Chapter 2

The Scientific Evidence

Introduction

2.1 The volume of literature on the possibility of climate change and sea level rise resulting from human activities is now immense and is growing rapidly. Much is highly speculative, especially those accounts that are designed to popularise scientific findings. Within the scientific literature itself more confidence can be attached to work based on atmospheric chemistry and physics, and on climate systems and processes, than on attempts to apply these to the climate of particular countries or regions or to the impact of climate change on natural systems and human societies. But the level of concern and the sense of urgency in international and national decision-taking circles are such that it is imperative to develop the best practical overall assessments now, as a basis for policies that will not wait.

2.2 While the Expert Group was neither qualified nor required to review the original scientific literature, its first task was naturally to examine enough of the secondary literature to satisfy itself that it was confronting a genuine phenomenon we need to take seriously. It was helped in this respect by studies commissioned by the Secretariat, referred to in Chapter 1, the sequence of reports published by ICSU under the International Geosphere-Biosphere Programme (IGBP) and by WMO under the World Climate Programme, and by certain case studies and reviews in the wider literature.

2.3 It has long been realised that the atmosphere acts in a similar way to the glass walls and roof of a greenhouse in trapping heat from the sun: the effect was described by John Tyndall in 1861. The possibility that increasing concentrations of carbon dioxide due to the burning of fossil fuel could lead to global warming was raised by Arrhenius in 1896, and he calculated that a doubling of carbon dioxide could raise average temperatures by 5°C. Another scientist, G. S. Callendar, attributed an apparent rise in surface temperatures from the 1880s to the 1930s to industrial pollution by carbon dioxide. Interest in the subject waned when the earlier temperature rise was not sustained. But it has returned with unprecedented strength now that evidence has accumulated of the rise in atmospheric concentrations of carbon dioxide and other greenhouse gases and because there are now clear indications of an actual rise in global mean temperature.

The Reality of Climate Change

2.4 Various estimates of the changes in the global mean surface temperature from year to year are now available, derived from the many millions of meteorological observations made on land and sea. They indicate that, since the late 19th century, the global mean temperature has shown irregular inter-annual and decadal fluctuations, but has risen overall by about 0.5°C (Jones *et al*, 1988). This warming is compatible with what might be expected to have resulted from the increase in atmospheric concentrations of carbon dioxide and other greenhouse gases (0.4 to 1.1°C), but proof of cause and effect is lacking and other explanations are possible. The warming has not been uniform over the globe (and indeed some countries have become cooler).

2.5 Sea level has also been rising. The best estimate is that the global mean sea level has risen by 10 to 15 cm over the past century, although the tide gauge records on which this conclusion is based are notoriously 'noisy' and regionally biased (Warrick, Jones and Russell, 1988)[1]. One-third to one-half of this past rise could be accounted for by the shrinking of mountain glaciers (Meier, 1984), while ocean expansion due to warming could account for 2 to 5cm (Wigley and Raper, 1987); any remainder could have been caused by polar ice sheet melting (for which, however, there is no convincing evidence). Again, the observed change in global mean sea level cannot be proved to result from a 'greenhouse effect', but it is not incompatible with the expected effects of the increased concentration of atmospheric CO_2 and other greenhouse gases.

The Causes of a Greenhouse Effect

2.6 There is no scientific doubt that the atmospheric concentrations of a number of 'greenhouse gases' capable of causing global warming have increased. Such gases are transparent to short-wave radiation from the sun, but retain long-wave radiation that would, in their

1. Some authors suggest that a figure of only half to one third of this value may be nearer reality (Pirazzoli, 1988), while others estimate a larger factor.

absence, pass from the Earth into space, thus warming the Earth's surface and lower atmosphere. These gases (excluding water vapour, also a greenhouse gas) are (data from Bolin *et al,* 1986, and Warrick *et al,* 1988):

a) carbon dioxide (CO_2), whose atmospheric concentration has increased from an estimated 275 parts per million by volume (ppmv) in 'pre-industrial' times (mid-eighteenth century) to 315 ppmv in 1958, and to about 350 ppmv in 1988.

b) methane (CH_4) which has increased annually by about 15 parts per billion by volume (ppbv) (equivalent to a growth rate of 1.0 per cent averaged over the ten years between 1975 and 1985), and has now reached over double the pre-industrial concentration of 700 ppbv;

c) nitrous oxide (N_2O) which has been increasing at about 0.25 per cent per year to reach about 310 ppbv by 1988, as against 280 ppbv in preindustrial times.

d) chlorofluorocarbons (CFCs), which increased rapidly (5 to 7 per cent per annum) throughout the 1970s.

In addition, tropospheric ozone, which is being produced near the earth's surface in industrialised areas as a result of chemical reactions involving hydrocarbons (largely from motor vehicle emissions) and nitrogen oxides, is also a greenhouse gas, but its contribution to the greenhouse effect is hard to estimate due in part to its high spatial and temporal variability.

2.7 The increasing concentration of greenhouse gases is the result of human activities related to energy use, agriculture and industrial expansion, especially the first. Some 65 to 90 per cent of the increase of carbon emissions in the atmosphere today is believed to come from the burning of 'fossil fuels' (coal, oil, gas), (Bolin *et al,* 1986; Warrick *et al,* 1988). The remainder presumably comes from the biosphere, and especially from the clearance of tropical forests, which appears to have accelerated in the late 1980s (Houghton and Woodwell, 1989). Emissions of methane probably come from fermentation processes in agriculture (especially wet rice paddy and livestock), from the burning of plant material, and from the extraction and combustion of fossil fuels. Nitrous oxide emissions are also linked to fossil fuel combustion and the burning of plant material, as well as to fertilizer use and the clearance of land for agriculture. Hence, the growth of human populations and the associated processes of agricultural expansion and development are intimately linked to the increased emission of these gases (Table 2.1).

Table 2.1: Greenhouse Gases and Their Man-Made Sources

	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)	Chlorofluoro-carbons (CFCs)	Tropo-spheric Ozone
% contribution to "greenhouse effect" over period 1950-1985	56	14	7	23	*a.*
Concentration of greenhouse gases – pre-industrial *b.*	275ppmv	700ppbv	280ppbv	zero	15ppbv
Concentration in 1988 *b.*	350ppmv	1700ppbv	310ppbv	0.26ppbv (CFC-11) 0.44ppbv (CFC-12)	335ppbv
Annual growth of concentrations in 1980s	0.5%	0.5%	0.25%	5 to 5.5%	1%
Sources of greenhouse gases	Fossil fuel burning Deforestation/land use changes	Rice paddy cultivation Rearing of ruminants (e.g. cows) Biomass burning Fossil fuel extraction and burning	Fertilizers Fossil fuel and biomass burning Land conversion for agriculture	Manufactured for: solvents; aerosol spray propellants; foam packaging	Product of sunshine and pollutants: carbon monoxide; methane; other hydrocarbons; nitrogen oxides

Source: for percentage contribution, Wigley (1987); for growth, Mintzer (1987); for concentrations, Ramanathan et al (1985), UNEP/Beijer (1989).

Notes: *a.* contributions of ozone not estimated, perhaps around 8 per cent of total.
b. ppmv is parts per million; ppbv is part per billion.

2.8 Although apparently large, the additions by human agency to the carbon flux of the atmosphere of some 7 billion tonnes of carbon annually are small by comparison with more than 200 billion tonnes exchanged each year between the atmosphere, living organisms, and the ocean. Similarly, the modifications of the global nitrogen cycle by human activity add only slight increments to the total flows of this element. The fact that such proportionately small alterations can none the less have widespread environmental effects is testimony to the intricacy—and delicate balance—of the whole system, and is itself a reason for great care.

2.9 By contrast, chlorofluorocarbons are synthetic products of industry, used especially as solvents, refrigerator fluids, aerosol propellants and agents to expand (or 'blow') insulating plastic foams. They began to be manufactured in the 1930s, and production of various formulations increased rapidly until the 1970s, when they began to be incriminated as a cause of depletion of the ozone in the upper atmosphere that screens the earth against damaging ultra-violet radiation from the sun. This concern led to the 1987 Montreal Protocol to the Vienna Convention on the Protection of the Ozone Layer and subsequent international agreement to limit production of CFCs and to eliminate their manufacture and use as soon as practicable (Ridley and Holdgate, 1989).

2.10 It is generally accepted within the scientific community that the continuing increase in greenhouse gas concentrations will result in substantial global warming. There is, however, uncertainty over the magnitude and timing of the warming, the regional patterns of climate change, the seasonal differences, the effects on climate variability and extreme events and the extent of changes in the global sea level.

2.11 Predictions of climate change depend on the validity of climate models and the accuracy with which the trends in greenhouse gas emissions and atmospheric concentrations are simulated. One of the objectives of the World Climate Research Programme and the ICSU International Geosphere-Biosphere Programme is to improve the accuracy of such models. Many of those used so far have grossly simplified the complex atmospheric system and, especially, have been unable to deal adequately with the crucial processes at the interface between atmosphere and ocean (eg Clark, 1982). Because of the resolution of the global climate models, cloud processes are not adequately represented. Despite the uncertainties, however, the best models available today are consistent with one another in indicating a warming of *global* mean temperature.

2.12 It is also important to model accurately the global carbon cycle. This is necessary in order to predict future CO_2 concentrations, as well as to suggest ways of effectively preventing further increases. About half the carbon dioxide emitted today is taken up by the oceans, which provide the main 'sink' for CO_2, for example in the shape of limestone sediments. Carbon cycle modellers have difficulty, however, in balancing their 'carbon budgets', and some components of the carbon cycle are not well understood. For example, it is not clear how far plant growth might be stimulated by higher atmospheric CO_2 concentrations and increase the global sink for CO_2.

Future Trends in Greenhouse Gas Concentrations

2.13 Future atmospheric concentrations of greenhouse gases will depend on world energy demands, and the ways in which they are met, on the effectiveness of a wide range of pollution controls, and on trends in agriculture and in the use (or dis-use) of CFCs. Current (1988) emissions of carbon dioxide from fossil fuel combustion are equivalent to about 5.6 billion tonnes of carbon per year. If future energy demand led to a continued increase in atmospheric CO_2 concentrations at a growth rate of 0.5 per cent per annum, a doubling of the pre-industrial CO_2 concentration would occur by about the year 2080 (for all greenhouse gases considered together, the doubling occurs much sooner).

2.14 Almost all analyses of likely energy scenarios involve continuing increases in CO_2 emissions. This holds even if energy conservation, increased industrial efficiency, and non-fossil sources (nuclear, solar, wind, wave, hydro- and geo-thermal) are expanded at the highest practicable rate. In part this is because, even if the developed nations are able to adopt sophisticated strategies, it is assumed that the development imperative in other regions will lead to an increasing combustion of fossil fuels. The developing nations are beginning to catch up with the developed world in this respect: in 1980 the former accounted for only 13 per cent of global CO_2 emissions from fossil fuels but between 1973 and 1980 their energy consumption grew at 6.2 per cent per year while that of the Western industrial countries grew at only 0.5 per cent per annum (in contrast to the annual increase in the latter of 4.8 per cent per year in 1960-73)—(Table 2.2). On this basis, the developing world could overtake the present (western) developed nations in only 27 years (Warrick *et al*, 1988), though other projections suggest that such a cross-over would occur much later (see Chapter 4).

2.15 Similarly, growth in methane and nitrous oxide emissions is almost inevitable if agriculture expands to feed the increasing human population and fossil fuel use continues to increase. Current projections are of a further doubling of the global population from the present 5.5 billion to around 10 billion before the number of human beings levels off in the latter part of the next century. Even if stability is reached below this figure, it is clear that intensification of agriculture on the land able to sustain it is more likely than its substantial extension onto new sites, and this intensification is most likely to bring about an expansion in greenhouse gas emissions more or less in proportion to the scale of agricultural activities.

Table 2.2: Sources of CO_2 Emissions from Fossil Fuels

	1950 (%)	1980 (%)
N. America	44.7	26.7
W. Europe	23.4	16.5
USSR/E. Europe	18.0	24.2
Japan/Australia	2.8	5.8
China/Communist Asia	1.4	8.5
Developing	5.7	12.2
Others	3.9	6.0
	100%	100%
Total	1.62bn tonnes	5.17bn tonnes

Source: UNEP/Beijer (1989).

2.16 There are mounting pressures today to eliminate chlorofluorocarbons because of concern over the likely impact of ozone depletion on human health and the functioning of biological systems. Substitutes are already available for many of the functions of CFCs, albeit at higher costs. Some of these proposed alternatives, however, are environmentally unsatisfactory because they are just as potent greenhouse gases as CFCs—a factor which should be taken into consideration before they are approved. Even if there is swift action to introduce truly satisfactory substitutes, atmospheric concentrations of CFCs will nevertheless continue to increase (although at a diminishing rate) for a number of decades, because these substances persist for a long time in the atmosphere. Moreover, even if a reduction is secured in the industrialised nations, and other chemicals are substituted, in the developing countries, where refrigerants are likely to be of growing importance, it will be difficult to maintain the tempo of development yet secure the elimination of CFCs unless significant assistance is available for the transfer of the new technology. We return to this question in Chapter 4.

2.17 It is clear that projections depend entirely on assumptions about the seriousness of the commitment of the world community to limit climate change and about the political and economic practicability of the necessary actions. However, a cautious judgement is needed, and we conclude that future growth in the atmospheric concentrations of all greenhouse gases is extremely likely for at least the next six decades, even if the rate of increase slows as a result of preventive action. In Figure 2.1 we present an envelope of feasible projections. As can be seen, these suggest a doubling of CO_2 equivalent concentration from pre-industrial times by the year 2030, when all greenhouse gases are considered together. There is already a commitment to global warming, with attendant consequences for the environment and human society, and further warming must be regarded as probable. As Table 2.3 shows, carbon dioxide, especially from energy generation is the dominant contributor to this global warming. This in turn constrains our options for limiting the greenhouse effect to which we return in Chapter 4.

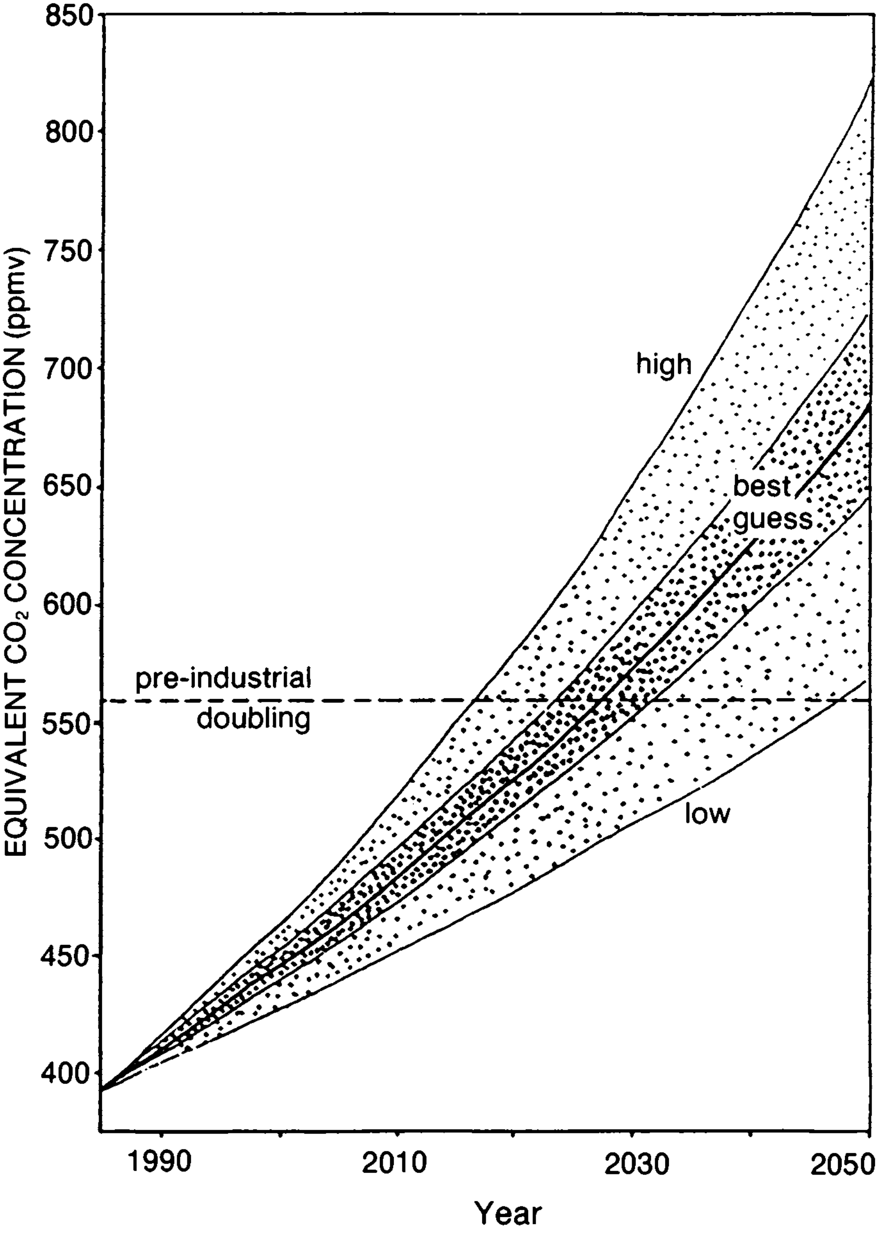
The Likely Magnitude of Global Temperature Change

2.18 Given the best estimates of future greenhouse gas concentrations and the climate sensitivity to such changes, it is most likely that, by the year 2030, the global mean temperature will be 1 to 2°C warmer than today. Given the full range of scientific uncertainties, the warming could be as little as about 0.5°C, or as large as 2.5°C. (See Fig. 2.2).

2.19 These estimates take account of substantial lags in the climate system due to the slow absorption of heat by the oceans. The most likely 'equilibrium' warming—that is, neglecting the lags—to which we would be committed by the projected greenhouse gas concentrations in 2030 lies between about 1.5°C and 3.0°C warmer than today. The implication is that today's generation is creating risks from which tomorrow's generation will suffer—and that corrective action today will not avert the risks to which we are already exposed as a result of past actions.

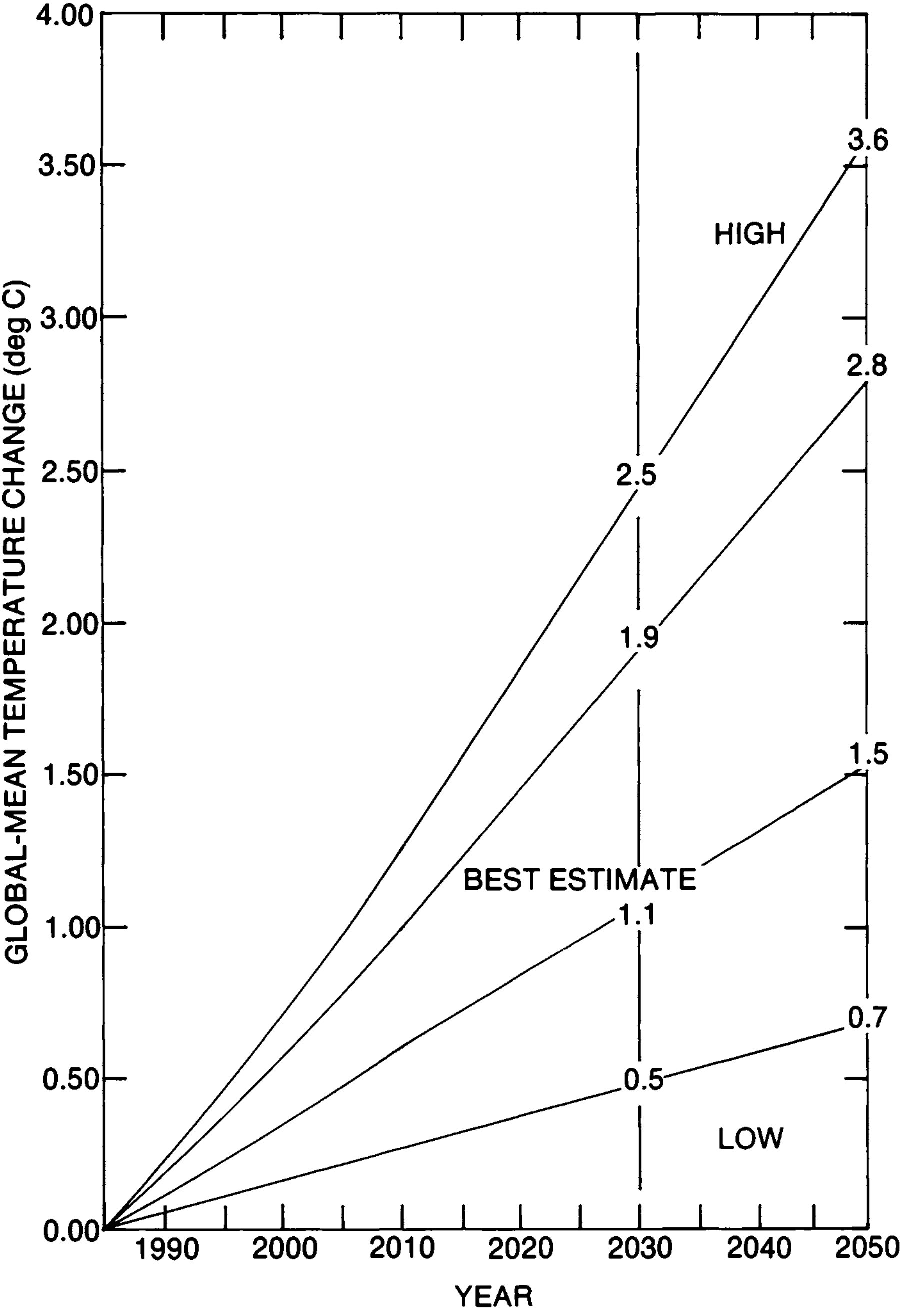
2.20 Two diagrams (Figures 2.3 and 2.4) summarise and demonstrate the seriousness of the problem. Figure 2.3 shows the projections of global temperature change at the upper and lower bounds of probability. It is evident that even the lower curve (which the actual trends of temperature seem more or less to follow) takes the world above the band of warmest climate experienced in the past 10,000 years. In fact, the likelihood is that by 2030 the earth will be warmer than at any time in the past 120,000 years.

Figure 2.1: GREENHOUSE GAS PROJECTIONS, 1985-2050



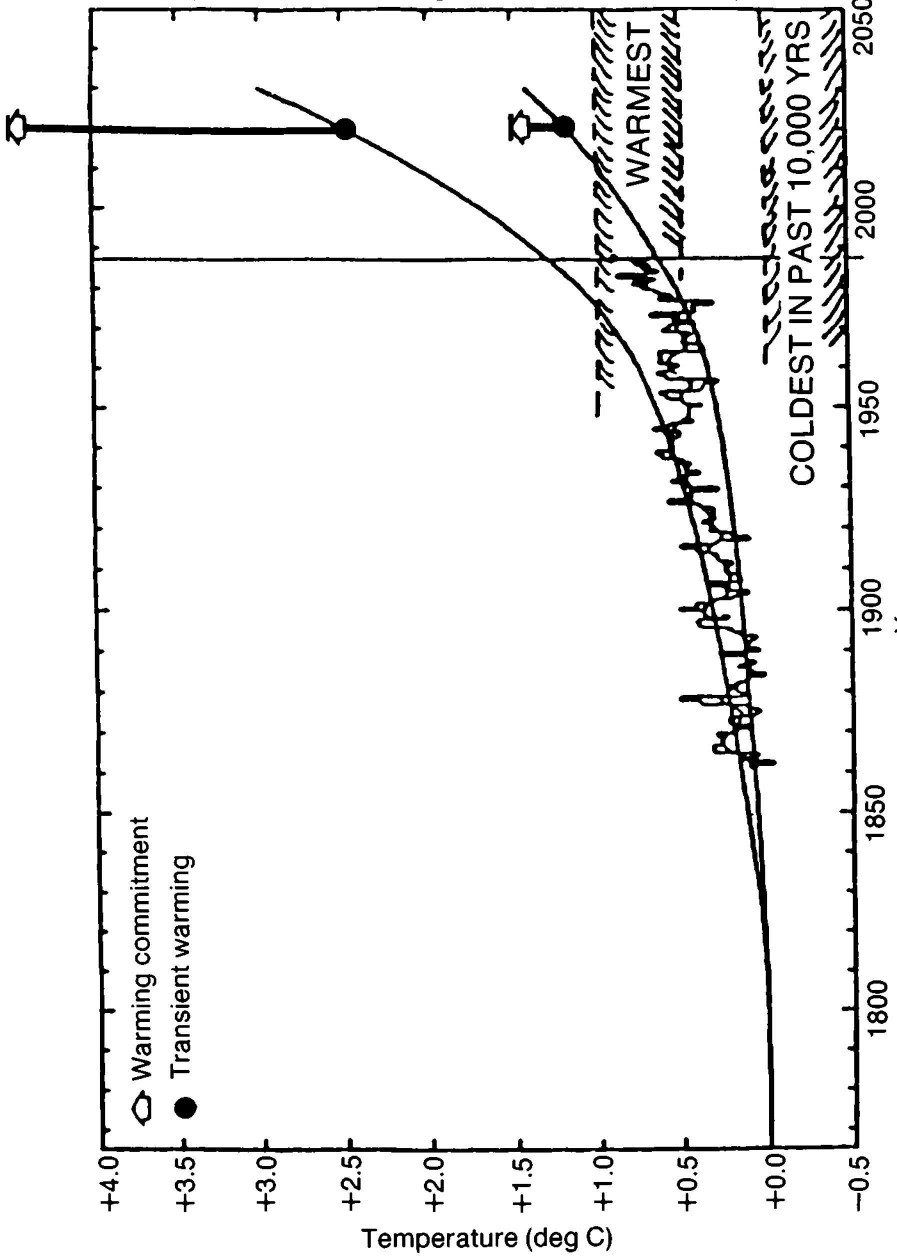
Source: T. Wigley (1989).

Figure 2.2: PROJECTED TEMPERATURE RISE, 1985-2050



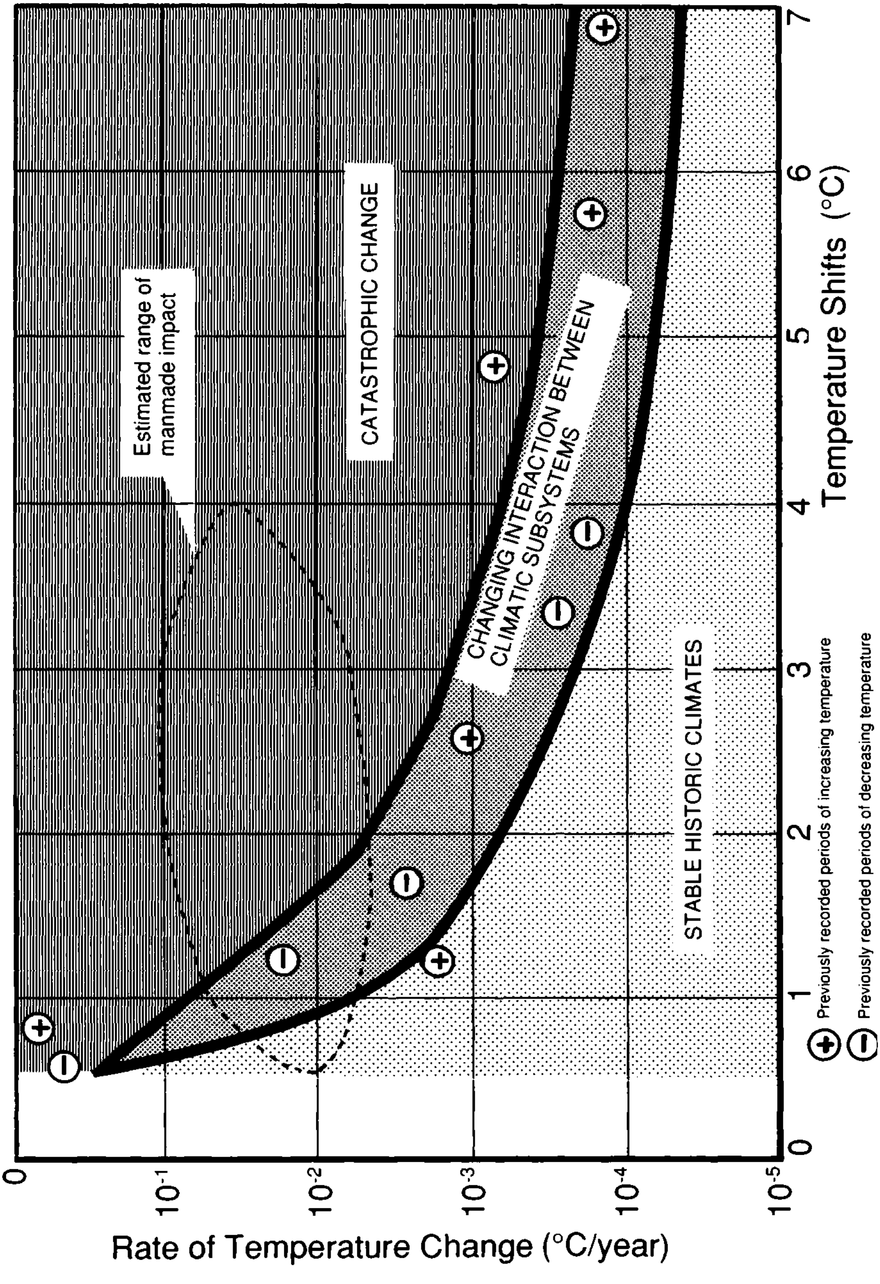
Source: T. Wigley (1989).

Figure 2.3: GLOBAL MEAN TEMPERATURE CHANGES
(Past 130 Years Compared with Next 40 Years)



Source: Based on T. Wigley (1989).

Figure 2.4: HISTORIC EXPERIENCE OF TEMPERATURE CHANGE



Source: Sassin et al (1988).

Table 2.3: Estimates of Contributions to Global Warming over 1980-2030 by Sector and Gas

	Carbon dioxide	Methane	Ozone	Nitrous oxide	CFCs	% by Sector
Energy–Direct	35	3	–	4	–	42
–Indirect		1	6	–		7
Deforestation	10	4	–	–	–	14
Agriculture	3	8	–	2	–	13
Industry	2	–	2	–	20	24
% by Gas	50	16	8	6	20	100

Source: UNEP/Beijer Institute (1989).

Note: Values based on current trends (if Montreal Protocol is implemented, CFC contribution would fall by half). All values subject to large margin of uncertainty.

2.21 Figure 2.4 is even more striking. It relates the magnitude of global temperature changes deduced from various analyses of past environments to the rates at which these changes have occurred. Changes of the order of several degrees Celsius have generally occurred over 1,000 to 10,000 years. Changes of over 0.5°C to 1.0°C per century have been seen only on a localised, regional, basis. As a best estimate, we now face changes of 1.0°C to 2.0°C in a time period of about 40 years and this lies outside the envelope of past experience at a global level. We have meagre historic evidence for predicting how ecosystems and human cultures will react.

The Likely Regional Variations in Effect

2.22 At present, it is not possible to predict how climate will change within specific regions of the world. The climate models are still unable to simulate reliably the regional details of climate and are likely to remain so for five years at the very least. But there are reasons to expect that some parts of the world will experience climate changes significantly greater than the global average. The greatest warming is likely to occur in winter in high latitude (60-90°), especially in the northern hemisphere, and the least warming in the tropical latitudes in summer. Climate models agree that global average precipitation should increase, with higher precipitation tending to occur in high latitudes in winter (Table 2.4). Some models suggest greater aridity in existing dry tropical areas and drier conditions in mid-continental locations. Further disaggregation would be highly speculative.

2.23 If the regional zonation of effect summarised in Table 2.4 is even crudely right, however, Canada would be the Commonwealth country experiencing greatest warming, with perhaps 2°C–6°C higher winter temperatures by 2030. Winter precipitation in the higher latitudes could be enhanced (there is already some evidence of an increase in this zone of the northern hemisphere over the past three decades). The key question is what proportion of this would fall as snow and what as rain and how early in the spring snow melt and run-off could occur and soil drying begin. There would be likely substantial ecological adjustments, discussed in Chapter 3. Reduction in pack ice would facilitate shipping and offshore energy exploitation in the Arctic.

Table 2.4: Regional Scenarios for Climate Change

Region	Temperature change (as a multiple of global average increase)		Precipitation change
	Summer	Winter	
High latitudes (60-90 deg)	0.5x to 0.7x	2.0x to 2.4x	Enhanced in winter
Mid latitudes (30-60 deg)	0.8x to 1.0x	1.2x to 1.4x	Possibly reduced in summer
Low latitudes (0-30 deg)	0.9x to 0.7x	0.9x to 0.7x	Enhanced in places with heavy rainfall today

Source: WCIP, 1988.

2.24 Most of the Commonwealth lies in low latitudes (0°–30°) where the warming in winter and summer is likely to be less than the global average. Some models suggest that precipitation may be enhanced by 5 to 20 per cent in the areas where rainfall is already heavy, but with some reduction in rainfall in today's semi-arid regions, aggravating the problems evident in places like the Sahel since the 1970s. Evaporation losses would increase in proportion to temperature, accentuating the contrasts.

2.25 If such changes were to occur, they would inevitably alter the productivity of agriculture in tropical regions that are already highly sensitive to the impacts of climate and are often marginal for agriculture. Africa, in particular, experienced a 15 per cent decline in *per capita* food production between 1970 and 1985 and conditions here could well become worse. Where water availability is reduced, fuelwood productivity would generally also decline. Even small climate changes are known to have serious potential impact on crops grown near their margins of tolerance and, on a detailed scale, considerable changes in the distribution of profitable cash cropping could occur.

2.26 These possible ecological and socio-economic implications for

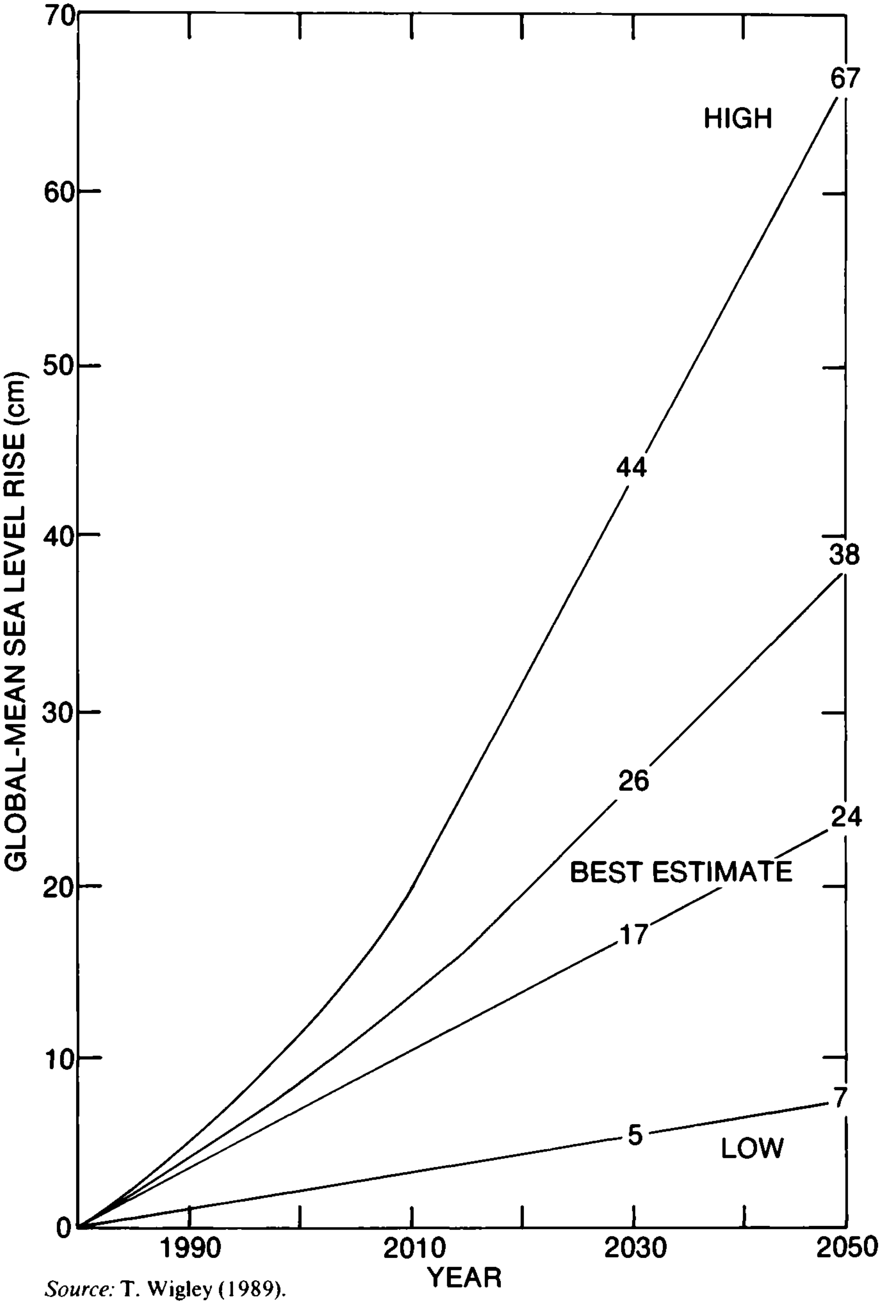
Commonwealth countries are discussed in more detail in Chapter 3. But one overall conclusion needs stating here: it cannot be assumed that the potential benefits that some countries will derive from climate change will balance the costs others will experience. All countries will be faced with the need to adapt to rapid change, with attendant costs; in many cases the resulting disruptions and tensions are likely to be considerable.

2.27 It is also likely that changes in climate will change the frequency of extreme climatic events such as severe tropical storms, floods, droughts or extremes of heat. Some changes in climatic extremes could be relatively large. With an average one degree increase in temperature in the UK, for instance, the extremely hot, dry year of 1976 would no longer be considered a rare event. Warmer conditions in the North American grain growing regions would most likely result in a higher frequency of crippling droughts, like that which occurred in 1988. Some analysts suggest an increase in the intensity of severe tropical storms—which are directly related to sea temperature—as a consequence of global and regional warming. One study suggests that a mean August ocean warming of 2.3°C to 4.8°C could increase the maximum intensity of tropical cyclones by up to 60 per cent, though not necessarily the number or the mean intensity of cyclones (Emmanuel, 1987). It is in this changed frequency of such short-term, climatic, extremes that the social impacts of long-term climate change are most likely to be manifested, just as it is in the succession of environmental disasters experienced in the 1980s that has brought home the extent of environmental stress more generally.

Sea Level Changes

2.28 There is a general consensus that global warming will be accompanied by a rise in global mean sea level. The 'best' estimate is that this will lie between about 17 and 26 cm by 2030, corresponding to the 1 to 2°C warming over the same period. Given the full range of uncertainties, the rise could be as little as about 5 cm or as large as about 45 cm (but these extremes are unlikely)—See Fig. 2.5. The main factors changing the ocean water volume are likely to be the melting of mountain glaciers and the expansion of the warming seas (Table 2.5). Changes in Antarctic ice sheets, where about 90 per cent of the Earth's land ice is located, are unlikely to contribute to sea level rise on this time-scale and in fact may have a small negative influence due to increased precipitation and ice accumulation. Greenland ice sheets are likely to make a small positive contribution to the rise. Because of the

Figure 2.5: PROJECTION OF SEA LEVEL RISE



Source: T. Wigley (1989).

slow process of heat transfer from atmosphere to ocean, and of the very long response times of polar ice, even if global warming stopped abruptly in 2030, global sea level would continue to rise for many decades, and possibly for hundreds or even many hundreds of years (Warrick *et al,* 1988).

Table 2.5: Sea Level Rise (centimetres), 1985–2030

Source	low	best guess	high
Thermal Expansion	4	9 to 14	18
Alpine Glaciers	2	8 to 12	19
Greenland	1	2 to 3	4
Antarctica	–2	–2 to –3	3
Total	5	17 to 26	44

Source: Warrick *et al.*

Note: Increases will continue past 2030.

2.29 Sea level is changing for reasons other than climate change on many of the world's coasts. In Scandinavia, for example, the land is still slowly rising following the disappearance of ice sheets some 10,000 years ago and relative sea level is declining, in some areas at a rate of 100 cm/century. Some coastal areas are sinking; in south-east England, the relative sea level is rising by about 25 cm per century—twice the global average. A number of islands have been built up by coral growth on the foundations of extinct volcanoes which are slowly subsiding. The pumping out of ground water is leading to the subsidence of some coastal areas. The Nile and Mississippi deltas are displaying rapid marine encroachment because of human interference with the sediment flow of those rivers. All these regional and local factors must be taken into account when estimating future sea level and judging the risk to particular areas.

2.30 Sea level rise brings several kinds of risk. The most obvious is a rapid loss of land to the sea. There is nothing new in this: the coasts of Europe, for example, display many areas of forest peat below present sea level, and history records the disappearance of various important towns, such as the English port of Dunwich, as a consequence of erosion and marine encroachment. Numerous Pacific islands have disappeared altogether over the past 10,000 years as a result of rising sea level caused by the melting of the northern hemisphere ice sheets (Lewis, 1988a). What is new is the prospect of a rapid acceleration of the process and its extension to new areas, including parts of the developing world which lack the resources to construct massive defensive works like those of the Netherlands. What is also new is that, unlike in earlier epochs, much of the low-lying land is settled and large investments have been made there. Many small island states would lose a significant part of their land area if there was a sea level rise of 1 metre (Lewis, 1988). The entire 1,190 small islands making up the Republic of the Maldives barely rise two metres above sea level (Gayoom, 1987).

2.31 At the regional scale, it is the coastal effect of sea level changes that can be forecast with least (albeit still with considerable) uncertainty. Half of humanity (and over half the citizens of the Commonwealth) inhabits coastal regions and it is here, too, that the pressures of population growth are most acute. Twenty-six Commonwealth Member States are island countries, and 21 of these are small island developing countries (Lewis, 1988a) so that almost half the Commonwealth countries are particularly vulnerable to the impact of sea level rise.

2.32 Rising sea level increases the vulnerability of coastal areas to flooding from storm surges. In the Bay of Bengal, where hundreds of thousands of lives are at risk, the impacts of severe storm surges on India and Bangladesh are already large and could be exacerbated by rising sea level. The incidence of sea flooding in low-lying areas is in large part a function of the narrowing difference between storm surge heights and the height of sea defences on the one hand, and the incidence and magnitude of storms on the other (the prediction of which requires regional details of climate changes). If sea levels rise and storms increase there can be a dramatic increase in the probability of inundation. Analyses in the Netherlands indicate that a 0.5 metre rise in sea level would bring a tenfold increase in the risk of storm surges overstepping sea defences (Goemans 1986, as reported in Warrick *et al,* 1988). Some regions are unprotected and particularly vulnerable. The low-lying delta of Bangladesh fronts the Bay of Bengal for a distance of 650 km, and little of this coastline has any protection works: 250,000 people were killed by a very high sea surge driven by a tropical cyclone in 1970. If the intensity of tropical storms increases, the risks can only increase.

2.33 Rising sea level also increases the intrusion of salt water into surface and ground water systems. The results can include loss of agricultural capacity and the need to replace, modify or expand domestic water supply systems. Damage from saline intrusion into fresh water wells has already been noted in southern Kiribati and in Tuvalu (Lewis, 1988).

2.34 Many low-lying tropical coasts are protected by coral reefs and mangroves. Both are under pressure in many areas from human activities including pollution, sedimentation as a result of bad land-use and construction processes, dynamite fishing and coral block quarrying, and the excessive cutting of mangrove for poles and fuelwood. A rising sea level poses two threats. It would tend to narrow the band of mangrove able to exist at the margin between the sea and human occupation (which would be unlikely to withdraw inland faster than it must) and it might outstrip the growth capacity of some coral reefs (see Chapter 3). In either case, the vulnerability of the coast to erosion and flooding would increase.

Conclusions

2.35 We have argued that there are good grounds for accepting the scientific consensus that rises in global mean temperature and sea level are likely. Beyond this, the speculative nature of the regional details of climate change summarised in this section is unsatisfactory. It is of crucial importance that governments support the research that is needed to permit more precise predictions of the probable implications of change for regions and individual countries. Governments obviously vary greatly in their ability to support such activities, unaided, but we believe that as a minimum, individual countries should have, or should be helped to acquire, some capacity to assess their own climate and sea level, and changes in them, even if not all countries can contribute to the basic science. Without such science, and effective monitoring, much money may be wasted in inappropriate responses—and much human anxiety risked by erroneous conclusions. We develop these thoughts further in Chapter 4.