts of different magnitudes and rates of climate change, as well as potential changes in extreme events, on the above systems, also considering changes in CO₂ concentrations, other changes in environmental systems, and socio-economic stresses)

- c) Projected costs of climate change = social costs
valuation problems for changes in non-market goods and services

3. What options are available for adapting to changes in climate?

- a) Adaptation options for ecosystems are not well developed

- b) Adaptation options for managed systems

- c) Potential benefits to increasing resilience of systems through sustainable management practices

- a) sequential decisions
b) portfolio approach
c) precautionary investments including "no regrets"
d) international public good

Factors influencing emissions dynamics of social system change over time

new section needed

2! how do we make decisions under uncertainty ??

What options are available

4. ~~What would be required~~ to stabilize concentrations and hence eventually to stabilize climate?

- a) Emissions trajectories to stabilize at different concentration levels
 - inverse calculation for CO₂
 - bring in other gases
 - aerosols
 - 50 and 100 year horizons
 - lag-times for climate
- b) Technical feasibility of stabilization options
 - time lag for capital stock turn-over
- c) Costs of and policy instruments that can be used to bring about stabilization
 - different costs of different emissions trajectories
 - RD&D
 - tax policies to affect energy prices, etc.
 - regulations
 - etc.

5. At what level should GHG concentrations be stabilized to avoid "dangerous" anthropogenic interference in the climate system?

- a) Governments must determine what is "dangerous"
(This section will briefly make the point that it is not possible for the scientific community to "objectively" determine a level of GHG concentrations that is dangerous because impacts will vary across systems and in different regions, and because different governments/societies have different values and levels of risk aversion)

- b) Because of the uncertainties, there are risks associated with delaying action, just as there may be unnecessary costs associated with acting "prematurely"
 - Detecting climate change (comparison of theory and observations)
 - It will be difficult to attribute ecological and socio-economic impacts to changes in climate alone, given the context of other environmental and socio-economic stresses on systems
 - Risks associated with delaying action (surprises -- e.g. thermohaline circulation collapse)

- c) The decision about what emissions/concentrations targets to set can be considered with a variety of decision-making frameworks and in the context of other policy issues

- cost-benefit analysis
- equity within countries and internationally
- intergenerational equity
- potential for "win-win" and low-cost mitigation options

Boxes:

- definitions of stabilization
- Articles

rename to
"Next Steps"

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