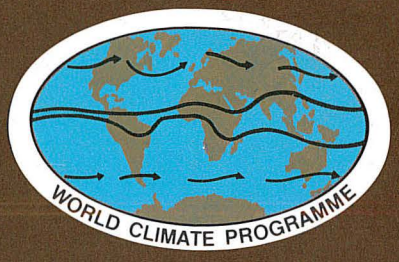
WORLD CLIMATE PROGRAMME

IMPACT STUDIES



DEVELOPING POLICIES FOR RESPONDING TO CLIMATIC CHANGE

A summary of the discussions and recommendations of the workshops held in Villach (28 September - 2 October 1987) and Bellagio (9-13 November 1987), under the auspices of the Beijer Institute, Stockholm

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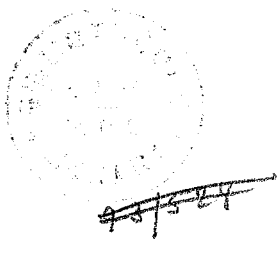
PREFACE

This discussion of the development of policies for responding to climatic change is a result of two workshops which took place in 1987. The first workshop, held in Villach, Austria from 28 September to 2 October, involved about 50 scientists and technical experts (see Appendix I for list of participants). It examined how climatic change resulting from increases of greenhouse gas concentrations in the atmosphere could affect various regions of the earth during the next century. In addition, the participants of the Villach workshop discussed the technical, financial and institutional options for limiting or adapting to climatic changes. The second workshop was held in Bellagio, Italy from 9 - 13 November. The 24 participants (Appendix II) used the technical material from the Villach workshop as background information and explored what policy steps might be considered for implementation in the near term and what institutional arrangements would be needed to achieve these steps.

The two workshops in 1987 were a direct response to the recommendations of an international conference sponsored by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP) and the International Council of Scientific Unions (ICSU) held in Villach, Austria in October 1985. Both workshops were seen by the Advisory Group on Greenhouse Gases (AGGG) of WMO, UNEP and ICSU as an important step in the process of policy development in response to possible climatic changes that was called for by the Villach Conference in October 1985.

The project to organize the 1987 workshops was initiated by the Beijer Institute (Stockholm), the Environmental Defense Fund (New York), and the Woods Hole Research Center (Massachusetts).The organization of the workshops and the writing of this document were guided by a steering committee, whose members were:

G.T. Goodman	(Beijer Institute, Stockholm), Chairman
B. Bolin	(International Meteorological Institute, Stockholm)
W.C. Clark	(International Institute for Applied Systems Analysis, Austria and Harvard University, U.S.A.)
W.Degefu	(Meteorological Services Agency, Ethiopia)
H. Ferguson	(Atmospheric Environment Service, Environment Canada, Canada)
F.K. Hare	(University of Toronto, Canada)
J. Jaeger	(Beijer Institute and F.R. Germany)
M. Oppenheimer	(Environmental Defense Fund, U.S.A.)
C.C. Wallen	(United Nations Environment Programme, Nairobi)
G.M. Woodwell	(Woods Hole Research Center, U.S.A.)



The workshops were sponsored by

United Nations Environment Programme
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Energy Research Commission, Sweden
Beijer Institute, Sweden
W.Alton Jones Foundation, U.S.A.

The organization and running of the workshops benefited from the assistance of Marilyn Brandl, Julian Dison, Lotta Koludrovic, Solveig Nilsson and Mary Stanojevic. Also, the staff of the Villach Congress House and the Bellagio Conference Center helped to make the workshops enjoyable and successful. Professors F.K. Hare (Toronto, Canada) and P. Crutzen (Mainz, F.R. Germany) kindly hosted meetings of the Steering Committee.

In December 1987 the AGGG meeting in Paris reviewed and approved a draft of this Report. Subsequently the Steering Committee reviewed the Report and met in January 1988 to discuss final changes. Finally, Pier Vellinga, Sir Peter Marshall, Jim Bruce, John Firor and Pierre Crosson reviewed a draft version of the Report and provided very constructive criticism. Given the complex nature of the problem and the diversity of interpretations of the present state of knowledge and priorities for action, the suggestions for changes in the report were in some cases divergent. The fact that there are differences in preferred emphasis and interpretation indicates that there is indeed a need, in particular, for policy research, as discussed in section 4 of this Report.

The following sections of the Report summarize the discussions at the 1987 workshops.In Section 1 the scientific consensus on greenhouse gases and climatic change reached at the conference in Villach in 1985 is discussed. This consensus was the starting point for the discussions at the two workshops in 1987. Section 2 looks at possible scenarios for future changes of climate and sea-level. Section 3 examines the effects of possible climatic changes on regions in the high latitudes, middle latitudes, humid tropics, semi-arid tropics, and coastal zones. In section 4 the management options for responding to the possible changes are discussed. Section 5 looks at a number of factors that might affect policy development and sets priorities for the next steps in policy action based on present knowledge.

EXECUTIVE SUMMARY

DEVELOPING POLICIES FOR RESPONDING TO CLIMATIC CHANGE

1. The atmospheric concentrations of a number of trace gases are increasing as a result of human activities. These gases have an important effect in trapping energy at the earth's surface and in the lower atmosphere (the "greenhouse effect") leading to a warming thus to changes of climate.

2. It is now generally agreed that if the present trends of greenhouse gas (GHG) emissions continue during the next hundred years, a rise of global mean temperature could occur that is larger than any experienced in human history.

3. A two stage workshop process held in Villach (Austria) and Bellagio (Italy) in 1987 examined how climatic change resulting from increasing GHG concentrations could affect environment and society during the next century and explored the policy steps that should be considered for implementation in the near term.

4. Scenarios of global climatic change that could occur between now and the end of the next century as a result of continuing emissions of GHGs were developed. The upper bound scenario, which considers a large increase of GHG emissions and a high sensitivity of the climatic response, gives a global surface temperature increase of 0.8 °C per decade from the present until the middle of the next century. The middle scenario, which considers current trends in GHG emissions, a reduction of chlorofluorcarbon emissions according to the Montreal Ozone Protocol, and a moderate climate sensitivity, gives a temperature increase of 0.3 °C per decade. The lower bound scenario, which assumes a strong global effort to reduce GHG emissions and relatively low climate sensitivity, gives a rate of temperature increase of 0.06 °C per decade.

5. The most extreme temperature increases would probably occur during winter in the high latitudes of the Northern Hemisphere, where the changes could be two to two and a half times greater and faster than the globally averaged annual values. Precipitation changes could include enhanced winter precipitation in the high latitudes, intensified rains in the presently rainy tropical latitudes, and, perhaps, a decrease in summer rainfall in the mid-latitudes.

6. GHG-induced global warming could accelerate the present sea-level rise, probably giving a rise of about 30 cm but possibly as much as 1.5 m by the middle of the next century. The effects of this will include: erosion of beaches and coastal margins; land-use changes; wetland loss; increased frequency and severity of flooding; damage to port facilities, coastal structures and water management systems.

7. In the middle latitudes the main impacts are expected to be on relatively unmanaged ecosystems, in particular the

forests. If the temperature change is rapid, dieback of trees will result and more and more forest would need managing to maintain it in a productive mode. For the lower bound scenario of temperature change, extinction of species, reproductive failure and large-scale forest dieback would not occur before the year 2100. A further effect could be the release of a significant amount of carbon from soils, trees and other plants as carbon dioxide and methane and this would enhance the greenhouse warming.

8. Climatic change will not occur in isolation. Increasing amounts of atmospheric and aquatic pollutants can be expected from urban-industrial growth. The response to climatic change will be affected by these pollutants. The importance of these interactions and the need to investigate them further cannot be overestimated.

9. In the semi-arid tropical regions the climatic changes that might occur by the middle of the next century as a result of the increasing concentrations of GHGs include a temperature increase of the order of 0.3 - 5 °C and a decrease in precipitation rate in one or more seasons. These changes could worsen the current critical problems of the semi-arid tropics, especially through their effects on food, water and fuelwood availability, human settlement patterns and the unmanaged ecosystems.

10. In the humid tropical regions it is expected that the GHG-induced changes could include a warming of 0.3 - 5 °C and an increase in rainfall amount. In addition, tropical storms might extend into regions where they are now less common. Coastal and river regions and regions of infertile soils in the uplands appear to be especially vulnerable.

11. In the high-latitude regions it is expected that the mean winter temperature could increase by between 0.8 to considerably more than 5 °C by the middle of the next century. In addition, there could be a withdrawal of the summer pack ice, increased cloudiness and precipitation, slow disappearance of the permafrost and changes in the tundra and in the northern limit of the boreal forest. These changes can be expected to affect marine transportation, energy development, marine fisheries, agriculture, human settlement, northern ecosystems, carbon emissions, air pollution, and security.

12. The rate of global temperature change that would occur if current trends of GHG emissions were to continue are large compared with observed historic changes and would have major effects on ecosystems and society. For this reason a coordinated international response will become inevitable.

13. **Adaptation** strategies for responding to a changing climate adjust the environment or our ways of using it to reduce the consequences of a changing climate; **Limitation** strategies control or stop the growth of GHG concentrations and limit the climatic change. A prudent response to climatic change would consider limitation and adaptation strategies.

14. Whatever limits on climatic change might be implemented, planning and decision-making could be facilitated by the use of long-term environmental targets, such as the rate of temperature or sea-level change. The choice of a target would be based on observed historic rates of change that did not put stress on the environment or society. The environmental target can be translated into emissions targets for GHGs that could be used for regulatory purposes.

15. An evaluation of the changes of GHG emissions that would be required to limit the global warming rate to the largest natural rates of increase observed in the last century, suggests that the limitation could only be accomplished with significant reductions in fossil fuel use.

16. Strategies for adapting to or limiting climatic change could involve high costs to global society. For policy-making purposes there is a need for detailed comparisons of the costs of various strategies.

17. There are many longer-term actions that will be required in order to ensure appropriate responses to climatic changes. The actions that should receive priority now are:

- Approval and implementation of the Montreal Protocol on Substances that Deplete the Ozone Layer.

- Reexamination of long-term energy strategies with the goals of achieving high end-use efficiency .Intensification of development of non-fossil energy systems.

- Strong support for measures to reduce deforestation and increase forested area.

- Development and implementation of measures to limit the growth of non-CO_2 GHGs in the atmosphere.

- Identification of areas vulnerable to sea-level rise. Planning for installations near the sea should allow for the risks of sea-level rise.

- Support for and coordination of policy research, global monitoring activities and policy-directed scientific research on the GHG issue at the national and international levels.

- Examination by organizations, including the inter governmental mechanism to be constituted by the WMO and UNEP in 1988, of the need for an agreement on a law of the atmosphere as a global commons or the need to move towards a convention along the lines of that developed for ozone.

- Consideration and development of the recommendations of the present Report at subsequent conferences, including the World Conference on the Changing Atmosphere (Toronto, June 1988) and the Second World Climate Conference (Spring, 1990).

Section 1

GREENHOUSE GASES AND CLIMATIC CHANGE

1.1 THE "GREENHOUSE EFFECT"

The atmospheric concentrations of a number of trace gases are increasing. Despite their very low concentrations, some of these gases, notably carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), chlorofluorocarbons (CFCs) and tropospheric ozone (O_3), have an important effect in trapping energy originating from the sun, in the form of heat, near the earth's surface (the "greenhouse effect"). The increased concentrations of the "greenhouse gases" (GHGs) lead to a warming of the earth's surface and the lower atmosphere and hence to changes of climate.

1.2 THE SCIENTIFIC CONSENSUS ON GREENHOUSE GASES AND CLIMATIC CHANGE REACHED AT VILLACH IN OCTOBER 1985

During the last ten years scientists have given increasing attention to possible future global climatic changes resulting from this greenhouse effect. It is now generally agreed that if present trends continue "in the first half of the next century a rise of global mean temperature could occur which is greater than any in man's history" (World Climate Programme, 1986).

At a joint UNEP/WMO/ICSU Conference held in Villach, October 1985 (World Climate Programme, 1986), scientists from 29 industrialized and developing countries agreed that:

> "Many important economic and social decisions are being made today on long-term projects... such as irrigation and hydro-power; drought relief; agricultural land use; structural designs and coastal engineering projects; and energy planning-all based on the assumption that past climatic data,...are a reliable guide to the future. This is no longer a good assumption since the increasing concentrations of GHGs are expected to cause a significant warming of the global climate in the

next century."

Furthermore, the participants at the 1985 conference emphasized that the amounts of the greenhouse gases in the atmosphere are increasing as a result of human activities and that the role of greenhouse gases other than CO_2 in changing the climate is already about as important as that of CO_2. A further conclusion was that future changes of climate of the order of magnitude obtained from climate models for a doubling of the atmospheric CO_2 concentration could have profound effects on global ecosystems, agriculture, water resources and sea ice.

The scientific consensus reached at the Villach Conference in 1985 and documented in the Conference Statement (World Climate Programme, 1986) provided an authoritative evaluation of the possible magnitude of future climatic changes resulting from greenhouse gas increases. In addition, it recommended a start on policy analysis to identify the widest possible range of social responses for limiting or adapting to climatic changes.

The conclusions of the 1985 Villach conference were used as a starting point for the 1987 Workshops on "Developing Policies for Responding to Climatic Change". The discussions and recommendations of these workshops are summarized in the remainder of this Report.

SOURCES OF INFORMATION

Bolin, B., B.R. Doos, J.Jaeger, and R.A. Warrick (eds.), 1986: The Greenhouse Effect, Climatic Change, and Ecosystems. SCOPE 29, J.Wiley and Sons, Chichester.

World Climate Programme, 1986: Report of the International Conference on the Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases on Climate Variations and Associated Impacts. WMO-No. 661, World Meteorological Organization, Geneva.

Section 2

POSSIBLE SCENARIOS FOR CLIMATIC CHANGE

In recent years, numerous studies have explored the potential consequences of accelerating global climatic changes and possible strategies for managing them. It has become increasingly clear that scientific assessments of climatic change must address three issues if they are to be useful for such policy discussions:

a) the rate and timing of climatic changes;

b) the expected changes of regional climates;

c) the uncertainties in forecasts of climatic changes.

A group of the technical experts who convened at Villach in 1987 considered these issues carefully; their findings are summarized in this section.

2.1 HOW MIGHT THE GLOBAL CLIMATE CHANGE IN RESPONSE TO CONTINUING EMISSIONS OF GHGs ?

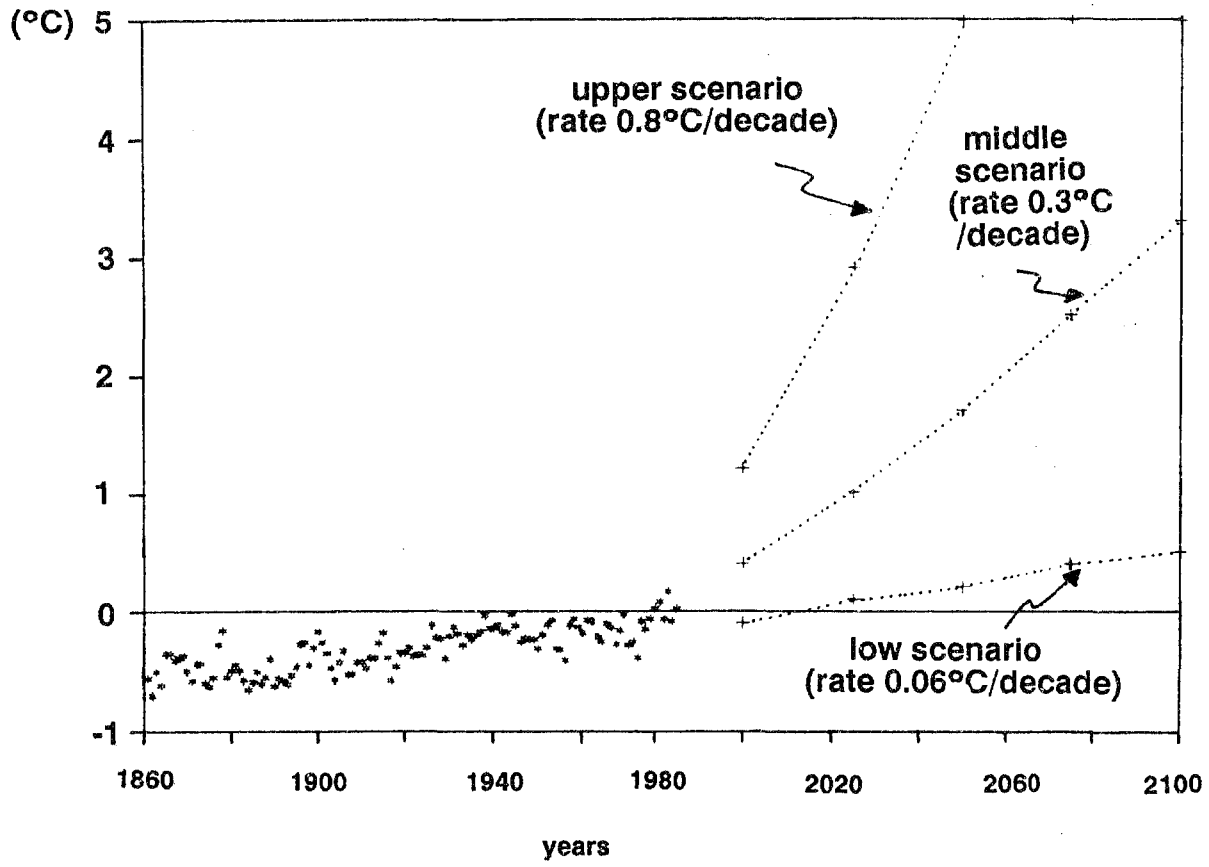
Figure 1 draws on the present understanding of the greenhouse effect to present a range of scenarios of global climatic change that might plausibly occur between now and the end of the next century as a result of continuing emissions of GHGs. The historical record of climatic changes since 1850 is included for perspective. In each of the scenarios the globally averaged temperature is higher during the next century than it was during the last hundred years. The middle and upper scenarios also have higher sea-level during the next century than in the last hundred years, while the low scenario shows a return to a global sea level of the order of that observed about one hundred years ago. This decrease of sea-level is basically a result of a predicted increase of snowfall which increases the mass of the Antarctic ice sheet. The resulting loss of water from the oceans is larger than the direct thermal expansion effects that would increase sea-level in the case of a slow global temperature increase. The intensity of the global hydrological cycle, as indicated by the global

FIGURE 1

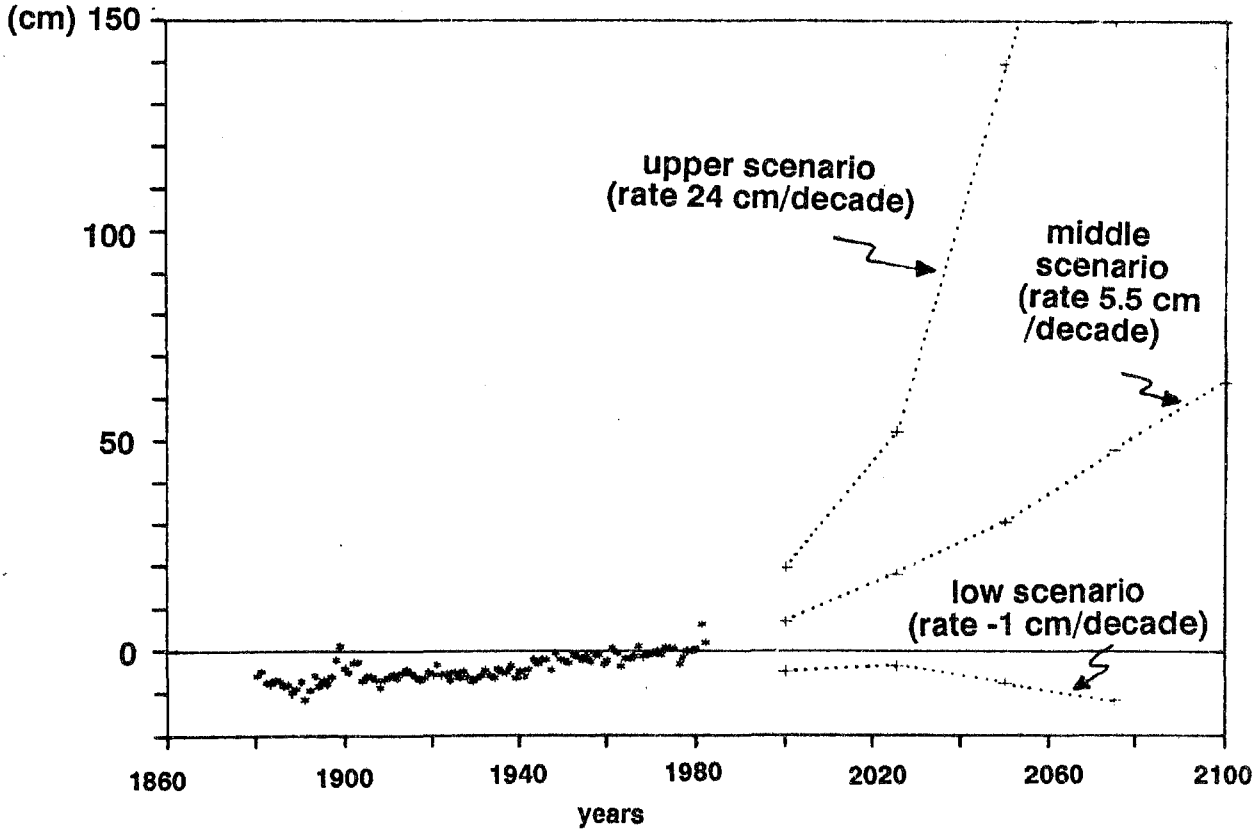
SCENARIOS OF TEMPERATURE AND SEA-LEVEL CHANGE

The figure shows scenarios of changes in (a) globally averaged temperature and (b) sea-level that might develop in response to continued emissions of atmospheric GHGs. The values are plotted as differences from the 1985 values. Each of the scenarios includes the time lags in the climatic response as a result of the ocean's heat capacity. The middle curve of each panel reflects a scenario of continued present trends of emissions (except for CFCs, see Section 2.2) and a moderate climate sensitivity. There is a chance of 5:10 that the actual path of climate change could lie below the middle curve. The upper curve of each panel reflects a scenario of accelerated greenhouse gas emissions and a relatively high climate sensitivity as predicted by some models. The lower curve of each panel reflects a scenario of radically curtailed GHG emissions and a relatively low climate sensitivity. In the professional judgement of the Villach 1987 experts group, there is a 9/10 chance that the actual future pattern of GHG-induced climatic change will lie within the bounds set by the upper and lower curves. The ceiling of 5 degrees on the temperature graph has been imposed because of the dubious relevance of present climate models in simulating the response to a global warming higher than around 5 degrees. Observed temperature data were provided by P.D. Jones, Climatic Research Unit, University of East Anglia, U.K. Observed sea-level data were provided by V. Gornitz, Goddard Space Flight Center, Institute for Space Studies, New York, N.Y.

(a) Global temperature change (°C).



(b) Global sea-level change (cm).



mean rates of both evaporation and precipitation, is expected to increase by 2-3 per cent for each degree of global warming. In most of the scenarios shown in Figure 1, the rate of climatic change significantly exceeds the average rate for the last century. The climatically induced sea-level changes shown in the Figure would be the same everywhere on Earth, although they will be affected by local geological (tectonic) phenomena. The temperature changes, in contrast, reflect the annual average condition of the world as a whole, not the conditions at any specific place. Regional changes in temperature and precipitation are summarized in Table 1, and discussed in section 2.3. Other factors that might affect temperature, such as volcanic aerosols and changes of incoming solar radiation, have not been included. Some combination of cooling factors seems to have affected global temperatures during the past half-century, reducing the greenhouse warming and slowing the rise of temperature and sea-level.

In constructing the scenarios of Figure 1, allowance has

been made for emissions of all the significant GHGs affecting climate, including the chlorofluorocarbons, (see Appendix 5) and for time-lags in the climatic response introduced by the ocean's heat capacity.

2.2 WHAT ARE THE UNCERTAINTIES IN FORECASTS OF GLOBAL CLIMATE CHANGE?

The wide range of scenarios depicted in Figure 1 reflects two kinds of uncertainty:

1) future patterns of fossil fuel use, rates of deforestation, and other activities leading to GHG emissions;
2) the response of the climate system to a given level of GHG emissions.

These uncertainties contribute about equally to our overall uncertainty in forecasting future climatic change. The envelope of scenarios pictured in Figure 1 has been constructed so that, in the judgement of the Villach 1987 experts, there is a 9:10 chance that the actual future pattern of GHG-induced climate change will lie within the bounds set by the upper and lower curves.

The possibility remains, however, that unanticipated effects of the warming or unforeseen technologies affecting GHG emissions could lead to climatic changes outside the envelope depicted in Figure 1. The speed with which the atmospheric concentrations of the various GHGs increase adds a new dimension to the problem: the possible occurrence of unpredicted changes in biotic, atmospheric and oceanic responses cannot be ruled out.

The upper bound of the envelope represents the climatic change that could result from a radical expansion of fossil fuel use (for example, it is assumed that coal use increases more than five fold by 2025) and other activities that emit GHGs, if the climatic response to GHGs exhibits the high sensitivity now predicted by a few studies. The lower bound of the envelope represents the climatic change that could result from a strong global effort to reduce GHG emissions (including, for example, a reduction of the CO_2 emissions

from fossil fuels by about half between 1975 and 2075), if the climatic response exhibits the relatively low sensitivity now predicted by a few other studies. The middle curve in the figure shows the climate change that could result from a continuation of present trends in GHG emissions, if the climatic response actually exhibits the moderate sensitivity to GHGs that many climate models now predict. It was assumed in calculating this curve that the recent protocol on protecting the ozone layer is successfully implemented, thus reducing the emissions of CFCs significantly below their recent rates of increase.

2.3 REGIONAL RESPONSES TO CLIMATIC CHANGE?

Essentially all scientific studies of the greenhouse effect agree that the resulting climate changes will differ among regions. Uncertainties in the forecasts of regional climatic responses are greater than those in the forecasts of global climatic response. Present knowledge of possible regional climatic changes is summarized in Table 1.

Table 1 suggests that the most extreme temperature increases in a warming world would probably occur during winter in the high latitudes of the Northern Hemisphere. Changes here could be two to two and a half times greater and faster than the globally averaged annual values shown in Figure 1. In contrast, temperature changes in the low latitudes will probably be somewhat smaller and slower than the globally averaged values of Figure 1.

Regional precipitation forecasts are the most uncertain of all the major climatic variables. Nonetheless, the studies used to derive the information in Table 1 suggest that changes could include enhanced winter precipitation in the high latitudes, intensified rains in the presently rainy low latitudes and, perhaps, a decrease in summer rainfall in the mid-latitudes.

SOURCES OF INFORMATION

Material in this section was based on Background papers prepared for the Villach Workshop (listed in Appendix 7). In addition, reference was made to:

Gornitz, V. and S. Lebedeff, 1987: Global sea-level changes during the past century. In, D. Nummedal, O.H. Pilkey, and J.D. Howard (eds.), Sea Level Change and Coastal Evolution. Society of Economic Paleontologists and Minerologists Publ. No. 41, 2-16.

Hansen, J., A. Lacis, D.Rind, G. Russel, P. Stone, I. Fung, R. Ruedy, and J. Lerner, 1984: Climatic sensitivity: Analysis of feedback mechanisms. In, J.E. Hansen and T. Takahashi (eds.), Climate Processes and Climate Sensitivity,Maurice Ewing Series No. 5, American Geophysical Union, Washington D.C., 368 pp.

Jones, P.D., T.M.L. Wigley, and P.B. Wright, 1986: Global temperature variations between 1861 and 1984. Nature, 322, 430-434.

Manabe, S. and R.J. Stouffer, 1980: Sensitivity of a global climate model to an increase of CO_2 concentration in the atmosphere. J. Geophys. Res., 85, 5529-5554.

Mintzer, I.M., 1987: A matter of degrees: The potential for controlling the greenhouse effect. Research Report No. 5, World Resources Institute, Washington, D.C.

Mitchell, J.F.B., C.A. Wilson, and W.M. Cunnington, 1987: On CO_2 climate sensitivity and model dependence of results. Quart. J. Roy. Meteor. Soc., 113, 293-322.

Nordhaus, W.D. and G.W. Yohe, 1983: Future paths of Energy and Carbon Dioxide Emissions. In, Changing Climate, Report of the Carbon Dioxide Assessment Committee, National Academy Press, Washington, D.C.

Reilly, J.M., J.A. Edmonds, R.H. Gardner, A.L. Brenkert, 1987: Uncertainty analysis of the IEA-ORAU CO_2 emissions model. The Energy Journal, 8, 1-29.

UNEP, 1987: Montreal Protocol on Substances that Deplete the Ozone Layer. Final Act. United Nations Environment Programme, Nairobi.

TABLE 1
REGIONAL SCENARIOS FOR CLIMATE CHANGE

Region (a)	Temperature change (b) (as a multiple of global average) Summer	Winter	Precipitation Change (c)
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

a) The figures in this table are taken from computer modelling results for the Northern Hemisphere. Low latitude trends are likely to be similar for the Southern Hemisphere. The mid-latitudes of the Southern Hemisphere may differ due to the smaller landmass. The high latitudes of the Southern Hemisphere could respond much differently from Arctic areas because of the high altitude and land-based nature of the Antarctic.

b) The regional temperature changes are presented here as multiples of the globally and annually averaged temperature changes shown in Figure 1. Thus, for example, if from Figure 1 one assumes that the globally averaged annual temperature change for the year 2040 could be 2.0 degrees C, then Table 1 says that high latitude winter temperatures in the same year might have risen by 4.0 to 4.8 degrees. Similarly, a rate of change in the global mean temperature of 0.3 degrees per decade from Figure 1 would translate via Table 1 to mean a rate of change in the high latitude winter temperatures of 0.6 to 0.7 degrees per decade.

The particular temperature figures cited in this table are taken from two general circulation models of the earth's atmosphere, selected to reflect the range of results being obtained from today's most advanced scientific studies. In particular, for each range of temperature multiples given in the table, the first value is drawn from the models of J. Hansen and his colleagues at NASA. The second value in each range comes from the work of S. Manabe and his colleagues at the US National Oceanographic and Atmospheric Administration laboratories in Princeton.

c) Precipitation is among the most difficult properties of climate to model or predict. The qualitative assessments quoted here are nonetheless supported by a number of studies. In particular, they are drawn from a recent review by Mitchell and colleagues at the British Meteorological Office. Note that the global mean rate of evaporation would also increase by the same amount as the global rate of precipitation.

Section 3

EFFECTS OF CLIMATIC CHANGE ON THE LATITUDINAL REGIONS

3.1 OCEANS AND COASTAL AREAS

Half of humanity inhabits coastal regions. The coastal zones are under great pressure due to accelerating population growth, pollution, flooding problems and upland water diversion.

In these regions the consequences of sea-level rise will generally outweigh any direct temperature effects of climatic change, such as enhancement or reduction of fishery resources. In particular, a rise of sea-level would, in many places, mean that high tides could penetrate further inland. In addition, the effects of rising sea-level would be experienced in terms of greater inland penetration of storm surges.

Global warming induced by greenhouse gases will accelerate the present sea-level rise giving a rise of probably about 30 cm and possibly as much as 1.5 m (see Fig. 1b) by the middle of the next century, as a result of thermal expansion of the sea-water and the melting of land ice. The rate of increase of sea-level could therefore be appreciably greater than the 0.01 m per decade long-term average for the last century.

The effects of sea-level rise will include:

Erosion of beaches and coastal margins: some 70 per cent of the world's beaches are presently eroding due to a combination of natural sea-level rise and human intervention. This process will be aggravated by the sea-level rise induced by global warming. For example, the cost of maintaining shores under threat on the East Coast of the USA will be of the order of 10-100 billion US dollars for a one metre sea-level rise.

Land-use Changes: decrease of usable land for various aspects of primary production, including aquaculture ,and for activities such as salt-making arises from the joint effects of subsidence due to river modification and sea-level rise. It is generally counteracted by dykes and other diversions. Where counteracting measures are not feasible, these changes can lead to large land and livelihood losses. In developed countries, lowland protection against sea-level rise will be costly. In developing countries without adequate technical and capital resources, it may be impossible.

Wetlands loss: natural wetlands are now under pressure: urbanization encroaches on salt marshes; mangroves are harvested or displaced by fishponds etc. In the natural state, wetlands adjust to sea-level increases by moving landward- a process that is inhibited by steep coastlines and human made structures. Where migration has become impossible, wetlands will be lost, with associated losses of natural resources, habitat and physical barriers against flooding.

Frequency and severity of flooding: a projected sea-level rise of as much as 1.5 m. within 75 years would cause many flood disasters, with large losses of life, property and farmland, particularly in the delta regions of South Asia. Damage to infrastructure in the industrialized countries would also result.

Damage to coastal structures and port facilities: sea-level rise will increase the hydraulic loading on coastal structures like breakwaters, locks, and bridges. Reinforcement will be required and maintenance costs will increase. Port facilities will have to be adjusted to a higher sea-level.

Damage to water management systems: sea level rise will also cause problems with drainage and irrigation systems. Salt-water intrusion into groundwater, rivers, bays, and farmland will increase. This will create a demand for reconstruction and extension of water management systems and structures, which may not always be economically feasible. To give an example of costs, in the Netherlands, a country that already has a finely-tuned coastal defences infrastructure, the Public Works Department has tentatively estimated that the minimum adjustments to the water management systems there for a 1m sea-level rise would require additional investments of the order of several billion dollars.

3.2 MID-LATITUDE REGIONS

In the middle latitude regions between 30 and 60 degrees latitude, the amount of warming caused by increasing GHG concentrations will be greater than the global average warming (Table 1). Additionally, the winter temperatures are expected to increase more than the summer temperatures. Changes in precipitation and soil moisture are uncertain, although soil moisture in summer could decrease as a result of enhanced evapotranspiration with the increased temperatures. The effects of climatic change on agriculture, water resources and soils have been considered but the most important effects are expected to be on relatively unmanaged ecosystems, especially forests. Two aspects of the global climatic changes are particularly important for these ecosystems:

- future climatic changes are likely to be much more rapid than those in the past;

- in the absence of measures to limit GHG emissions, the climate will continue to change and the changes will persist indefinitely into the future.

Forests: The forests of the middle latitudes contain, in trees, other plants and soils, a quantity of carbon that is comparable in magnitude to the amount of carbon currently stored in the atmosphere. The effects of the climatic changes anticipated include the possibility of the release of a significant amount of carbon from this source into the atmosphere as carbon dioxide and methane, which would further increase the greenhouse warming.

The possible responses of mid-latitude forests to climatic change have been assessed, taking into consideration the rate of seed migration, changes in reproductive success with changes in temperature, and climatic stress on standing trees (see Appendix 6). The reproductive success of many tree species would be reduced by a warming and both tree and plant mortality would increase. These changes would be conspicuous first along the warmer and drier limits of the range of the species. There is no threshold below which effects do not occur.

The upper limit of the climatic changes shown in Figure 1 suggests a rate of warming of 0.8-1.0 °C per decade in the middle latitudes. Major effects on forests were estimated to begin around the year 2000 with forest dieback starting between 2000 and 2050. The net effect of the warming would be a reduction in area and standing stock of carbon in forests. The seriousness of the changes depends on the rate of change of temperature.

For the lower bound of the temperature scenario, which gives an average rate of change of mid-latitude temperature of 0.06 - 0.07 °C per decade, extinction of species, reproductive failure and large-scale forest dieback would not occur before the year 2100, although the warming would cause some changes in the forested regions. However, with the rates of temperature change of the lower scenario the changes in the forested regions would be at rates that are low enough to approximate to the rates at which forests have accommodated to climatic changes observed in the recent past.

These estimates illustrate the importance of the rate of change of temperature for the effects on forests. If the temperature change is rapid, dieback of trees will result, with replacement of successional trees supporting smaller standing crops. The outcome of this trend would be that more and more forest would need planting (or managing) to retain it in a productive mode. Such labour-intensive intervention may be economically non-viable for formerly unmanaged forests.

Agriculture: warming will cause intra-regional shifts in productivity in the mid latitudes. For all but the most rapid warming, adaptation based on agricultural research should

permit maintenance of total global food supplies. However, there will be local disruptions. For the faster rates, agricultural adaptations may be out of step in time with effects of climatic change, generating erratic reductions in food availability. Taken alone, climatic warming would have probably little net effect on agriculture in the mid-latitude band: productivity in the lower-latitude zone of the band might be negatively affected because of increased evapotranspiration, while the higher latitudes of the band would benefit from the longer growing season. Agriculture is dependent on the availability of fertile soils. Shifts of crops due to GHG-induced climatic changes may be affected positively or negatively by this factor. There are also major uncertainties about changes in precipitation and evapotranspiration, so that it is not possible to predict at this stage whether the net effects of change will be positive or negative for specific regions except that irrigated agriculture in semi-arid areas in the mid-latitudes will probably be adversely affected by the warming.

Interacting Effects: climatic change will not occur in isolation. Increasing amounts of atmospheric and aquatic pollutants can be expected from urban-industrial growth. The response to climatic changes will be affected by these increased pollutants. The importance of these interactions and the need to investigate them further cannot be overemphasized. Such interactions are now causing widespread mortality of many species of coniferous and broad-leaved trees in Europe and in eastern North America.

3.3 THE SEMI-ARID TROPICAL REGIONS

The semi-arid tropical regions lie within the broad latitudinal band 5-35 °N and S. Within this zone the semi-arid and sub-humid regions are defined as areas receiving mean annual precipitation somewhere within the range 400-1000mm, unevenly distributed seasonally, with high spatial and interannual variability.

Climatic variability is a problem for the semi-arid tropical regions. Any future changes in the frequency distribution of extreme events will have important effects. The climatic changes that might occur by the middle of the next century as a result of the increasing concentrations of trace gases in the atmosphere include:

- Increases of regional temperature of the order of 0.3-5 °C.
- On average for the latitudinal belt as a whole, climate model results are variable, but a tendency

for a decrease in precipitation rate in one or more seasons is generally apparent. In addition, temperature increases would reduce soil moisture availability.

The semi-arid tropical regions already suffer from seasonal and interannual climatic variability. Precipitation data for the zone 5 - 35 °N show a pronounced downward trend since the early 1950s, resulting in prolonged drought and active desertification processes. These regions are very sensitive to climatic variability, generally with negative impacts. Therefore, future climatic changes could worsen the current critical problems of the semi-arid tropics. The major effects are expected to be on:

Food availability: temperature increases, precipitation pattern changes and CO_2 concentration changes would alter the agriculture and agricultural production potential within a region which is already highly sensitive to the impacts of climate and often marginal for agriculture. Productivity changes could aggravate current difficulties in meeting basic nutritional needs. Resource degradation through increased desertification could ensue.

Water Availability: in general, evaporation would increase and runoff would be reduced. Water availability would be further reduced by increased demand.

Fuelwood Availability: changes in biomass productivity and soil moisture will probably lead to reduced fuelwood availability.

Human Settlement: as agricultural and resource potential changes, human populations are expected to move in response- including increased rural-to-urban migration.

Unmanaged Ecosystems: climatic changes and human responses are expected to increase pressure upon unmanaged ecosystems and heritage sites. Biotic resources will be stressed by habitat changes and development pressures.

3.4 THE HUMID TROPICAL REGIONS

By the middle of the next century it is expected that the addition of CO_2 and other trace gases will warm the humid tropical regions by 0.3-5 degrees C. This warming, somewhat less than the global average warming, will be accompanied by an increase in rainfall amount, perhaps in the range of 5-20 per cent. In a region that is already often too hot and too wet, even such relatively modest climatic changes could have

important effects. The increased rainfall may occur largely through increases in rainfall intensity. Superimposed on these general tendencies would be shifts in the geographical patterns of rainfall and cloudiness. Since the warming will increase potential evapotranspiration, there could be a tendency toward more drought stress in many, if not most, of the regions in the humid tropics. With the increased ocean temperatures tropical storms might extend into regions where they are now less common. Where they already occur, increased intensity of winds and rainfall might be expected.

The major effects of climatic changes would therefore result from:

- Rising water levels along coasts and rivers, resulting from a combination of increasing sea-level, greater chance of tropical storm surges and rising peak runoff. These will result in larger areas being subject to flooding and a risk of salinization.
- Changing spatial and temporal distribution of temperature and precipitation with effects on industry, settlement, agriculture, grazing lands, fisheries and forests.

Two provinces of the humid tropics appear especially vulnerable to the kinds of climatic change that may occur over the next century:

- coastal and river regions subject to changes of sea-level and storminess;
- regions of infertile soils in uplands.

3.5 HIGH-LATITUDE REGIONS

The high-latitude areas include regions north of 60 °N and south of 60 °S. The effects discussed here are those that could occur in the northern high latitudes.

The magnitude of expected climatic changes

By far the largest changes would occur in winter (Table 1). As a result of increases of GHGs, it is expected

that by the middle of the next century the mean winter temperature of this region could increase by 0.8 to considerably more than 5 °C by the middle of the next century. The following effects are the most important:

- Changes of the pack ice conditions could be very great. A warming could result in the withdrawal of summer pack-ice, leaving the Arctic ice-free around Spitzbergen and along the north Siberian coast. Loss of pack-ice would significantly decrease the proportion of incoming solar radiation that is reflected back to the atmosphere (albedo), which is the reason for the enhancement of the warming effect in these regions.

- There would most likely be increased cloudiness and precipitation in the high latitude regions of the northern hemisphere. Because of the penetration of moisture-rich, warm air into higher latitudes, the precipitation would increase more than evaporation in high latitudes. Thus the rate of runoff into the Arctic Basin would increase markedly. In the 60-70 N region, duration of snowcover would be shorter.

- Permafrost, particularly in northern Canada and Siberia would slowly disappear.

- Changes in the tundra and in the northern limit of the boreal forest will include both a stimulation of growth and carbon fixation and rapid decay of organic matter. The overall effect on carbon storage is not predictable. The possibility exists for a large net release of carbon from soils to the atmosphere as a result of increased respiration.

Changes of Arctic pack ice (including decreased albedo) could have major implications for the climatic changes in lower latitudes. In the absence of the pack ice there would be changes of the atmospheric and oceanic circulations that would cause climatic anomalies in high, middle and low latitudes. The potential magnitude of these anomalies is not known at present.

Given the above potential changes, the following effects may be expected:

Marine Transportation: the possible changes of sea-ice offer opportunities for increased use of the Northeast and Northwest passages. However, prediction of route enhancement is complicated by inadequate understanding of expected changes of ocean currents, cloudiness, fog, ice fields, and icebergs.

Energy Development: higher temperatures and a reduction of sea-ice could reduce some of the difficulties of offshore oil development, but onshore development could become more difficult and expensive in regions of melting of permafrost, affecting construction practices and existing developments. A reduction of sea-ice extent could lead to higher snowfall over the land surrounding the Arctic Ocean, making operating conditions more difficult.

Marine Fisheries: different marine ecosystems could be affected positively and negatively by the increased atmospheric and oceanic temperatures. Useful predictions of the effects on fish migration and species distribution will require further research.

Agriculture: is practised in Scandinavian countries north of 60° N. At present however, its importance, as in other circumpolar countries, is small. With warming, agricultural opportunities should improve, but only over limited areas because of lack of suitable soils. Current food-market conditions make it unlikely that extreme northern areas would ever be exploited for the international agricultural markets.

Human Settlement: climatic warming will make northern mines, forests and ports more exploitable as growth centres. Opening of the Arctic to shipping will increase the cultural shock which has already stressed native peoples. Warmer climates will induce migration into some areas, putting native peoples at risk of losing traditional cultures and environmental values.

Northern Ecosystems: the changes of precipitation, temperature and sea-level will affect the natural ecosystems. Rapid shifts in growth conditions could cause dislocation or disruption of ecosystems as well as movement of the limits of agriculture and forestry northwards.

Carbon Emissions: Nordic regions are important in the global carbon cycle. It has been suggested that the climatic warming could result in a substantial increase of methane emissions from tundra, thus increasing the emissions of GHGs into the atmosphere. Siberian and other boreal soils are often highly organic and would rapidly decay upon withdrawal of permafrost, if they subsequently dry up, thus increasing CO_2 loading to the atmosphere.

Air Pollution and Acid Rain: Arctic haze (already circumpolar) and acid deposition in nordic regions would be affected by climatic changes. The result could be a shift of the region subject to acid deposition, particularly if atmospheric circulation patterns change. There could be a

significant degradation of some aquatic and terrestrial ecosystems and perhaps an improvement of others. The importance of these interactions and the need to investigate them further cannot be overemphasized.

Security: the northern ice-bound land borders of North America, Europe and Siberia are highly sensitive national defence zones for all states with Arctic territory. If these coastlines become navigable, fundamental security readjustments will be required.

SOURCES OF INFORMATION

This section is based on the reports of the Working Groups at the Villach workshop, on the background papers prepared for the workshop (see Appendix 7) and the keynote papers presented by:

E.F. Roots on "The response of the Nordic Areas to climatic change";

G.M. Woodwell on "The warming of the industrialized middle latitudes 1985-2050: Causes and consequences.";

P. Crosson on "Climate change and mid-latitudes agriculture: Perspectives on consequences and policy responses.";

J. Mabbutt on "Issues raised by future climatic change in semi-arid tropical regions";

H. Sternberg on "The humid tropics - the case of Amazonia";

J. Bardach on "Global warming and the coastal zone".

Information on precipitation changes in the semi-arid zones was obtained from:

Bradley, R.S., H.F. Diaz, J.K. Eischeid, P.D. Jones, P.M. Kelly, and C.M. Goodess, 1987: Precipitation fluctuations over Northern Hemisphere land areas since the mid-19th century. Science, 237, 171-175.

Section 4

RESPONDING TO CLIMATIC CHANGE

4.1 CLIMATIC CHANGE: ADAPTATION AND LIMITATION

As the previous sections have shown, the increasing concentrations of GHGs could cause climatic changes within the next half century with major implications for environment and society. For this reason it is necessary to consider strategies for responding to climatic change. These strategies fall into two categories. **Adaptation** strategies adjust the environment or our ways of using it to reduce the consequences of a changing climate; **Limitation** strategies control or stop the growth of GHG concentrations in the atmosphere and limit the climatic change. As discussed in the following section, adaptation can be subdivided into "anticipatory" adaptation" and "forced adaptation". A prudent response to climate change would consider both limitation and adaptation strategies. In fact, even if a very concerted effort were made now to limit emissions, some adaptation would still be necessary. This is because of the climatic changes, forced by GHG-producing human activities during the recent decades, that may already be underway and also by those that would occur before the limitation strategy had become effective.

Constraints on Adaptation to Climate Change

Anticipatory adaptation will involve large expenditures. Measures to adapt to climatic change may occur on a variety of scales, at different times, and with widely different costs. Some environmental modification measures, such as changes in coastal defences and freshwater supply systems, require large investments in infrastructure beginning decades in advance of anticipated climatic effects. On the other hand, many adjustments will consist of behavioural changes at the individual level occurring in immediate response to perceived climatic or sea-level changes, with

little advanced planning. These include changes in diet and physical activity, as well as some cropping practices and changes in habitation. Certain adaptation measures occurring gradually as climate changes will require anticipation but not as much as that required for hydrological planning. For example, agricultural research on new crop varieties should begin in advance of large climatic change but does not require massive investments decades ahead.

It has been estimated that a partial adaptation to the increases in sea-level which would occur in the next 50 years as a result of the GHGs already emitted would involve global expenditures of the order of tens of billions of US dollars, over a planning and construction time of twenty to forty years to produce a solution that would be only temporary as the climatic change continued. These measures include construction of sea walls, dykes and drainage systems, as well as other aspects of coastal maintenance. The best estimate for sea level rise over the past century is 12cm, about one-fifth of the projected rate of 6cm per decade for the next century if emissions growth continues at current rates (middle scenario, Figure 1).

The ability of societies to manage such changes is highly variable. Current coastal flooding in South Asian deltaic regions results in substantial annual loss of life. A combination of sea-level rise and local subsidence over the next century could flood an area of Bangladesh where between eight and twenty-four million people now reside.

Agricultural research has permitted the adaptation of production to a large range of soil and climate conditions. However, at the upper end of the projected rate of warming (about 0.8 degrees C per decade globally, Upper Scenario Figure 1a), research capabilities may be severely tested and adaptations may lag behind the rate of climate change.

Changes in agricultural practices at farm level will include substitution of thermal and moisture stress resistant varieties, alterations in fertilizer application, water use efficiency investments, and improved drainage to reduce erosion. At the national level, governments could ease the

impact of warming by maintaining an institutional capacity for flexible response, particularly in agricultural research and in trade policy. But other policy decisions will require longer planning horizons. These include land use and water management decisions, improvement of food storage and distribution systems, as well as famine identification and assistance plans.

Natural ecosystems will not adapt effectively to rapid climatic change. Inland migration of wetlands may be facilitated at some locations by reserving open coastal land. With regard to forests, habitats for plants and animals cannot be re-created or transplanted rapidly. Continuing climatic changes would strain the capabilities of management practices even in commercial tree plantations.

Constraints on Limitation of Climate Change

If GHG emissions continue to increase at current rates, the global temperature increase in the next century would be about 0.3 °C per decade (middle scenario, Figure 1). Whatever limits on climatic change might be implemented, some procedural mechanism is needed to guide planning and decision-making. In this regard, the use of long-term environmental targets, such as the rate of temperature change or sea-level change, would be extremely advantageous as a management tool. Such environmental targets would be based on observed historic rates of change of temperature or sea-level, and on expected consequences for ecosystems and society. Given a rate of change as a target, it should be possible to translate this into emissions targets for greenhouse gases that could be used for regulatory purposes. Such target rates of change could be supplemented with absolute limits on temperature which capture other features of the environmental response to climate, since unlimited warming at any rate must sooner or later become problematic.

For instance, mid-latitude forests may experience dieback of standing trees and replacement of canopy trees with successional species for rates of temperature change around 0.3 °C per decade (middle scenario, Figure 1). Such consequences should not affect forests generally and will

occur more slowly over the next century for rates of temperature increase of about 0.1 °C/decade and will be partially accomodated by changes in species and by expansion of forests into new land. Furthermore, historical experience of industrial societies coping with sea-level rise is restricted to a period when warming rates remained near 0.1 °C per decade or less and sea-level rise was limited to 2 - 3 cm per decade.

Constraints on the limitation of GHG emissions to keep the rate of temperature increase below 0.1 °C per decade may be judged by examining the sources of the individual GHGs. The middle scenario in Figure 1 already takes into account the reduction in CFC production required by the year 2010 under the recent Protocol on Substances that Deplete the Ozone Layer. This is estimated to lead to a 15-25 per cent decrease in the rate of temperature rise. The development of substitutes for CFCs may lead to the elimination of emissions of these chemicals. Although uncertainties are substantial, growth in tropospheric ozone, methane and nitrous oxide concentrations in the atmosphere will be partly governed by increases in fossil fuel use and may be limited in part with available air emissions technology.

Emissions of the non-CO_2 trace gases will contribute about one half of projected warming over the next fifty years, if current trends continue. The sources of these gases are widely distributed around the globe and certainly not easy to limit. However, it has been estimated that it may be feasible to cut this contribution by somewhere between one-half to two-thirds with current technology.

If other conditions of the middle scenario of Figure 1 held, such reductions in non-CO_2 trace gases would reduce the rate of warming to ca 0.2 °C per decade. In order to achieve a target warming rate of 0.1 °C per decade, a reduction of up to two-thirds in the rate of increase of CO_2 concentrations in the atmosphere would still be required. The current contribution from fossil fuel combustion amounts to about 5 Gigatons (Gtons) carbon per year. Current additions from deforestation contribute at least 1 Gton per year (and

perhaps considerably more) if the carbon uptake by the oceans amounts to at least 50-60 percent of the emissions. If deforestation can be significantly reduced, a decrease in fossil fuel emissions to 2-3 Gtons per year would approach the target warming rate. Experience with the response of the atmosphere to these emissions changes will help define long-term policies.

There are basically five options for achieving CO_2 reductions in spite of continued population growth, and in a manner consistent with continued economic expansion:

1) A reduction of fossil fuel use through increases of end-use energy efficiency. Efficiency advances are also technically feasible in generation and transmission. In the opinion of several respected analysts, consumption of energy in industrialized nations could be reduced by fifty percent with available technology. This could be achieved at about one percent per year with no strain on GDP growth. Greater rates are feasible and many efficiency improvements could be achieved with net economic savings.

2) Replace fossil fuel combustion with alternative energy sources. This strategy is the only viable long-term approach to offset the consequences of continued population and economic growth. Available options include solar energy, wind energy, hydroelectric power, nuclear power, tidal energy and ocean thermal conversion. Judgments on local availability and environmental consequences will govern particular decisions on the energy mix. The development of a suitable carrier medium for energy storage and transport would speed the penetration of these alternatives. Research on the efficacy of hydrogen gas as a carrier is underway. The early construction of production and storage facilities for hydrogen could stimulate the penetration of alternative technologies and avoid dependence on CO_2-rich synthetic fuels.

3) Reverse the current deforestation trend. Elimination of net forest loss would reduce the amount of fossil fuel reduction needed. Deforestation contributes to atmospheric increases in the other trace gases as well (CFCs excepted).
Large-scale **reforestation** has a limited potential to slow down CO_2 increases in the atmosphere and buy time to reduce fossil fuel emissions.

4) Shift the fossil fuel use mix from high to low CO_2-emitting fuels. The CO_2 emissions per unit energy differ according to fuel type; the lowest emissions per unit energy are from natural gas (0.43 Gt carbon per TWyr, see Appendix 4 for definition of TW), followed by oil (0.62 Gt carbon per TWyr), coal (0.75 Gt carbon per TWyr).

5) Dispose of CO_2 in the deep ocean. In principle, CO_2 from large stationary sources can be removed from the flue gas and transported to the deep ocean. For example, thermal power plants account for about fifteen percent of CO_2 emissions currently. Ninety percent removal of CO_2 and subsequent disposal may double the cost of producing electricity. Such costs are of the same magnitude as current pollution control requirements in several countries.

Global Energy Use

The limitation of global warming to 0.1 degrees per decade could be accomplished only with significant reductions in fossil fuel use. If reasonable economic growth rates are to be maintained, these reductions can be achieved only with two major changes: large efficiency increases of the order of one-half in industrial nations; and rapid deployment of alternative energy sources. The former goal appears to be achievable with current technology. The latter goal would require expanded research and development of alternatives. For instance, the World Commission on Environment and

Development has discussed growth in primary energy consumption from 10.3 Terawatt years per year in 1980 to about 20 Terawatt years per year in 2025, which allows modest per capita energy growth in developing countries but does not allow growth of per capita consumption in industrialized countries. About 16 Terawatt years per year of this total would be supplied by fossil fuels, if no penetration of renewable energy sources is assumed. Even if efficiency of generation and use of fossil fuel energy were doubled, as much as 5 Terawatt years per year of fossil fuel consumption would still need to be shifted to renewables to attain the target warming rate. This projection assumes that the contribution of deforestation to atmospheric carbon dioxide will become insignificant.

4.2 THE USE OF RATES OF CLIMATIC CHANGE AS A MANAGEMNENT TOOL

The goal of 0.1 °C per decade was selected after considering the observed limited ability of natural ecosystems and societies to adapt successfully to faster changes. The chosen rate is of the same order as recent historical variations. As illustrated in section 4.1, the setting of a goal makes it possible to calculate the rates of emission of trace gases that would be permitted globally in order to achieve a warming rate at the target level. It also permits comparison of strategies for achieving the target through limitation of the different greenhouse gases. Clearly, a great deal of careful analysis will be required before a firm global environmental target can be agreed upon. In addition, even with a long-term environmental target, an adjustment process in reaching this target will be required and interim targets would have to be set. Since at the present it is obvious that the developed countries have greater possibilities for controlling emissions, it might be appropriate to set different interim emissions goals for the developed and developing countries. The interim target might also have to be periodically adjusted to take into account the changes in scientific knowledge, the introduction of new technologies

and the time required to do this, and changing perceptions of the nature of the problem. In addition, the interim targets must be justifiable in terms of the estimated costs of achieving the required emission goals.

4.3 THE TIMING OF RESPONSES TO CLIMATIC CHANGE

Uncertainty and surprise: Global mean temperature has risen about 0.5 °C over the last century and sea level has risen about 12 cm. Current atmospheric levels of GHGs may already have committed the world to an additional 0.5 °C of warming, and an additional 10-30cm of sea-level rise over the next fifty years, even if the atmospheric composition were stabilized immediately. Consideration of some adaptation measures appears to be inevitable, and in fact some measures, such as beach restoration, have already been undertaken.

On the other hand, continuation of growth in the concentrations of atmospheric trace gases could lead to unmanageable consequences for coastal zones, forests and, in specific areas, for the agricultural sector, since the rate of global mean temperature increase could possibly approach 0.8 °C per decade over the next century (Upper scenario, Fig. 1a). In some areas, forest and coastal ecosystems currently suffer severe stress due to air pollution, and land and water misuse by humans. These existing problems will be compounded by climatic change.

Furthermore, our understanding of the atmosphere and the oceans and natural ecosystems is limited and the possibility exists that wholly unforseen changes will occur which are large and abrupt enough to overwhelm our adaptive capabilities and far exceed natural rates of change in ecosystems. The sudden deepening of the Antarctic ozone hole over the last decade exemplifies such a surprise. The likelihood of surprise increases as climate deviates from historical bounds.

Timing of Measures: The timing of initiatives to limit and adapt to climatic change is critical from both an environmental and a financial perspective. It would be

inappropriate to postpone action until the consequences of warming, which lag behind emissions, are clearly visible. Policy actions already implemented or under consideration for other reasons could limit or mitigate the consequences of warming. For example, energy conservation measures since the 1970s have materially slowed the rate of increase of the atmospheric CO_2 concentration. In addition, a gradual reduction in carbon dioxide and other emissions over the next fifty to seventy-five years has quite different warming implications than a rapid reduction, particularly with reference to the magnitude of the cumulative global warming.

4.4 THE COSTS OF RESPONDING TO CLIMATIC CHANGE

If current perceptions about the range of possible harmful environmental and socio-economic effects (outlined in Section 3) are substantially correct, then the costs incurred by doing nothing about climatic change would be large. However, strategies for adapting to climatic change or limiting it by controlling greenhouse gas emissions, or both, could also involve high costs to global society.

Clearly, it would be preferable to be more certain about the magnitude and rate of onset of global warming and about its environmental and socio-economic effects before taking expensive adaptation and/or limitation actions. In addition, for policy-making purposes there is a need for detailed comparisons of the costs of various strategies. What kind of approach and process could provide estimates of such costs ? Developing a useful framework will pose major challenges to existing methods of economic and policy analysis. A major problem is the current practice of "discounting" the future, since it is inappropriate to discount into present monetary values the risk of major transformations to the world of future generations. Likewise, much is lost by using single numbers to combine the effects of, for example, flooding an island with the costs of providing irrigation to an arid region in North America. Methods are needed that build on the

best of risk-benifit analysis and intergenerational equity studies, in order to take into account the complex character of long-term, large-scale effects of climatic change.

Some of the items that must be included in any scheme for comparing the costs of different strategies are shown in Figure 2. The figure considers three scenarios : Business as Usual; Moderate Effort; and Concerted Effort. The scenarios are distinguished by the level of effort and ambition of policies undertaken explicitly to deal with climatic change induced by greenhouse gases. Steps that limit greenhouse gas-induced climatic change but that are undertaken for other reasons (e.g. to protect the stratospheric ozone layer) are not considered.

The Scenarios In the Business as Usual scenario, no policies explicitly directed at greenhouse gas limitation are undertaken. Moderate Efforts and Concerted Efforts reflect the level of effort devoted to energy policy (energy end-use efficiency and renewable energy sources) , deforestation and greenhouse gas reduction strategies. The Surprise scenario differs from the other three scenarios, since it could occur in any one of the other scenarios, although it is perhaps less likely to occur in the case of concerted efforts than that of business-as-usual. It is intended to highlight the consequences of a surprise event, such as an abrupt change of global climate as a result of an unforseen change of the oceanic circulation.

The Responses Limitation refers to steps taken to reduce emissions. Anticipatory adaption refers to steps taken before effects occur, while forced adaptation occurs in response to physical and biological impacts. Residual costs are absorbed costs, i.e., those for which adaptation steps are not, or cannot be, undertaken. These will largely be costs involving externalities such as the global commons, unmanaged ecosystems and human suffering. It is worth noting that ultimately adaptation strategies will have to be replaced by limitation strategies, since an unlimited warming would sooner or later become intolerable no matter how much is spent on adaptation.

Also, limitation strategies cannot totally avoid future build up of GHGs some adaptation will be required, especially as a result of the emissions that have already occurred. A balance limitation and adaptation will be required.

FIGURE 2.

Relative costs of four different types of effort undertaken in three different strategies for responding to climatic change. The relative costs are indicated by w,x,y,z. In addition, the relative costs of a surprise occurence are shown.

	LIMITATION (reduce emissions)	ANTICIPATORY ADAPTATION (primarily adjust to effects)	FORCED ADAPTATION	RESIDUAL (absorbed costs)
Business as Usual	w	xx	yyyyy	zzzzz
Moderate Efforts	ww	xxxx	yyy	?
Concerted Efforts	wwwww	xx	y	z
Surprise			yyyyyyy	zzzzzzzz
Comments	long lead time	varying lead time	no lead time	

Units of Costs Different types of costs (symbolized by the use of w, x, y, and z) are used to emphasize that the costs of limitation and of anticipatory adaptation can be monetized. Forced adaptation, however, would involve both monetized costs (e.g., costs of rebuilding a flooded village) and unmonetized costs (e.g., loss of human life, environmental damage). Residual costs will be almost entirely unmonetized.

The symbols are given only to indicate relative costs going down a column. In the absence of more data, it is not

possible to compare across the rows. The costs in the limitation column would be investment costs that could become net positive investments (i.e., generators of profit). For example, many end-use efficiency improvements could pay for themselves in a few years. Different measures to reduce emissions would have different long-term cumulative costs. If "concerted efforts" concentrated on increases of energy end-use efficiency the cumulative costs would be different than if "concerted efforts" concentrated on a restructuring of the energy supply system and large-scale introduction of solar or nuclear energy. Costs for adaptation would in many cases involve bills to repair damage.

Geographic Scale of Action and Analysis Limitation strategies will generally be implemented at the national level with agreements to undertake limitation being taken at international levels., On the other hand, adaptation strategies do not require international agreements, although for some adaptation alternatives an agreement could be beneficial, e.g., in the case of international trade agreements. Adaptation strategies will be implemented at local levels and to a lesser extent at the national level.

It is clearly impossible to analyse adaptation costs on a global level and probably even at the national level for the larger countries. Comparisons of local adaptation costs and national limitation costs could best be made on the basis of regional studies, where a fraction of the national cost for limitation is assigned to the region on the basis of the contribution of the region to GNP, total energy demand, GHG emissions, or some other appropriate measure.

Residual costs, as pointed out above, will not be monetized. However, it will be necessary to characterize at least those involving unmanaged ecosystems and the global commons on a global basis.

Timing Issues The costs shown as w, x, and y should be studied for the period of roughly 1990 - 2050, perhaps by

decade, with the aggregate costs integrated over time. This length of time is required to get a preliminary measure of net costs (of, for example, investments in new energy technologies) as opposed to initial costs.

Costs for Developed and Developing Countries There are major differences among the scenarios regarding the relative costs to be met by different countries. Given the present knowledge of costs and of expected climatic changes it is not possible to make reliable intercomparisons of costs of different scenarios in different countries. At a crude level of aggregation, the majority of the costs of the "Concerted Efforts" scenario would be borne by developed countries in the form of research, development and deployment of new energy technologies, development of alternatives to CFCs and GHG abatement techniques. Similarly, in the "Moderate Efforts" scenario, where substantial effort would go into anticipatory adaptation, developed countries will spend more money and make most attempts at anticipatory adaptation, since it is generally these countries that have the scientific and technical knowledge and the bureaucratic and management resources to implement the needed changes and the economic resources to pay for them. International assistance would be needed to pay for anticipatory adaptation in many developing countries, so additional bilateral and multilateral funding would be required.

"Forced Adaptation" costs in both the "Moderate Effort" and "Business-as-Usual" scenarios would be larger in many developing countries, to the extent that they will have been less able to carry out "Anticipatory Adaptation". The same is true for the "Residual Costs". Here again, many developing countries would probably have more costs, to the extent that they had not been able to carry out "Forced Adaptation".

Thus, in Figure 2 the developed countries will pay the most in the left and lower boxes, while the burden shifts more towards the developing countries as one moves from left to right and from bottom to top in the figure. From this

perspective, the "Business-as-Usual" scenario looks worst from the point of view of the developing countries, while the "Concerted Effort" scenario looks the best.

4.5 POLICY RESEARCH REQUIREMENTS

In the previous sections several items were discussed that require further policy research in the immediate future. These items are listed in the following paragraphs, with some discussion of their relevance. Research on these items should be started now so that preliminary results can be reviewed at the Second World Climate Conference in 1990.

When to act ? The entire issue of increasing concentrations of greenhouse gases and the resulting climatic change involves a high level of uncertainty. If decision-makers were to wait until the scientific uncertainty is "acceptably" small, most policy responses would be too late. Further investigation is, therefore, needed regarding the main factors involved and the appropriate time for action.This will involve analysis of the rate at which scientific uncertainty can be expected to decrease compared with the rate at which GHG concentrations are increasing. An alternative approach to this question would be to ask "Why haven't we acted so far ? Why have limitation strategies that are claimed to be "feasible" not been implemented ?"

What are the policy alternatives and how much will they cost ?

The costing framework discussed in the previous section (pages 27 to 31) should be developed and applied on an experimental basis in order to evaluate its utility. For the purposes of policy development it would also be useful if the costing of scenarios could be used to provide an estimate of the aggregate effects of climatic change on a single region.

Further, there is a need for a reexamination of the question of discounting within the context of climatic change and at the implications of transnational and transgenerational transfers of costs.

What institutional mechanisms are required for developing policies in response to climatic change ?

What role can bilateral or multilateral agreements realistically be expected to play in developing policies for limiting or adapting to climatic change ? How can we deal with the urgency of the problem ? How can developed and developing countries begin to develop a joint response to climatic change ?

Targets Detailed studies are now required to examine the relationships between GHG emissions and environmental effects, with a view to setting targets for both. The emissions rates of all GHGs must be made intercomparable by using, for example, the concept of the "CO_2 equivalent" (i.e., expressing the amount of each GHG in terms of the amount of CO_2 that would produce the same radiative effect). This would allow a total emissions picture to be obtained in warming terms. Likewise, all reliably quantifiable indicators of GHG-induced environmental change should be analysed, especially rates of temperature and sea-level change. Ideally, the management steps that could be taken if enough information is available are: first, determine the target (e.g. rate of global surface temperature change) that should be reached if large-scale environmental and social problems are to be avoided; second, specify the changes of rates of GHG emissions that would be needed to reach this target; third, regulate GHG emissions so that the environmental target can be reached. The utility of absolute temperature targets over a specified period of time should also be considered. Once a target is agreed upon, the relative weights given to adaptation and limitation strategies can be settled and the decision of "when to act" could be made.

What can we learn from previous experience ? In several respects the problem of climatic changes resulting from emissions of greenhouse gases is unique. Although the emissions of these gases are distributed unevenly in time and

space, the atmosphere rapidly spreads the trace gases evenly throughout the globe. The resulting climatic changes are expected to be unevenly distributed but it is not possible at present to make reliable predictions of regional changes of climate. One aim of policy research should be to review the development of other international agreements (e.g., the Law of the Sea, the Ozone Convention) and ascertain their utility as models for the development of policy responses to changing climate.

Section 5

DEVELOPING POLICIES FOR RESPONDING TO CLIMATIC CHANGE

5.1 POLICY ACTIONS

In discussing how to develop policies for responding to climatic change the participants at the Bellagio workshop were guided by four sets of considerations:

First, in spite of uncertainties about the scale and speed of climatic change and the factors which affect it, it is clear that the common assumption underlying many decisions in the social and economic sphere still is that past climatic data are a reliable guide to the future. This assumption is no longer valid. If present trends continue, climatic change will be more rapid in the future than it has been in the last few millennia. Lead times for many of the measures needed to deal with accelerated climatic change are long.

Secondly, the participants emphasized the relationship between the issue of climatic change and a number of other issues, above all in the field of environment and development (for example, the increase in chlorofluorocarbon concentrations in the atmosphere acts both to decrease the amount of ozone in the stratosphere and to increase the greenhouse effect in the lower atmosphere). The report of the Brundtland Commission has examined the ramifications of these numerous interconnections. The significance of the difference in regional effects should not, however, be allowed to detract from the emphasis on the problem as a whole and the response of the international community as a whole in facing it. Still less should it encourage any attempts to divide countries or regions into "winners" or "losers". This is not a "zero-sum" game. Unless action is taken, it could be a negative sum game of highly uncertain proportions.

Thirdly, the participants looked at policies in response to climatic change under three headings: "Limitation", i.e., measures to slow or reverse the growth of greenhouse gas concentrations in the atmosphere; "Adaptation", i.e., adjusting the physical environment or our ways of using it to reduce the consequences of a change in climate; and "Institutional" changes, which include the measures necessary for the world to organize itself to prepare and take action. A prudent policy will require a combination of all three measures. They are, of course, interdependent in a number of ways.

Fourthly, the participants looked at policy response with regard to several criteria - as a means of helping to judge what sort of actions are required. First, there are actions which are already identified and can be pursued forthwith. Further, there is an urgent need to identify and clarify the areas in which policy or scientific research is required. There is a need to strengthen the conceptual framework for dicussion of the problem and hence of the remedial action required. There is an overarching demand for increasing awareness worldwide of all the problems posed by GHG emissions and of the necessity for adopting measures to tackle them.

5.2 PRIORITIES FOR ACTION

There are many longer-term actions that will be required in order to ensure appropriate responses to climatic changes. The actions that are listed in this section are those that should receive priority now because several of the responses to climatic change could be made using institutional mechanisms that already exist. For this reason they have been given high priority, since they could be introduced without delay. The rate of global temperature change that would occur if current trends of GHG emissions were to continue (see Figure 1a) is large compared with observed historic changes and would have major effects on ecosystems and society. **For this reason, a coordinated international response seems inevitable and rapid movement towards it is urged.**

Immediate steps to limit GHG increases in the atmosphere

(1) Ozone Protocol The Protocol on Substances that Deplete the Ozone Layer should be approved and implemented without delay. The protocol should be ratified as a matter of urgency and after expedited scientific review consideration should be given to acceleration of the schedule for reductions of CFC emissions and eventual elimination of emissions. This step would be important not only for ozone layer protection but also for greenhouse gas limitation.

(2) Energy Policies Governments should immediately begin to reexamine their long-term energy strategies with the goals of achieving high end-use efficiency, reducing multiple forms of air pollution and reducing CO2 emissions.

Research and development relevant to these issues, in particular the development of alternative (non-fossil) energy systems, must be greatly intensified.

(3) Forest Policies Deforestation is a source of carbon dioxide and other greenhouse gases. Measures to reduce deforestation in both tropical and extratropical areas through locally appropriate action plans are already jus-

tified by the consequences of deforestation for soil erosion, drought, flooding, and energy and agricultural resources. Some initiatives have already been taken to limit deforestation. The contribution to greenhouse gases in the atmosphere is an additional reason for measures to counter deforestation.

The expansion of the forested area of the earth provides many benefits, including the provision of a system for absorbing atmospheric CO_2.

In general, the role of the forests in the GHG issue points to a need for improved forest management throughout the world.

(4) Other Trace Gases Measures should be undertaken to limit the growth of non-CO_2 GHGs in the atmosphere and to avoid industrial and societal actions which unduly contribute to such growth. Some measures could be implemented now. Others need only a small amount of additional research and development to evaluate their utility. Some require considerable additional study. The first category includes the tapping of methane emissions from solid waste landfills for energy production and the further control of CO, NO_x and hydrocarbon emissions from combustion sources to limit growth in methane and ground-level ozone. The second group includes limitation of nitrous oxide emissions through combustion controls and through modification of type and method of fertilizer application. The third category includes methane emissions limitation through altered agricultural practices. Research and development of these measures should be supported now.

Immediate steps to limit the impact of sea-level rise

(5) River, Estuarine and Coastal Zone Policies International unions of geographic, coastal and geodetic and soil sciences and/or governmental and intergovernmental agencies should develop geographic information systems to identify areas vulnerable to sea-level rise, to the consequences of

river regulation and to intensified land-use. Already there are ongoing activities of this kind under the auspices of UNEP. Planning for large new industrial, tourist and urban installations near the sea should allow for the risks of sea-level rise.

Immediate steps to improve understanding of the greenhouse effect and options for dealing with it

(6) Policy Research Requirements A number of institutions already exist that should be actively encouraged to carry out the policy research that was identified at the Bellagio meeting. This research should be carried out simultaneously by governmental and intergovernmental groups at an international level and by national and international governmental and nongovernmental organizations.

Policy and scientific research should investigate further the utility of particular goals as management tools. An environmental goal expressed in terms of a rate of change of temperature or sea-level is easy to relate to observed historic rates of change. Such an environmental goal is related to the ambient concentration of greenhouse gases (expressed in terms of CO2 equivalence) and thus to the emissions. For each of these, regulatory targets need to be defined. This would help to keep the risks associated with climatic change within acceptable bounds.

Priority should also be given to the development of methods that could provide useful estimates of the costs and benefits of various scenarios. Further, an important research topic would involve an analysis of the various strategies for the limitation of emissions of GHGs to estimate how much limitation particular strategies could provide within certain timeframes. This would enable a more quantitative intercomparison of the strategies.

(7) Monitoring for modelling and detection of climatic change

The problem of significant climate warming calls for a considerable increase in global monitoring activities and the

further development of climate models to improve our understanding of and to reduce uncertainties about the extent of regional and global climatic changes and their impacts on the environment and major socio-economic sectors.

It is, therefore, recommended that WMO/WCP (World Meteorological Organization/World Climate Programme) and UNEP/GEMS (United Nations Environment Programme/Global Environmental Monitoring System) carry out a joint study of:

- What new climate observing system activities are required for monitoring the changing global climate ?

- What basic emissions data on GHGs need to be continuously monitored and archived globally ?

- What activities are required for monitoring the consequences of the changing climate ?

- What advantages and opportunities exist for simultaneous integrated multi-media monitoring of climate and its impacts on biota and ecosys tems at selected interdisciplinary research sites ?

The IOC through the Global Sea Level Observing System should give urgent attention to strengthening the monitoring of sea-level changes worldwide.

(8) Scientific Research Much of the scientific research that is required because of remaining uncertainties about climatic change will be organized nationally and carried out at individual institutions. However, increased support for scientific research and assessment at the international level should be given high priority.

The World Climate Programme (WCP) is jointly supported by ICSU, UNEP and WMO. This programme is the focus for the further international assessment of both basic research

issues concerning global climatic change and questions about climatic impact. The World Climate Research Programme (WCRP) is an important component of the WCP, because the assessment of possible or likely future climatic changes rests on a comprehensive understanding of the global climate system.

Similarly, the new research programme IGBP (International Geosphere Biosphere Programme), initiated by ICSU, addresses the scientific problems that we are now confronting when trying to understand the biological and geochemical interactions that contribute to future climatic change and are of importance for understanding climatic impacts.

In all cases, the scientific research on matters related to the GHG issue should be planned with due consideration of policy requirements.

Institutional Requirements

(9) The Advisory Group on Greenhouse Gases (AGGG) The AGGG was established by WMO, UNEP and ICSU in response to the Villach 1985 conference on greenhouse gases, climatic change and ecosystems (the members of the AGGG are listed in Appendix 3). The recommendations of the Bellagio meeting were presented to the AGGG at their meeting in Paris in December 1987. The AGGG recommended the setting up of three working groups to carry out some of the necessary policy research. It is important that financial support is provided to carry out this work and to expand the activities of the AGGG.

(10) Other Institutions Organizations, including the intergovernmental mechanism to be constituted by WMO and UNEP in 1988, should examine the need for an agreement on a law of the atmosphere as a global commons, as was developed in the Law of the Sea, or the need to move towards a convention along the lines of that developed for ozone.

(11) Conferences The development of policy responses to climatic change would be facilitated if the recommendations of the present Report were considered and developed through-

out a series of subsequent meetings. In June 1988 the Canadian Government will host a World Conference on The Changing Atmosphere. The WMO, with ICSU and UNEP is organizing the Second World Conference, which will be held in Geneva in Spring 1990.

(12) Protocols The World Commission on Environment and Development (the Brundtland Commission) was established following a resolution of the UN General Assembly and completed its report in February 1987. The resolution of the Brundtland Commission report at the 1987 UN General Assembly is to be welcomed. It should be strongly recommended that an Auxilliary Resolution dealing with Global Change should be brought to the next UN General Assembly with a list of actions that have to be taken, research that needs to be done etc.

(13) Implementation A mechanism, perhaps in the form of a professional secretariat, should be established to help to ensure that the recommendations of the Bellagio workshop are implemented and to coordinate the necessary policy and scientific research.

APPENDIX 1

DEVELOPING POLICIES FOR RESPONDING TO FUTURE CLIMATIC CHANGE
Villach, Austria
28 September - 2 October 1987

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APPENDIX 2

DEVELOPING POLICIES FOR RESPONDING TO FUTURE CLIMATIC CHANGE
Policy Workshop
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APPENDIX 3

The Advisory Group on Greenhouse Gases

This Group was set up in response to the recommendations of the Villach 1985 Conference on The Assessment of the Role of Carbon Dioxide and of other Greenhouse Gases on Climate Variations and Associated Impacts. The group advises WMO, UNEP and ICSU on matters relating to the greenhouse gas issue.

The members of the AGGG in December 1987 were:

F.K. Hare (Chairman)
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APPENDIX 4

Acronyms and abbreviations used in the report

AGGG	The Advisory Group on Greenhouse Gases (see Appendix 3)
CFC	Chlorofluorocarbon. Chlorofluorocarbons are added to the atmosphere as a result of human activities. They act both to destroy the stratospheric ozone layer and add to the greenhouse effect.
GEMS	Global Environment Monitoring System
GHG	Greenhouse gas
ICSU	International Council of Scientific Unions
IGBP	International Geosphere Biosphere Program
IOC	International Oceanographic Commission
UNEP	United Nations Environment Programme
WCED	World Commission on Environment and Development
WCP	World Climate Programme
WMO	World Meteorological Organization

TWyr Terawatt year. 1 Terawatt is the unit of energy equivalent to 1 billion kilowatts (kW) or 10^{12} watts. 1TW, if emitted continuously for a year is 1 TWyr. Using 1 TWyr/year is equivalent to burning approximately 1 billion tons of coal annually.

APPENDIX 5

Assumptions Made in Deriving the Emissions Scenarios

Current Trends Scenario

Carbon Dioxide (CO2): Scenario uses fossil fuel emissions from Reilly et al. (1987), Table 10. An additional 1.5 x 10^{15} gC/yr was assumed from deforestation, including both land use changes for energy and other purposes. The atmospheric retention rate (airborne fraction) was assumed to be 0.5.

Chlorofluorocarbons (CFCl3, CF2Cl2): Scenario assumes that the recent CFC protocol is successfully implemented.

Methane (CH4): Assumes 1980 concentration of 1.65 ppm and the rate of growth of the concentration at 1.1% per year (current rate).

Nitrous oxide (N2O): Assumes 1980 concentration of 0.3 ppmv and the rate of growth of the concentration at 0.8%/yr. (current rate).

Low Emissions Scenario

Scenario taken from Mintzer (1987).

Assumes high rates of improvement in end-use energy efficiencies, low costs of renewable energy technologies, high costs of fossil fuels,

Cheap substitutes for chlorofluorocarbons that do not affect the global radiation balance are found.

0.4%/yr rate of growth of atmospheric methane.

High Emissions Scenario

Scenario taken from Mintzer (1987).

Assumes low costs of fossil fuel using technologies.

High cost of renewable resources energy technologies.

Rapid deforestation

Collapse of the CFC protocol

2.3%/yr growth in atmospheric methane.

REFERENCES for Appendix 5

Mintzer, I.M., 1987: A Matter of Degrees. World Resources Institute, Washington D.C.

Reilly, J.M., J.A. Edmonds, R.H. Gardner, A.L. Brenkert, 1987: Uncertainty analysis of the IEA-ORAU CO_2 emissions model. The Energy Journal, 8 (3), 1-29.

APPENDIX 6

Assumptions Made in Assessing Effects on Mid-latitude Forests

The latitudinal change in annual mean temperature in the middle latitudes is 100 - 150 km per °C.

A change in temperature of 1 °C changes rates of respiration by 10 - 30%, occasionally more. An increase in temperature of 1 °C can be expected to increase rates of decay of organic matter in soils, swamps and bogs, increasing the rate of emission of CO_2 and CH_4. The carbon released from such sources was not estimated in the present study but it is potentially large enough to affect the atmosphere significantly.

The reproductive success of trees would be reduced by a warming and would be conspiuous first along the warmer and drier limits of the range of the species. A 1 °C warming in a century would produce measurable effects. There is no threshold below which effects do not occur.

Populations of trees and other plants will suffer increased mortality in response to a climatic warming. Effects will be most conspicuous at the warmer and drier limits of distribution and on marginal sites. A warming of 1°C per century would produce measurable effects at these sites. Effects would be continuous for a warming.

Populations of climax trees of major vegetation types commonly migrate at rates of 25-50 km per century. Successional species such as poplar (populus spp.) and birch (Betula spp.) often have lighter seeds that move more readily.

The normal lifespan of forest trees in unmanaged temperate zone forests is more than 100 years.

The effects of pollution on forests were not considered but they can be expected to make the effects of climatic changes more severe.

APPENDIX 7

Background Papers prepared for the Villach Workshop

1. Transient Climate Response to a CO_2 Increase. L.D.D. Harvey, University of Toronto, Canada.

2. Uncertainties of Estimates of Climatic Change. R.E. Dickinson, National Center for Atmospheric Research, Boulder, Colorado, U.S.A.

3. Emissions Reduction and Control. J. Laurmann, Gas Research Institute, Chicago, U.S.A.

4. Greenhouse Warming and Changes in Sea-Level. J. Oerlemans, University of Utrecht, Netherlands.

5. Lags in Vegetation Response to Climatic Change. M.B. Davis, University of Minnesota, U.S.A.

6. The Ecology of Agriculture, Environment and Economy. D.J. Dudek, Environmental Defense Fund, New York, U.S.A.

7. The Biogeochemistry of the Sea and the Impact of CO_2. E.T. Degens, University of Hamburg, F.R. Germany.

8. Climate Change and Environmental Pollution: Physical and Biological Interactions. M. Oppenheimer, Environmental Defense Fund, New York, U.S.A.

9. Sea-level Rise, Consequences and Policies. P. Vellinga, Delft Hydraulics, The Netherlands.

10. Adapting Resources Management to Global Climate Change. P.Williams, San Fransiscc, U.S.A.

11. Can Market Mechanisms Ameliorate the Effects of Long-Term Climatic Change ? C. Weiss, Maryland, U.S.A.

12. Climate Change, Intergenerational Equity and International Law. E. Brown-Weiss, Georgetown University, U.S.A.

13. Effects of Climatic Changes on Agriculture - And possible responses. M.L. Parry, University of Birmingham, U.K.

14. The Implications of Global Climatic Changes for International Security. P.H. Gleick, University of California, U.S.A.