INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

IPCC FIRST ASSESSMENT REPORT

Volume I:

Overview

WGI Policymakers Summary

WGII Policymakers Summary

WGIII Policymakers Summary

Policymakers Summary of the Special Committee on the Participation of Developing Countries

August 1990

External Affairs and
International Trade Canada

Canada

WMO

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NOTE TO THE READER

THE FIRST ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

The IPCC First Assessment Report consists of

* the Overview
* the policymakers summaries of the IPCC Working Groups and Special Committee on the Participation of Developing Countries
* the reports of the IPCC Working Groups.

This volume contains the IPCC Overview and the policymakers summaries.

The report of Working Group I has already been published commercially; there are plans to publish the other two reports also, each separately, by the end of the year. They are available, on request, from the IPCC Secretariat, World Meteorological Organization, P.O.Box 2300, CH 1211 Geneva 2, Switzerland.

N. Sundararaman
IPCC Secretary
October 1990

WMO

UNEP

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

IPCC FIRST ASSESSMENT REPORT

OVERVIEW

31 AUGUST 1990

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PREFACE

TO THE IPCC OVERVIEW

The IPCC First Assessment Report consists of

* this IPCC Overview,
* the Policymakers Summaries of the three IPCC Working Groups (concerned with assessment respectively of the science, impacts and response strategies) and the IPCC Special Committee on the Participation of Developing Countries, and
* the three reports of the Working Groups.

The Overview brings together material from the four Policymakers Summaries. It presents conclusions, proposes lines of possible action (including suggestions as to the factors which might form the basis for negotiations) and outlines further work which is required for a more complete understanding of the problems of climate change resulting from human activities.

Because the Overview cannot reflect all aspects of the problem which are presented in the three full reports of the Working Groups and the four Policymakers Summaries, it should be read in conjunction with them.

The issues, options and strategies presented in the Report are intended to assist policymakers and future negotiators in their respective tasks. Further consideration of the Report should be given by every government as it cuts across different sectors in all countries. It should be noted that the Report reflects the technical assessment of experts rather than government positions, particularly those governments that could not participate in all Working Groups of IPCC.

This Overview reflects the conclusions of the reports of (i) the three IPCC Working Groups on science, impacts, and response strategies, and (ii) the Policymakers Summaries of the IPCC Working Groups and the IPCC Special Committee on the Participation of Developing Countries.

1. SCIENCE

This section is structured similarly to the Policymakers Summary of Working Group I.

We are certain of the following:

* There is a natural greenhouse effect which already keeps the Earth warmer than it would otherwise be.

* Emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface. The main greenhouse gas, water vapour, will increase in response to global warming and further enhance it.

We calculate with confidence that:

* Some gases are potentially more effective than others at changing climate, and their relative effectiveness can be estimated. Carbon dioxide has been responsible for over half of the enhanced greenhouse effect in the past, and is likely to remain so in the future.

* Atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide and the CFCs) adjust only slowly to changes of emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for centuries ahead. The longer emissions continue to increase at present-day rates, the greater reductions would have to be for concentrations to stabilize at a given level.

* For the four scenarios of future emissions which IPCC has developed as assumptions (ranging from one where few or no steps are taken to limit emissions, viz., Scenario A or Business as Usual Scenario, through others with increasing levels of controls respectively called Scenarios B, C and D), there will be a doubling of equivalent carbon dioxide concentrations from pre-industrial levels by about 2025, 2040 and 2050 in Scenarios A, B, and C respectively (see the section "Which gases are the most important?" in the Policymakers Summary of Working Group I for a description of the concept of equivalent carbon dioxide). See the Appendix for a description of the IPCC emissions scenarios.

* Stabilization of equivalent carbon dioxide concentrations at about twice the pre-industrial level would occur under Scenario D towards the end of the next century. Immediate reductions of over 60% in the net (sources minus sinks) emissions from human activities of long-lived gases would achieve stabilization of concentration at today's levels; methane concentrations would be stabilized with a 15-20% reduction.

* The human-caused emissions of carbon dioxide are much smaller than the natural exchange rates of carbon dioxide between the atmosphere and the oceans, and between the atmosphere and the

terrestrial system. The natural exchange rates were, however, in close balance before human-induced emissions began; the steady anthropogenic emissions into the atmosphere represent a significant disturbance of the natural carbon cycle.

Based on current model results, we predict:

* An average rate of increase of global mean temperature during the next century of about 0.3°C per decade (with an uncertainty range of 0.2 - 0.5°C per decade) assuming the IPCC Scenario A (Business as Usual) emissions of greenhouse gases; this is a more rapid increase than seen over the past 10,000 years. This will result in a likely increase in the global mean temperature of about 1°C above the present value by 2025 (about 2°C above that in the pre-industrial period), and 3°C above today's value before the end of the next century (about 4°C above pre-industrial). The rise will not be steady because of other factors.

* Under the other IPCC emissions scenarios which assume progressively increasing levels of controls, rates of increase in global mean temperature of about 0.2°C per decade (Scenario B), just above 0.1°C per decade (Scenario C) and about 0.1°C per decade (Scenario D). The rise will not be steady because of other factors.

* Land surfaces warm more rapidly than the oceans, and higher northern latitudes warm more than the global mean in winter.

* The oceans act as a heat sink and thus delay the full effect of a greenhouse warming. Therefore, we would be committed to a further temperature rise which would progressively become apparent in the ensuing decades and centuries. Models predict that as greenhouse gases increase, the realized temperature rise at any given time is between 50 and 80% of the committed temperature rise.

* Under the IPCC Scenario A (Business as Usual) emissions, an average rate of global mean sea-level rise of about 6 cm per decade over the next century (with an uncertainty range of 3 - 10 cm per decade), mainly due to thermal expansion of the oceans and the melting of some land ice. The predicted rise is about 20 cm in global mean sea level by 2030, and 65 cm by the end of the next century. There will be significant regional variations.

With regard to uncertainties, we note that:

* There are many uncertainties in our predictions particularly with regard to the timing, magnitude and regional patterns of climate change, especially changes in precipitation.

  - These uncertainties are due to our incomplete understanding of sources and sinks of greenhouse gases and the responses of clouds, oceans and polar ice sheets to a change of the radiative forcing caused by increasing greenhouse gas concentrations.

  - These processes are already partially understood, and we are confident that the uncertainties can be reduced by further research. However, the complexity of the system means that we cannot rule out surprises.

<u>Our judgement is that</u>:

* Global mean surface air temperature has increased by 0.3 to 0.6°C over the last 100 years, with the five global-average warmest years being in the 1980's. Over the same period global sea-level increased by 10 to 20 cm. These increases have not been smooth in time, nor uniform over the globe.

* The size of the warming over the last century is broadly consistent with the prediction by climate models, but is also of the same magnitude as natural climate variability. If the sole cause of the observed warming were the human-made greenhouse effect, then the implied climate sensitivity would be near the lower end of the range inferred from models. Thus the observed increase could be largely due to this natural variability; alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.

* Measurements from ice cores going back 160,000 years show that the Earth's temperature closely paralleled the amount of carbon dioxide and methane in the atmosphere. Although we do not know the details of cause and effect, calculations indicate that changes in these greenhouse gases were part, but not all, of the reasons for the large (5-7°C) global temperature swings between ice ages and interglacial periods.

* Natural sources and sinks of greenhouse gases are sensitive to a change in climate. Although many of the response (feedback) processes are poorly understood, it appears that, as climate warms, these feedbacks will lead to an overall increase, rather than a decrease, in natural greenhouse gas abundances. For this reason, climate change is likely to be greater than the estimates given above.

2. IMPACTS

The report on impacts of Working Group II is based on the work of a number of subgroups, using independent studies which have used different methodologies. Based on the existing literature, the studies have used several scenarios to assess the potential impacts of climate change. These have the features of:

i) an effective doubling of CO_2 in the atmosphere between now and 2025 to 2050;

ii) a consequent increase of global mean temperature in the range of 1.5°C to 4° - 5°C;

iii) an unequal global distribution of this temperature increase, namely a smaller increase of half the global mean in the tropical regions and a larger increase of twice the global mean in the polar regions; and

iv) a sea-level rise of about 0.3 - 0.5 m by 2050 and about 1 m by 2100, together with a rise in the temperature of the surface ocean layer of between 0.2° and 2.5°C.

These scenarios pre-date, but are in line with, the assessment of Working Group I which, for Scenario

A (Business as Usual) has estimated the magnitude of sea-level rise at about 20 cm by 2030 and about 65 cm by the end of the next century. Working Group I has also predicted the increase in global mean temperatures to be about 1°C above the present value by 2025 and 3°C before the end of the next century.

Any predicted effects of climate change must be viewed in the context of our present dynamic and changing world. Large-scale natural events such as El Niño can cause significant impacts on agriculture and human settlement. The predicted population explosion will produce severe impacts on land use and on the demands for energy, fresh water, food and housing, which will vary from region to region according to national incomes and rates of development. In many cases, the impacts will be felt most severely in regions already under stress, mainly the developing countries. Human-induced climate change due to continued uncontrolled emissions will accentuate these impacts. For instance, climate change, pollution and ultraviolet-B radiation from ozone depletion can interact, reinforcing their damaging effects on materials and organisms. Increases in atmospheric concentrations of greenhouse gases may lead to irreversible change in the climate which could be detectable by the end of this century.

Comprehensive estimates of the physical and biological effects of climate change at the regional level are difficult. Confidence in regional estimates of critical climatic factors is low. This is particularly true of precipitation and soil moisture, where there is considerable disagreement between various general circulation model and palaeoanalog results. Moreover, there are several scientific uncertainties regarding the relationship between climate change and biological effects and between these effects and socioeconomic consequences.

This impact study part of the Overview does not attempt to anticipate any adaptation, technological innovation or any other measures to diminish the adverse effects of climate change that will take place in the same time frame. This is especially important for heavily managed sectors, e.g., agriculture, forestry and public health.

Finally, the issue of timing and rates of change need to be considered; there will be lags between:

i) emissions of greenhouse gases and doubling of concentrations;

ii) doubling of greenhouse gas concentrations and change in climate;

iii) changes in climate and resultant physical and biological effects; and

iv) changes in physical and ecological effects and resultant socioeconomic (including ecological) consequences. The shorter the lags, the less the ability to cope and the greater the socioeconomic impacts.

There is uncertainty related to these time lags. The changes will not be steady and surprises cannot be ruled out. The severity of the impacts will depend to a large degree on the rate of climate change.

Despite these uncertainties, Working Group II has been able to reach some major conclusions. These are presented below.

2.1 Agriculture and forestry

Sufficient evidence is now available from a variety of different studies to indicate that changes of climate would have an important effect on agriculture and livestock. Studies have not yet conclusively determined whether, on average, global agricultural potential will increase or decrease. Negative impacts could be felt at the regional level as a result of changes in weather and pests associated with climate change, and changes in ground-level ozone associated with pollutants, necessitating innovations in technology and agricultural management practices. There may be severe effects in some regions, particularly decline in production in regions of high present-day vulnerability that are least able to adjust. These include Brazil, Peru, the Sahel Region of Africa, Southeast Asia, and the Asian region of the USSR and China. There is a possibility that potential productivity of high and mid latitudes may increase because of a prolonged growing season, but it is not likely to open up large new areas for production and it will be mainly confined to the Northern Hemisphere.

Patterns of agricultural trade could be altered by decreased cereal production in some of the currently high-production areas, such as western Europe, southern USA, parts of South America and western Australia. Horticultural production in mid-latitude regions may be reduced. On the other hand, cereal production could increase in northern Europe. Policy responses directed to breeding new plant cultivars, and agricultural management designed to cope with changed climate conditions, could lessen the severity of regional impacts. On the balance, the evidence suggests that in the face of estimated changes of climate, food production at the global level can be maintained at essentially the same level as would have occurred without climate change; however, the cost of achieving this is unclear. Nonetheless, climate change may intensify difficulties in coping with rapid population growth. An increase or change in UV-B radiation at ground level resulting from the depletion of stratospheric ozone will have a negative impact on crops and livestock.

The rotation period of forests is long and current forests will mature and decline during a climate in which they are increasingly more poorly adapted. Actual impacts depend on the physiological adaptability of trees and the host-parasite relationship. Large losses from both factors in the form of forest declines can occur. Losses from wildfire will be increasingly extensive. The climate zones which control species distribution will move poleward and to higher elevations. Managed forests require large inputs in terms of choice of seedlot and spacing, thinning and protection. They provide a variety of products from fuel to food.

The degree of dependency on products varies among countries, as does the ability to cope with and to withstand loss. The most sensitive areas will be where species are close to their biological limits in terms of temperature and moisture. This is likely to be, for example, in semi-arid areas. Social stresses can be expected to increase and consequent anthropogenic damage to forests may occur. These increased and non-sustainable uses will place more pressure on forest investments, forest conservation and sound forest management.

2.2 Natural terrestrial ecosystems

Natural terrestrial ecosystems could face significant consequences as a result of the global increases in the atmospheric concentrations of greenhouse gases and the associated climatic changes. Projected changes in temperature and precipitation suggest that climatic zones could shift several hundred kilometres towards the poles over the next fifty years. Flora and fauna would lag behind these climatic shifts, surviving in their present location and, therefore, could find themselves in a different climatic regime. These regimes may be more or less hospitable and, therefore, could increase productivity for some species and decrease that of others. Ecosystems are not expected to move as a single unit, but would have a new structure as a consequence of alterations in distribution and abundance of species.

The rate of projected climate changes is the major factor determining the type and degree of climatic impacts on natural terrestrial ecosystems. These rates are likely to be faster than the ability of some species to respond and responses may be sudden or gradual.

Some species could be lost owing to increased stress leading to a reduction of global biological diversity. Increased incidence of disturbances such as pest outbreaks and fire are likely to occur in some areas and these could enhance projected ecosystem changes.

Consequences of CO_2 enrichment and climate change for natural terrestrial ecosystems could be modified by other environmental factors, both natural and man-induced (e.g. by air pollution).

Most at risk are those communities in which the options for adaptability are limited (e.g. montane, alpine, polar, island and coastal communities, remnant vegetation, and heritage sites and reserves) and those communities where climatic changes add to existing stresses. The socioeconomic consequences of these impacts will be significant, especially for those regions of the globe where societies and related economies are dependent on natural terrestrial ecosystems for their welfare. Changes in the availability of food, fuel, medicine, construction material and income are possible as these ecosystems are changed. Important fibre products could also be affected in some regions.

2.3 Hydrology and water resources

Relatively small climate changes can cause large water resource problems in many areas, especially arid and semi-arid regions and those humid areas where demand or pollution has led to water scarcity. Little is known about regional details of greenhouse-gas-induced hydrometeorological change. It appears that many areas will have increased precipitation, soil moisture and water storage, thus altering patterns of agricultural, ecosystem and other water use. Water availability will decrease in other areas, a most important factor for already marginal situations, such as the Sahelian zone in Africa. This has significant implications for agriculture, for water storage and distribution, and for generation of hydroelectric power. In some limited areas, for example, under an assumed scenario of a 1°C to 2°C temperature increase, coupled with a 10% reduction in precipitation, a 40-70% reduction in annual runoff could occur. Regions such as southern Asia, that are dependent on unregulated river systems, are particularly vulnerable to hydrometeorological change. On the other hand, regions such as the western USSR and western United States that have large regulated water resource systems are less sensitive to the range of hydrometeorological changes in the assumed scenario. In addition to changes in water supply, water demand may also change through human efforts to conserve, and through improved growth efficiency of plants in a higher CO_2 environment. Net socioeconomic consequences must consider both supply and demand for water. Future design in water resource engineering will need to take possible impacts into account when considering structures with a life span to the end of the next century. Where precipitation increases, water management practices, such as urban storm drainage systems, may require upgrading in capacity. Change in drought risk represents potentially the most serious impact of climate change on agriculture at both regional and global levels.

2.4 Human settlements, energy, transport, and industrial sectors, human health and air quality

The most vulnerable human settlements are those especially exposed to natural hazards, e.g. coastal or river flooding, severe drought, landslides, severe wind storms and tropical cyclones. The most vulnerable populations are in developing countries, in the lower-income groups: residents of coastal lowlands and islands, populations in semi-arid grasslands, and the urban poor in squatter settlements, slums and shanty towns, especially in megacities. In coastal lowlands such as in Bangladesh, China and Egypt, as well as in small island nations, inundation due to sea-level rise and storm surges could lead to significant movements of people. Major health impacts are possible, especially in large urban areas, owing to changes in availability of water and food and increased health problems due to heat stress spreading of infections. Changes in precipitation and temperature could radically alter the patterns of vector-borne and viral diseases by shifting them to higher latitudes, thus putting large populations at risk. As similar events have in the past, these changes could initiate large migrations of people, leading over a number of years to severe disruptions of settlement patterns and social instability in some areas.

Global warming can be expected to affect the availability of water resources and biomass, both major sources of energy in many developing countries. These effects are likely to differ between and within regions with some areas losing and others gaining water and biomass. Such changes in areas which lose water may jeopardize energy supply and materials essential for human habitation and energy. Moreover, climate change itself is also likely to have different effects between regions on the availability of other forms of renewable energy such as wind and solar power. In developed countries some of the greatest impacts on the energy, transport and industrial sectors may be determined by policy responses to climate change such as fuel regulations, emission fees or policies promoting greater use of mass transit. In developing countries, climate-related changes in the availability and price of production resources such as energy, water, food and fibre may affect the competitive position of many industries.

Global warming and increased ultraviolet radiation resulting from depletion of stratospheric ozone may produce adverse impacts on air quality such as increases in ground-level ozone in some polluted urban areas. An increase of ultraviolet-B radiation intensity at the Earth's surface would increase the risk of damage to the eye and skin and may disrupt the marine food chain.

2.5 Oceans and coastal zones

Global warming will accelerate sea-level rise, modify ocean circulation and change marine ecosystems, with considerable socioeconomic consequences. These effects will be added to present trends of rising sea-level, and other effects that have already stressed coastal resources, such as pollution and over-harvesting. A 30-50 cm sea-level rise (projected by 2050) will threaten low islands and coastal zones. A 1 m rise by 2100 would render some island countries uninhabitable, displace tens of millions of people, seriously threaten low-lying urban areas, flood productive land, contaminate fresh water supplies and change coastlines. All of these impacts would be exacerbated if droughts and storms become more severe. Coastal protection would involve very significant costs. Rapid sea-level rise would change coastal ecology and threaten many important fisheries. Reductions in sea ice will benefit shipping, but seriously impact on ice-dependent marine mammals and birds.

Impacts on the global oceans will include changes in the heat balance, shifts in ocean circulation which will affect the capacity of the ocean to absorb heat and CO_2 and changes in upwelling zones associated with fisheries. Effects will vary by geographic zones, with changes in habitats, a decrease in biological diversity and shifts in marine organisms and productive zones, including commercially important species. Such regional shifts in fisheries will have major socioeconomic impacts.

2.6 Seasonal snow cover, ice and permafrost

The global areal extent and volume of elements of the terrestrial cryosphere (seasonal snow cover, near-surface layers of permafrost and some masses of ice) will be substantially reduced. These reductions, when reflected regionally could have significant impacts on related ecosystems and social and economic activities. Compounding these impacts in some regions is that, as a result of the associated climatic warming positive feedbacks, the reductions could be sudden rather than gradual.

The areal coverage of seasonal snow and its duration are projected to decrease in most regions, particularly at mid latitudes, with some regions at high latitudes possibly experiencing increases in seasonal snow cover. Changes in the volume of snow cover, or the length of the snow cover season, will have both positive and negative impacts on regional water resources (as a result of changes in the volume and the timing of runoff from snowmelt), on regional transportation (road, marine, air and rail), and on recreation sectors.

Globally, the ice contained in glaciers and ice sheets is projected to decrease, with regional responses complicated by the effect of increased snowfall in some areas which could lead to accumulation of ice. Glacial recession will have significant implications for local and regional water resources, and thus impact on water availability and on hydroelectric power potential. Glacial recession and loss of ice from ice sheets will also contribute to sea-level rise. Permafrost, which currently underlies 20-25% of the land mass of the Northern Hemisphere, could experience significant degradation within the next 40-50 years. Projected increases in the thickness of the freeze-thaw (active) layer above the permafrost and a recession of permafrost to higher latitudes and altitudes could lead to increases in terrain instability, erosion and landslides in those areas which currently contain permafrost. As a result, overlying ecosystems could be significantly altered and the integrity of man-made structures and facilities reduced, thereby influencing existing human settlements and development opportunities.

3. RESPONSE STRATEGIES

The consideration of climate change response strategies presents formidable difficulties for policymakers. The information available to make sound policy analyses is inadequate because of:

(a) uncertainty with respect to how effective specific response options or groups of options would be in actually averting potential climate change;

(b) uncertainty with respect to the costs, effects on economic growth, and other economic and social implications of specific response options or groups of options.

The IPCC recommends a programme for the development and implementation of global, comprehensive and phased action for the resolution of the global warming problem under a flexible and progressive approach.

* A major dilemma of the issue of climate change due to increasing emission of greenhouse gases in the atmosphere is that actions may be required well before many of the specific issues that are and will be raised can be analyzed more thoroughly by further research.

* The CFCs are being phased out to protect the stratospheric ozone layer. This action will also effectively slow down the rate of increase of radiative forcing of greenhouse gases in the atmosphere. Every effort should be made to find replacements that have little or no greenhouse warming potential or ozone depletion potential rather than the HCFCs and HFCs that are now being considered.

* The single largest anthropogenic source of radiative forcing is energy production and use. The energy sector accounts for an estimated 46% (with an uncertainty range of 38-54%) of the enhanced radiative forcing resulting from human activities.

* It is noted that emissions due to fossil fuel combustion amounts to about 70-90% of the total anthropogenic emissions of CO_2 into the atmosphere, whereas the remaining 10-30% is due to human use of terrestrial ecosystems. A major decrease of the rate of deforestation as well as an increase in afforestation would contribute significantly to slowing the rate of CO_2 concentrations increase in the atmosphere; but it would be well below that required to stop it. This underlines that when forestry measures have been introduced, other measures to limit or reduce greenhouse emissions should not be neglected.

3.1 Roles of industrialized and developing countries

* Industrialized and developing countries have a common but varied responsibility in dealing with the problem of climate change and its adverse effects. The former should take the lead in two ways:

i) A major part of emissions affecting the atmosphere at present originates in industrialized countries where the scope for change is greatest. Industrialized countries should adopt domestic measures to limit climate change by adapting their own economies in line with future agreements to limit emissions.

ii) To co-operate with developing countries in international action, without standing in the way of the latter's development by contributing additional financial resources, by appropriate transfer of technology, by engaging in close co-operation in scientific observation, analysis and research, and finally by means of technical co-operation geared to forestalling and managing environmental problems.

* Sustainable development[1] in industrialized as well as developing countries requires proper concern for environmental protection as the basis for continued economic growth. Environmental considerations must be systematically integrated into all plans for development. The right balance must be struck between economic growth and environmental objectives.

* Emissions from developing countries are growing in order to meet their development requirements and thus, over time, are likely to represent an increasingly significant percentage of global emissions. As the greenhouse gas emissions in developing countries are increasing with their population and economic growth, rapid transfer, on a preferential basis, to developing countries, of technologies which help to monitor, limit or adapt to climate change, without hindering their economic development, is an urgent requirement. Developing countries should, within the limits feasible, take measures to suitably adapt their economies. Recognizing the poverty that prevails among the populations of developing countries, it is natural that achieving economic growth is given priority by them. Narrowing the gap between the industrialized and developing world would provide a basis for a full partnership of all nations in the world and would assist developing countries in dealing with the climate change issue.

1. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs and does not imply in any way encroachment upon national sovereignty. (Annex II to decision 15/2 of the 15th session of the UNEP Governing Council, Nairobi, May 1989)

3.2 <u>Options</u>

* The climate scenario studies of Working Groups I and III outline control policies on emissions that would slow global warming from the presently predicted value of about 0.3°C per decade to about 0.1°C per decade (see Appendix).

* The potentially serious consequences of climate change give sufficient reasons to begin adopting response strategies that can be justified immediately even in the face of significant uncertainties. The response strategies include:

o phasing out of CFC emissions and careful assessment of the greenhouse gas potential of proposed substitutes;

- o efficiency improvements and conservation in energy supply, conversion and end use, in particular through improving diffusion of energy-efficient technologies, improving the efficiency of mass-produced goods, reviewing energy-related price and tariff systems to better reflect environmental costs;

- o sustainable forest management and afforestation;

- o use of cleaner, more efficient energy sources with lower or no emissions of greenhouse gases;

- o review of agriculture practices.

* There is no single quick-fix technological option for limiting greenhouse gas emissions. Phased and flexible response strategies should be designed to enhance relevant technological research, development and deployment, including improvement and reassessment of existing technologies. Such strategies should involve opportunities for international co-operation. A comprehensive strategy addressing all aspects of the problem and reflecting environmental, economic and social costs and benefits is necessary.

* Because a large, projected increase in world population will be a major factor in causing the projected increase in global greenhouse gases, it is essential that global climate change strategies take into account the need to deal with the issue of the rate of growth of the world population.

* Subject to their particular circumstances, individual nations, or groups of nations, may wish to consider taking steps now to attempt to limit, stabilize or reduce the emission of greenhouse gases resulting from human activities and prevent the destruction and improve the effectiveness of sinks. One option that governments may wish to consider is the setting of targets for CO_2 and other greenhouse gases.

* A large number of options were preliminarily assessed by IPCC Working Group III. It appears that some of these options may be economically and socially feasible for implementation in the near-term while others, because they are not yet technically or economically viable, may be more appropriate for implementation in the longer term. In general, the Working Group found that the most effective response strategies, especially in the short term, are those which are:

- o beneficial for reasons other than climate change and justifiable in their own right, for example increased energy efficiency and lower greenhouse gas emission technologies, better management of forests, and other natural resources, and reductions in emissions of CFCs and other ozone depleting substances that are also radiatively important gases;

- o economically efficient and cost effective, in particular those that use market-based mechanisms;

- o able to serve multiple social, economic and environmental purposes;

- flexible and phased, so that they can be easily modified to respond to increased understanding of scientific, technological and economic aspects of climate change;

- compatible with economic growth and the concept of sustainable development;

- administratively practical and effective in terms of application, monitoring and enforcement;

- reflecting obligations of both industrialized and developing countries in addressing this issue, while recognizing the special needs of developing countries, in particular in the areas of financing and technology.

The degree to which options are viable will also vary considerably depending on the region or country involved. For each country, the implications of specific options will depend on its social, environmental and economic context. Only through careful analysis of all available options will it be possible to determine which are best suited to the circumstances of a particular country or region. Initially, the highest priority should be to review existing policies with a view to minimizing conflicts with the goals of climate change strategies. New policies will be required.

* In the long-term perspective, work should begin on defining criteria for selection of appropriate options which would reflect the impacts of climate change and its costs and benefits on the one hand, and social and economic costs and benefits of the options on the other.

* Consideration of measures for reducing the impacts of global climate change should begin as soon as possible, particularly with regard to disaster preparedness policies, coastal zone management and control measures for desertification, many of these being justified in their own right. Measures to limit or adapt to climate change should be as cost-effective as possible while taking into account important social implications. Limitation and adaptation should be considered as an integrated package.

* Assessing areas at risk from sea-level rise and developing comprehensive management plans to reduce future vulnerability of populations and coastal developments and ecosystems as part of coastal zone management plans should begin as soon as possible.

* Environmental objectives can be pursued through regulations and/or through market based economic instruments. The latter, through their encouragement of flexible selection of abatement measures, tend to encourage innovation and the development of improved technologies and practices for reducing emissions and therefore frequently offer the possibility of achieving environmental improvements at lower costs than through regulatory mechanisms. It is not likely, however, that economic instruments will be applicable to all circumstances.

* Three factors are considered as potential barriers to the operation of markets and/or the achievement of environmental objectives through

market mechanisms. These are:

i) information problems, which can often cause markets to produce less effective or unfavourable environmental outcomes;

ii) existing measures and institutions, which can encourage individuals to behave in environmentally damaging ways; and

iii) balancing competing objectives (social, environmental and economic).

An initial response strategy may therefore be to address information problems directly and to review existing measures which may be barriers. For example, prior to possible adoption of a system of emission charges, countries should examine existing subsidies and tax incentives on energy and other relevant greenhouse gas producing sectors.

* With respect to institutional mechanisms for providing financial co-operation and assistance to developing countries, a two track approach was considered:

i) one track built on work underway or planned in existing institutions. Bilateral donors could further integrate and reinforce the environmental components of their assistance programmes and develop cofinancing arrangements with multilateral institutions while ensuring that this does not impose inappropriate environmental conditions.

ii) parallel to this track the possibility of new mechanisms and facilities was considered. Some developing and industrialized countries suggested that new mechanisms directly related to a future climate convention and protocols that might be agreed upon, such as a new international fund, were required.

* Governments should undertake now:

o accelerated and co-ordinated research programmes to reduce scientific and socioeconomic uncertainties with a view towards improving the basis for response strategies and measures;

o review of planning in the fields of energy, industry, transportation, urban areas, coastal zones and resource use and management;

o encouragement of beneficial behavioral and structural (e.g. transportation and housing infrastructure) changes;

o expansion of the global ocean observing and monitoring systems.

It should be noted that no detailed assessments have been made as of yet of the economic costs and benefits, technological feasibility or market potential of the underlying policy assumptions.

4. PARTICIPATION OF DEVELOPING COUNTRIES

It is obvious that the impact on and the participation by the developing countries in the further development of a future strategy is essential. The IPCC has attempted to address this specific issue by establishing a Special Committee on the Participation of Developing Countries and requested it to identify factors inhibiting the full participation of the developing countries in IPCC and recommend remedial measures where possible. The Committee stressed that full participation includes not only the physical presence at meetings but also the development of national competence to address all issues of concern such as the appreciation of the scientific basis of climate change, the potential impacts on society of such change and evaluations of practical response strategies for national/regional applications.

The factors that kept developing countries from fully participating were identified by the Special Committee as:

- o insufficient information;
- o insufficient communication;
- o limited human resources;
- o institutional difficulties;
- o limited financial resources.

On some of these factors, the IPCC Working Groups have developed policy options which are to be found in their respective reports.

* Developing countries will, in some cases, need additional financial resources for supporting their efforts to promote activities which contribute both to limiting greenhouse gas emissions and/or adapting to the adverse effects of climate change, while at the same time promote economic development. Areas of co-operation could include, inter alia:

- o efficient use of energy resources, the use of fossil fuels with lower greenhouse gas emission rates or non-fossil sources, the development of clean and renewable energy sources, such as: biomass, windpower, wave-power, hydroelectric and solar, wherever applicable;

- o increased rational utilization of forest products, sound forest management practices and agricultural techniques which reduce the negative effects on climate;

- o facilitating the development and transfer of clean and safe technologies in areas which could include:

  - the building and manufacturing industries;
  - public transport systems;
  - industry;

- o measures which enhance the capacity of developing countries to develop programmes to address climate change, including research and development activities and public awareness and education programmes, such as:

  - the development of the human resources necessary to tackle the problem of climate change and its adverse effects;

  - the provision of study and training programmes in subjects and techniques related to climate change;

  - the provision of skilled personnel and the material necessary to organize education programmes to develop locally the skills necessary to assess climate change and combat its adverse effects;

- the development of climate-related research programmes organized on a regional basis;

o facilitating the participation of developing countries in fora and organizations such as: the International Geosphere-Biosphere Programme, the Land-Ocean Inter-actions in the Coastal Zone, the Biosphere Aspects of the Hydrological Cycle, the Global Change Impact on Agriculture and Society, the World Climate Programm-e, the Man and the Biosphere Programme;

o facilitating participation by developing countries in international fora on global climate change such as the IPCC;

o strengthening existing education and research institutions and the development of new ones at national and regional levels.

* Further, co-operation and assistance for adaptive measures would be required, noting that for some regions and countries, adaptation rather than limitation activities are potentially most important.

* The IPCC concludes that the recommendations of the Special Committee need not and should not await the outcome of future negotiations on a climate convention. It appeals to the multilateral and bilateral funding organizations to implement its recommendations. It further appeals to governments for continuing and increased contributions to the IPCC Trust Fund on an urgent basis.

5. INTERNATIONAL CO-OPERATION AND FUTURE WORK

* The measures noted above require a high degree of interna-tional co-operation with due respect for national sovereignty of states. The international negotiations on a framework convention should start as quickly as possible after presentation of this Report in line with Resolution SS II/3 Climate.C. (August 1990) of the UNEP Governing Council and Resolution 8 (EC-XLII, June 1990) of the WMO Executive Council. Many, essentially develop-ing, countries stressed that the negotiations must be conducted in the forum, manner and with the timing to be decided by the UN General Assembly.

This convention, and any additional protocols that might be agreed upon, would provide a firm basis for effective co-operation to act on greenhouse gas emissions and adapt to any adverse effects of climate change. The convention should recognize climate change as a common concern of mankind and, at a minimum, contain general principles and obligations. It should be framed in such a way as to gain the adherence of the largest possible number and most suitably balanced range of countries while permitting timely action to be taken.

Key issues for negotiations will include the criteria, timing, legal form and incidence of any obligations to control the net emissions of greenhouse gases, how to address equitably the consequences for all, any institutional mechanisms including research and monitoring that may be required, and in particular, the requests of the developing countries for additional financial resources and for the transfer of technology on a preferential basis. The possible elements of a framework convention on climate change were identified and discussed by Working Group III in its legal measures topic paper, appended to its Policymakers Summary.

* The IPCC recommends that research regarding the science of climate change in general, technological development and the international economic implications, be intensified.

* Because climate change would affect, either directly or indirectly, almost every sector of society, broad global understanding of the issue will facilitate the adoption and the implementation of such response options as deemed necessary and appropriate. Further efforts to achieve such global understanding are urgently needed.

APPENDIX

Emissions scenarios developed by IPCC

The IPCC used two methods to develop scenarios of future emissions:

* One method used global models to develop four scenarios which were subsequently used by Working Group I to develop scenarios of future warming. All of these four scenarios assumed the same global economic growth rates taken from the World Bank projections and the same population growth estimates taken from the United Nations studies. The anthropogenic emissions of carbon dioxide and methane from these scenarios are shown in Figures 1 and 2 below.

* The second method used studies of the energy and agriculture sectors submitted by over 21 countries and international organizations to estimate CO_2 emissions.

Both scenario approaches indicate that CO_2 emissions will grow from about 7 BtC (billion or 1000 million tonnes carbon) per year now to 12-15 BtC per year by the year 2025. Scenario A (Business as Usual) includes a partial phase-out of CFCs under the Montreal Protocol and lower CO_2 and CH_4 emissions than the Reference Scenario. The Reference Scenario developed through country and international studies of the energy and agriculture groups, includes higher CO_2 emissions and assumed a total CFC phase-out. The results indicate that the CO_2 equivalent concentrations and their effects on global climate are similar.

Figure 1. Projected Man-Made CO_2 Emissions
(Billion or 1000 million tonnes carbon per year)

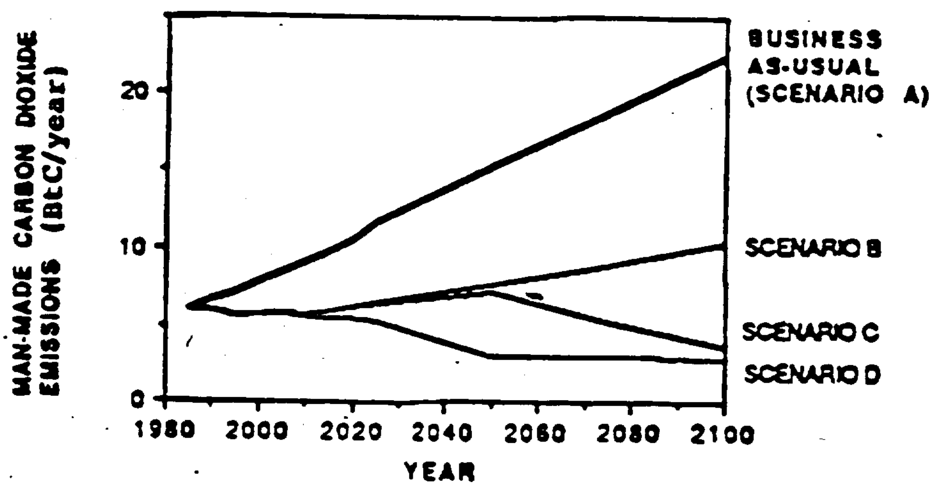
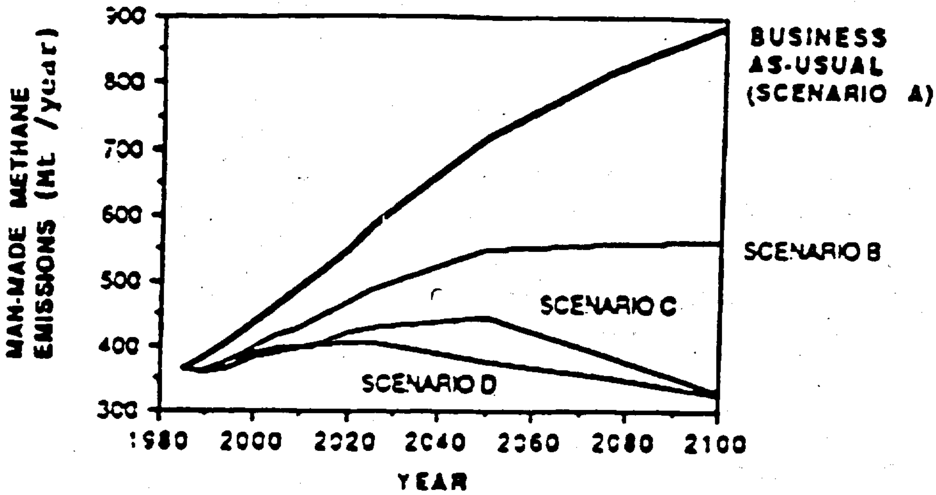


Figure 2. Projected Man-Made Methane Emissions
(Million tonnes per year)



Method 1[2]

Scenario A (Business as Usual) assumes that few or no steps are taken to limit greenhouse gas emissions. Energy use and clearing of tropical forests continue and fossil fuels, in particular coal, remain the world's primary energy source. The Montreal Protocol comes into effect but without strengthening and with less than 100 percent compliance. Under this scenario, the equivalent of a doubling of pre-industrial CO_2 levels occurs, according to Working Group I, by around 2025.

Scenario B (Low Emissions Scenario) assumes that the energy supply mix of fossil fuels shifts towards natural gas, large efficiency increases

[2] All of the scenarios assumed some level of compliance with the Montreal Protocol but not with all of the (June 1990) amendments agreed to in London. The London amendments to the Montreal Protocol, when fully implemented, would result in a virtually complete elimination of production of fully halogenated CFCs, halons, carbon tetrachloride and methyl chloroform early in the 21st century. The Parties of the Protocol also call for later elimination of HCFCs. Thus, the assumptions of Scenarios A and B overestimate the radiative forcing potential of CFCs and halons. Additionally, the UN has provided recent population projections that estimate higher population than used in the global model scenarios (Scenarios A through D); use of these newer projections would increase future CO_2 emissions. Additionally, the Reference Scenario CO_2 emissions are higher than Scenario A (Business as Usual), suggesting Scenario A (Business as Usual) may be an underestimate.

are achieved, deforestation is reversed and emissions of CFCs are reduced by 50% from their 1986 levels. This results in an equivalent doubling of pre-industrial carbon dioxide by about 2040.

Scenario C (Control Policies Scenario) assumes that a shift towards renewable energies and safe nuclear energy takes place in the latter part of the next century, CFC gases are phased out and agricultural emissions (methane and nitrous oxide) are limited; an equivalent doubling of pre-industrial carbon dioxide will occur in about 2050.

Scenario D (Accelerated Policies Scenario) assumes that a rapid shift to renewable energies and safe nuclear energy takes place early in the next century, stringent emission controls in industrial countries and moderate growth of emissions in developing countries. This scenario, which assumes carbon dioxide emissions are reduced to 50% of 1985 levels, stabilizes equivalent carbon dioxide concentrations at about twice the pre-industrial levels towards the end of the next century.

Method 2 (see footnote 2 on previous page)

Using the second method, the so-called Reference Scenario was developed by the Energy and Industry Subgroup and Agriculture and Forestry Subgroup of Working Group III. Under the Reference Scenario, global CO_2 emissions from all sectors grow from approximately 7.0 BtC (per year) in 1985 to over 15 BtC (per year) in 2025. The energy contribution grows from about 5 BtC (per year) to over 12 BtC (per year). Primary energy demand more than doubles between 1985 and 2025 with an average growth rate of 2.1%. The per capita energy emissions in the industrialized countries increase from 3.1 tonnes carbon (TC) in 1985 to 4.7 TC in 2025; for the developing countries, they rise from 0.4 TC in 1985 to 0.8 TC in 2025.

Summary

All of the above scenarios provide a conceptual basis for considering possible future patterns of emissions and the broad responses that might affect those patterns. No full assessment was made of the total economic costs and benefits, technological feasibility, or market potential of the underlying policy assumptions. Because of the inherent limitations in our ability to estimate future rates of population and economic growth, individual behaviour, technological innovation, and other factors which are crucial for determining emission rates over the course of the next century, there is some uncertainty in the projections of greenhouse gas emissions. Reflecting these inherent difficulties, the IPCC's work on emissions scenarios are the best estimates at this time covering emissions over the next century, but continued work to develop improved assumptions and methods for scenario estimates will be useful to guide the development of response strategies.

WMO

UNEP

INTERGOVERNMENTAL PANEL ON
CLIMATE CHANGE

POLICYMAKERS SUMMARY

OF THE

SCIENTIFIC ASSESSMENT OF
CLIMATE CHANGE

Report Prepared for IPCC
by Working Group I

June 1990

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EXECUTIVE SUMMARY

We are certain of the following:

- there is a natural greenhouse effect which already keeps the Earth warmer than it would otherwise be.

- emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface. The main greenhouse gas, water vapour, will increase in response to global warming and further enhance it.

We calculate with confidence that:

- some gases are potentially more effective than others at changing climate, and their relative effectiveness can be estimated. Carbon dioxide has been responsible for over half the enhanced greenhouse effect in the past, and is likely to remain so in the future.

- atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide and the CFCs) adjust only slowly to changes in emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for centuries ahead. The longer emissions continue to increase at present day rates, the greater reductions would have to be for concentrations to stabilise at a given level.

- the long-lived gases would require immediate reductions in emissions from human activities of over 60% to stabilise their concentrations at today's levels; methane would require a 15-20% reduction.

Based on current model results, we predict:

- under the IPCC Business-as-Usual (Scenario A) emissions of greenhouse gases, a rate of increase of global mean temperature during the next century of about 0.3°C per decade (with an uncertainty range of 0.2°C to 0.5°C per decade); this is greater than that seen over the past 10,000 years. This will result in a likely increase in global mean temperature of about 1°C above the present value by 2025 and 3°C before the end of the next century. The rise will not be steady because of the influence of other factors.

- under the other IPCC emission scenarios which assume progressively increasing levels of controls, rates of increase in global mean temperature of about 0.2°C per decade (Scenario B), just above 0.1°C per decade (Scenario C) and about 0.1°C per decade (Scenario D).

- that land surfaces warm more rapidly than the ocean, and high northern latitudes warm more than the global mean in winter.

- regional climate changes different from the global mean, although our confidence in the prediction of the detail of regional changes is low. For example, temperature increases in Southern Europe and central North America are predicted to be higher than the global mean, accompanied on average by reduced summer precipitation and soil moisture. There are less consistent predictions for the tropics and the southern hemisphere.

- under the IPCC Business as Usual emissions scenario, an average rate of global mean sea level rise of about 6cm per decade over the next century (with an uncertainty range of 3 - 10cm per decade), mainly due to thermal expansion of the oceans and the melting of some land ice. The predicted rise is about 20cm in global mean sea level by 2030, and 65cm by the end of the next century. There will be significant regional variations.

There are many uncertainties in our predictions particularly with regard to the timing, magnitude and regional patterns of climate change, due to our incomplete understanding of:

- sources and sinks of greenhouse gases, which affect predictions of future concentrations
- clouds, which strongly influence the magnitude of climate change
- oceans, which influence the timing and patterns of climate change
- polar ice sheets which affect predictions of sea level rise

These processes are already partially understood, and we are confident that the uncertainties can be reduced by further research. However, the complexity of the system means that we cannot rule out surprises.

Our judgement is that:

- Global - mean surface air temperature has increased by 0.3°C to 0.6°C over the last 100 years, with the five global-average warmest years being in the 1980s. Over the same period global sea level has increased by 10-20cm. These increases have not been smooth with time, nor uniform over the globe.
- The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase could be largely due to this natural variability; alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.
- There is no firm evidence that climate has become more variable over the last few decades. However, with an increase in the mean temperature, episodes of high temperatures will most likely become more frequent in the future, and cold episodes less frequent.
- Ecosystems affect climate, and will be affected by a changing climate and by increasing carbon dioxide concentrations. Rapid changes in climate will change the composition of ecosystems; some species will benefit while others will be unable to migrate or adapt fast enough and may become extinct. Enhanced levels of carbon dioxide may increase productivity and efficiency of water use of vegetation. The effect of warming on biological processes, although poorly understood, may increase the atmospheric concentrations of natural greenhouse gases.

To improve our predictive capability, we need:

- to **understand** better the various climate-related processes, particularly those associated with clouds, oceans and the carbon cycle
- to **improve** the systematic observation of climate-related variables on a global basis, and further investigate changes which took place in the past
- to **develop** improved models of the Earth's climate system.
- to **increase** support for national and international climate research activities, especially in developing countries
- to **facilitate** international exchange of climate data

Introduction: what is the issue ?

There is concern that human activities may be inadvertently changing the climate of the globe through the enhanced greenhouse effect, by past and continuing emissions of carbon dioxide and other gases which will cause the temperature of the Earth's surface to increase - popularly termed the "global warming". If this occurs, consequent changes may have a significant impact on society.

The purpose of the Working Group I report, as determined by the first meeting of IPCC, is to provide a scientific assessment of:

1) the factors which may affect climate change during the next century especially those which are due to human activity.

2) the responses of the atmosphere - ocean - land - ice system.

3) current capabilities of modelling global and regional climate changes and their predictability.

4) the past climate record and presently observed climate anomalies.

On the basis of this assessment, the report presents current knowledge regarding predictions of climate change (including sea level rise and the effects on ecosystems) over the next century, the timing of changes together with an assessment of the uncertainties associated with these predictions.

This Policymakers Summary aims to bring out those elements of the main report which have the greatest relevance to policy formulation, in answering the following questions:

- What factors determine global climate?
- What are the greenhouse gases, and how and why are they increasing?
- Which gases are the most important?
- How much do we expect the climate to change?
- How much confidence do we have in our predictions?
- Will the climate of the future be very different ?
- Have human activities already begun to change global climate?
- How much will sea level rise?
- What will be the effects on ecosystems?
- What should be done to reduce uncertainties, and how long will this take?

This report is intended to respond to the practical needs of the policymaker. It is neither an academic review, nor a plan for a new research programme. Uncertainties attach to almost every aspect of the issue, yet policymakers are looking for clear guidance from scientists; **hence authors have been asked to provide their best-estimates wherever possible**, together with an assessment of the uncertainties.

This report is a summary of our understanding in 1990. Although continuing research will deepen this understanding and require the report to be updated at frequent intervals, basic conclusions concerning the reality of the enhanced greenhouse effect and its potential to alter global climate are unlikely to change significantly. Nevertheless, the complexity of the system may give rise to surprises.

What factors determine global climate ?

There are many factors, both natural and of human origin, that determine the climate of the earth. We look first at those which are natural, and then see how human activities might contribute.

What natural factors are important?

The driving energy for weather and climate comes from the sun. The Earth intercepts solar radiation (including that in the short-wave, visible, part of the spectrum); about a third of it is reflected, the rest is absorbed by the different components (atmosphere, ocean, ice, land and biota) of the climate system. The energy absorbed from solar radiation is balanced (in the long term) by outgoing radiation from the Earth and atmosphere; this terrestrial radiation takes the form of long-wave invisible infra-red energy, and its magnitude is determined by the temperature of the Earth-atmosphere system.

There are several natural factors which can change the balance between the energy absorbed by the Earth and that emitted by it in the form of longwave infra-red radiation; these factors cause the **radiative forcing** on climate. The most obvious of these is a change in the output of energy from the Sun. There is direct evidence of such variability over the 11-year solar cycle, and longer period changes may also occur. Slow variations in the Earth's orbit affect the seasonal and latitudinal distribution of solar radiation; these were probably responsible for initiating the ice ages.

One of the most important factors is the **greenhouse effect**; a simplified explanation of which is as follows. Shortwave solar radiation can pass through the clear atmosphere relatively unimpeded. But long-wave terrestrial radiation emitted by the warm surface of the Earth is partially absorbed and then re-emitted by a number of trace gases in the cooler atmosphere above. Since, on average, the outgoing long wave radiation balances the incoming solar radiation, both the atmosphere and the surface will be warmer than they would be without the greenhouse gases.

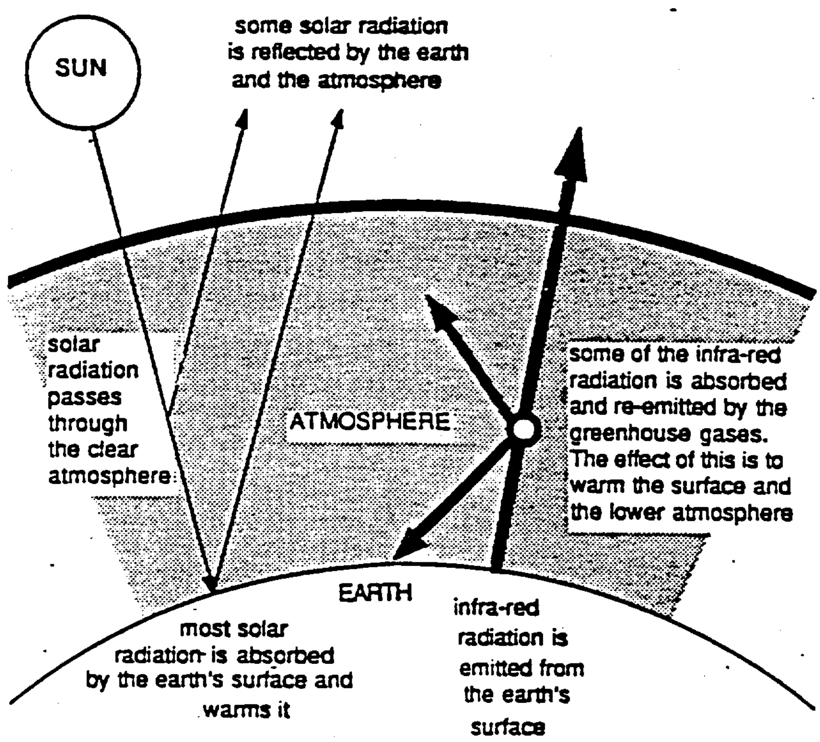
The main natural greenhouse gases are not the major constituents, nitrogen and oxygen, but water vapour (the biggest contributor), carbon dioxide, methane, nitrous oxide, and ozone in the troposphere (the lowest 10-15km of the atmosphere) and stratosphere.

Aerosols (small particles) in the atmosphere can also affect climate because they can reflect and absorb radiation. The most important natural perturbations result from explosive volcanic eruptions which affect concentrations in the lower stratosphere. Lastly, the climate has its own **natural variability** on all timescales and changes occur without any external influence.

How do we know that the natural greenhouse effect is real?

The greenhouse effect is real; it is a well understood effect, based on established scientific principles. We know that the greenhouse effect works in practice, for several reasons.

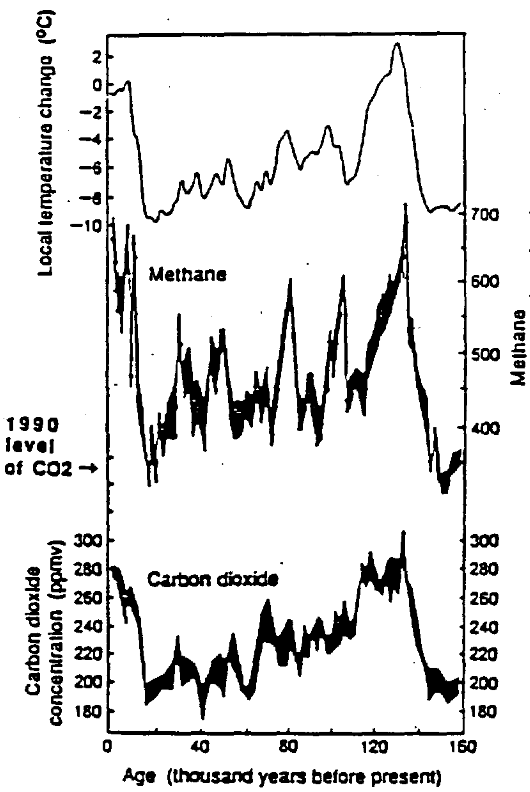
Firstly, the mean temperature of the Earth's surface is already warmer by about 33°C (assuming the same reflectivity of the earth) than it would be if the natural greenhouse gases were not present. Satellite observations of the radiation emitted from the earth's surface and through the atmosphere demonstrate the effect of the greenhouse gases.



A simplified diagram illustrating the greenhouse effect.

Secondly, we know the composition of the atmospheres of Venus, Earth and Mars are very different, and their surface temperatures are in general agreement with greenhouse theory.

Thirdly, measurements from ice cores going back 160,000 years show that the earth's temperature closely paralleled the amount of carbon dioxide and methane in the atmosphere. Although we do not know the details of cause and effect, calculations indicate that changes in these greenhouse gases were part, but not all; of the reason for the large (5-7°C) global temperature swings between ice ages and interglacial periods.



Analysis of air trapped in Antarctic ice cores shows that methane and carbon dioxide concentrations were closely correlated with the local temperature over the last 160,000 years. Present day concentrations of carbon dioxide are indicated

How might human activities change global climate ?

Naturally occurring greenhouse gases keep the Earth warm enough to be habitable. By increasing their concentrations, and by adding new greenhouse gases like chlorofluorocarbons (CFCs), humankind is capable of raising the global-average annual-mean surface-air temperature (which, for simplicity, is referred to as the "global temperature"), although we are uncertain about the rate at which this will occur. Strictly, this is an enhanced greenhouse effect - above that occurring due to natural greenhouse gas concentrations; the word "enhanced" is usually omitted, but it should not be forgotten. Other changes in climate are expected to result, for example changes in precipitation, and a global warming will cause sea levels to rise; these are discussed in more detail later.

There are other human activities which have the potential to affect climate. A change in the albedo (reflectivity) of the land, brought about by desertification or deforestation affects the amount of solar energy absorbed at the Earth's surface. Human-made aerosols, from sulphur emitted largely in fossil fuel combustion, can modify clouds and this may act to lower temperatures. Lastly, changes in ozone in the stratosphere due to CFCs may also influence climate.

What are the greenhouse gases and why are they increasing?

We are certain that the concentrations of greenhouse gases in the atmosphere have changed naturally on ice-age time-scales, and have been increasing since pre-industrial times due to human activities. The table below summarizes the present and pre-industrial abundances, current rates of change and present atmospheric lifetimes of greenhouse gases influenced by human activities. Carbon dioxide, methane, and nitrous oxide all have significant natural and human sources, while the chlorofluorocarbons are only produced industrially.

SUMMARY OF KEY GREENHOUSE GASES AFFECTED BY HUMAN ACTIVITIES

	Carbon Dioxide	Methane	CFC-11	CFC-12	Nitrous Oxide
Atmospheric concentration	ppmv	ppmv	pptv	pptv	ppbv
Pre-industrial (1750-1800)	280	0.8	0	0	288
Present day (1990)	353	1.72	280	484	310
Current rate of change per year	1.8 (0.5%)	0.015 (0.9%)	9.5 (4%)	17 (4%)	0.8 (0.25%)
Atmospheric lifetime (years)	(50-200)†	10	65	130	150

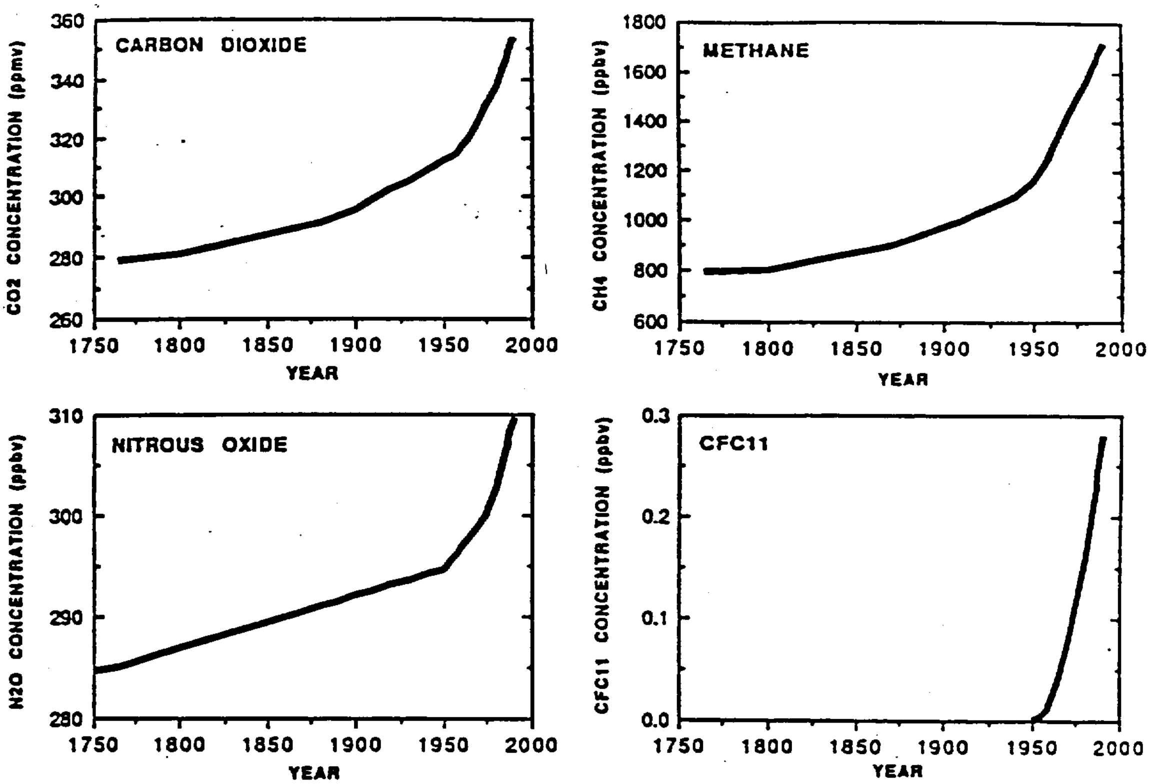
ppmv = parts per million by volume;
ppbv = parts per billion (thousand million) by volume;
pptv = parts per trillion (million million) by volume.
† The way in which CO_2 is absorbed by the oceans and biosphere is not simple and a single value cannot be given; refer to the main report for further discussion.

Two important greenhouse gases, water vapour and ozone, are not included in the table above. Water vapour has the largest greenhouse effect, but its concentration in the troposphere is determined internally within the climate system, and, on a global scale, is not affected by human sources and sinks. Water vapour will increase in response to global warming and further enhance it; this process is included in climate models. The concentration of ozone is changing both in the stratosphere and the troposphere due to human activities, but it is difficult to quantify the changes from present observations.

For a thousand years prior to the industrial revolution, abundances of the greenhouse gases were relatively constant. However, as the world's population increased, as the world became more industrialized and as agriculture developed, the abundances of the greenhouse gases increased markedly. The figures below illustrate this for carbon dioxide, methane, nitrous oxide and CFC-11.

Since the industrial revolution the combustion of fossil fuels and deforestation have led to an increase of 26% in carbon dioxide concentration in the atmosphere. We know the magnitude of the present day fossil-fuel source, but the input from deforestation cannot be estimated accurately. In addition, although about half of the emitted carbon dioxide stays in the atmosphere, we do not know well how much of the remainder is absorbed by the oceans and how much by terrestrial biota. Emissions of chlorofluorocarbons, used as aerosol propellants, solvents, refrigerants and foam blowing agents, are also well known; they were not present in the atmosphere before their invention in the 1930s.

The sources of methane and nitrous oxide are less well known. Methane concentrations have more than doubled because of rice production, cattle rearing, biomass burning, coal mining and ventilation of natural gas; also, fossil fuel combustion may have also contributed through chemical reactions in the atmosphere which reduce the rate of removal of methane. Nitrous oxide has increased by about 8% since pre-industrial times, presumably due to human activities; we are unable to specify the sources, but it is likely that agriculture plays a part.



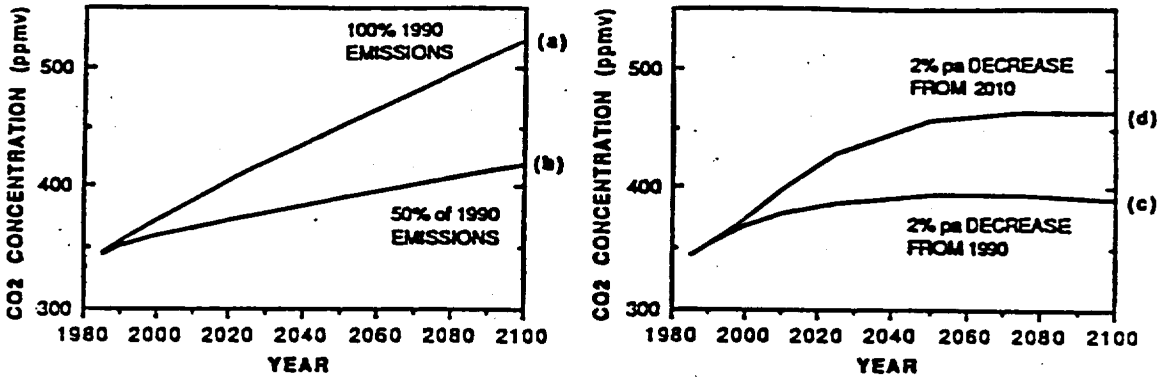
Concentrations of carbon dioxide and methane after remaining relatively constant up to the 18th century, have risen sharply since then due to man's activities. Concentrations of nitrous oxide have increased since the mid-18th century, especially in the last few decades. CFCs were not present in the atmosphere before the 1930s

The effect of ozone on climate is strongest in the upper troposphere and lower stratosphere. Model calculations indicate that ozone in the upper troposphere should have increased due to human-made emissions of nitrogen oxides, hydrocarbons and carbon monoxide. While at ground level ozone has increased in the northern hemisphere in response to these emissions, observations are insufficient to confirm the expected increase in the upper troposphere. The lack of adequate observations prevents us from accurately quantifying the climatic effect of changes in tropospheric ozone.

In the lower stratosphere at high southern latitudes ozone has decreased considerably due to the effects of CFCs, and there are indications of a global-scale decrease which, while not understood, may also be due to CFCs. These observed decreases should act to cool the earth's surface, thus providing a small offset to the predicted warming produced by the other greenhouse gases. Further reductions in lower stratospheric ozone are possible during the next few decades as the atmospheric abundances of CFCs continue to increase.

Concentrations, lifetimes and stabilisation of the gases

In order to calculate the atmospheric concentrations of carbon dioxide which will result from human-made emissions we use computer models which incorporate details of the emissions and which include representations of the transfer of carbon dioxide between the atmosphere, oceans and terrestrial biosphere. For the other greenhouse gases, models which incorporate the effects of chemical reactions in the atmosphere are employed.



The relationship between hypothetical fossil fuel emissions of carbon dioxide and its concentration in the atmosphere is shown in the case where (a) emissions continue at 1990 levels, (b) emissions are reduced by 50% in 1990 and continue at that level, (c) emissions are reduced by 2% pa from 1990, and (d) emissions, after increasing by 2% pa until 2010, are then reduced by 2% pa thereafter.

The atmospheric lifetimes of the gases are determined by their sources and sinks in the oceans, atmosphere and biosphere. Carbon dioxide, chlorofluorocarbons and nitrous oxide are removed only slowly from the atmosphere and hence, following a change in emissions, their atmospheric concentrations take decades to centuries to adjust fully. Even if all human-made emissions of carbon dioxide were halted in the year 1990, about half of the increase in carbon dioxide concentration caused by human activities would still be evident by the year 2100.

In contrast, some of the CFC substitutes and methane have relatively short atmospheric lifetimes so that their atmospheric concentrations respond fully to emission changes within a few decades.

To illustrate the emission-concentration relationship clearly, the effect of hypothetical changes in carbon dioxide fossil fuel emissions is shown below: (a) continuing global emissions at 1990 levels; (b) halving of emissions in 1990; (c) reductions in emissions of 2% per year (pa) from 1990 and (d) a 2% pa increase from 1990-2010 followed by a 2% pa decrease from 2010.

Continuation of present day emissions are committing us to increased future concentrations, and the longer emissions continue to increase, the greater would reductions have to be to stabilise at a given level. If there are critical concentration levels that should not be exceeded, then the earlier emission reductions are made the more effective they are.

STABILISATION OF ATMOSPHERIC CONCENTRATIONS

Reductions in the human-made emissions of greenhouse gases required to stabilise concentrations at present day levels:

Carbon Dioxide	>60%
Methane	15 - 20%
Nitrous Oxide	70 - 80%
CFC-11	70 - 75%
CFC-12	75 - 85%
HCFC-22	40 - 50%

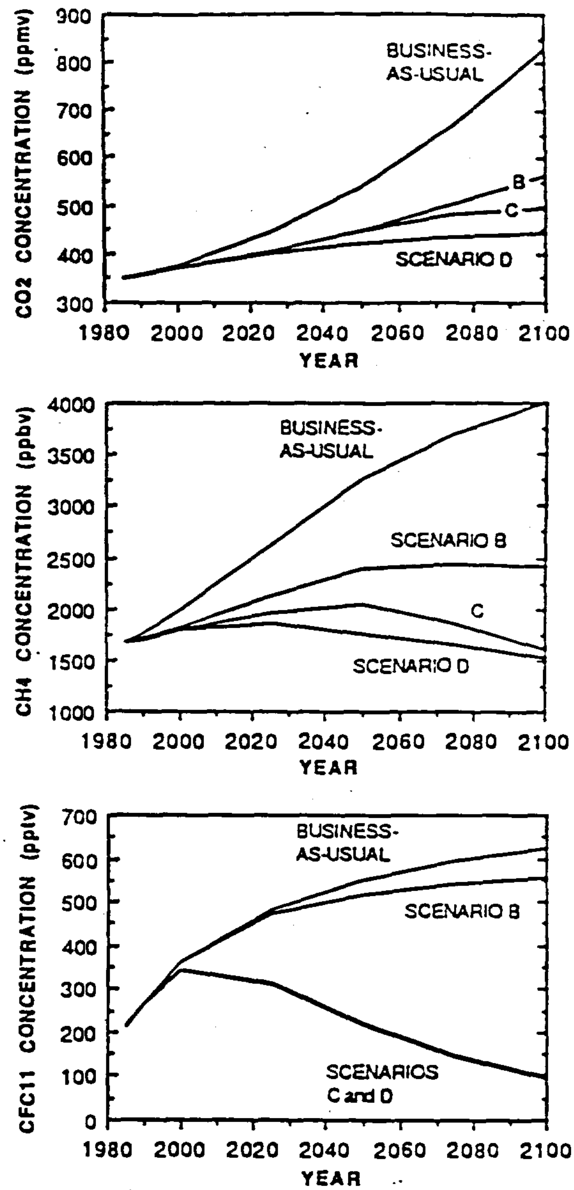
Note that the stabilisation of each of these gases would have different effects on climate, as explained in the next section.

The term "atmospheric stabilisation" is often used to describe the limiting of the concentration of the greenhouse gases at a certain level. The amount by which human-made emissions of a greenhouse gas must be reduced in order to stabilise at present day concentrations, for example, is shown in the box opposite. For most gases the reductions would have to be substantial.

How will greenhouse gas abundances change in the future?

We need to know future greenhouse gas concentrations in order to estimate future climate change. As already mentioned, these concentrations depend upon the magnitude of human-made emissions and on how changes in climate and other environmental conditions may influence the biospheric processes that control the exchange of natural greenhouse gases, including carbon dioxide and methane, between the atmosphere, oceans and terrestrial biosphere - the greenhouse gas "feedbacks".

Four scenarios of future human-made emissions were developed by Working Group III. The first of these assumes that few or no steps are taken to limit greenhouse gas emissions, and this is therefore termed Business-as-Usual (BaU). (It should be noted that an aggregation of national forecasts of emissions of carbon dioxide and methane to the year 2025 undertaken by Working Group III resulted in global emissions 10-20% higher than in the BaU scenario.) The other three scenarios assume that progressively increasing levels of controls reduce the growth of emissions; these are referred to as scenarios B, C, and D. They are briefly described in the Annex. Future concentrations of some of the greenhouse gases which would arise from these emissions are shown opposite.



Atmospheric concentrations of carbon dioxide, methane and CFC-11 resulting from the four IPCC emissions scenarios

Greenhouse gas feedbacks

Some of the possible feedbacks which could significantly modify future greenhouse gas concentrations in a warmer world are discussed in the following paragraphs.

The net emissions of carbon dioxide from terrestrial ecosystems will be elevated if higher temperatures increase respiration at a faster rate than photosynthesis, or if plant populations, particularly large forests, cannot adjust rapidly enough to changes in climate.

A net flux of carbon dioxide to the atmosphere may be particularly evident in warmer conditions in tundra and boreal regions where there are large stores of carbon. The opposite is true if higher abundances of carbon dioxide in the atmosphere enhance the productivity of natural ecosystems, or if there is an increase in soil moisture which can be expected to stimulate plant growth in dry ecosystems and to increase the storage of carbon in tundra peat. The extent to which ecosystems can sequester increasing atmospheric carbon dioxide remains to be quantified.

If the oceans become warmer, their net uptake of carbon dioxide may decrease because of changes in (i) the chemistry of carbon dioxide in seawater (ii) biological activity in surface waters and (iii) the rate of exchange of carbon dioxide between the surface layers and the deep ocean. This last depends upon the rate of formation of deep water in the ocean which, in the North Atlantic for example, might decrease if the salinity decreases as a result of a change in climate.

Methane emissions from natural wetlands and rice paddies are particularly sensitive to temperature and soil moisture. Emissions are significantly larger at higher temperatures and with increased soil moisture; conversely, a decrease in soil moisture would result in smaller emissions. Higher temperatures could increase the emissions of methane at high northern latitudes from decomposable organic matter trapped in permafrost and methane hydrates.

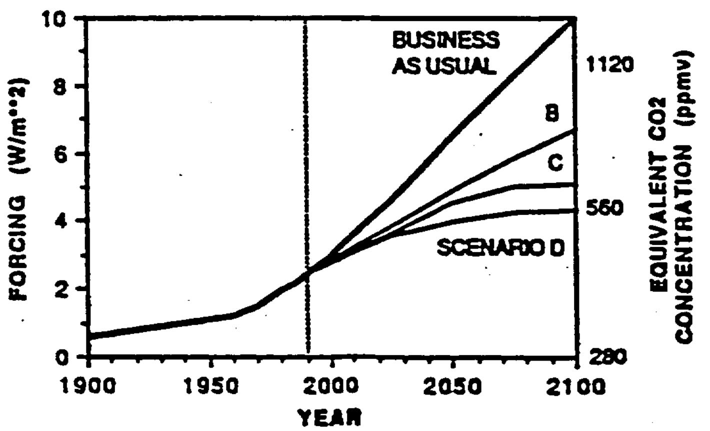
As illustrated earlier, ice core records show that methane and carbon dioxide concentrations changed in a similar sense to temperature between ice ages and interglacials.

Although many of these feedback processes are poorly understood, it seems likely that, overall, they will act to increase, rather than decrease, greenhouse gas concentrations in a warmer world.

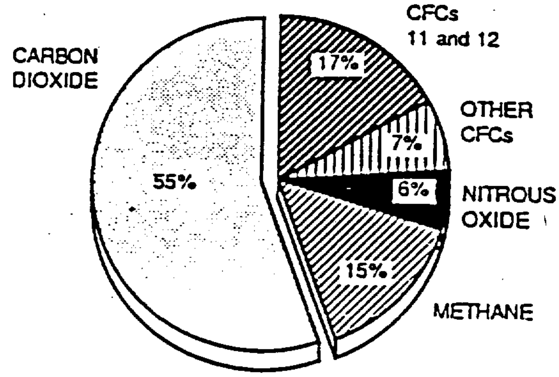
Which gases are the most important?

We are certain that increased greenhouse gas concentrations increase radiative forcing. We can calculate the forcing with much more confidence than the climate change that results because the former avoids the need to evaluate a number of poorly understood atmospheric responses. We then have a base from which to calculate the relative effect on climate of an increase in **concentration** of each gas in the present-day atmosphere, both in absolute terms and relative to carbon dioxide. These relative effects span a wide range; methane is about 21 times more effective, molecule-for-molecule, than carbon dioxide, and CFC-11 about 12,000 times more effective. On a kilogram-per-kilogram basis, the equivalent values are 58 for methane and about 4,000 for CFC-11, both relative to carbon dioxide. Values for other greenhouse gases are to be found in the full report.

The total radiative forcing at any time is the sum of those from the individual greenhouse gases. We show in the figure below how this quantity has changed in the past (based on observations of greenhouse gases) and how it might change in the future (based on the four IPCC emissions scenarios). For simplicity, we can express total forcing in terms of the amount of carbon dioxide which would give that forcing; this is termed the **equivalent carbon dioxide concentration.** Greenhouse gases have increased since pre-industrial times (the mid-18th century) by an



Increase in radiative forcing since the mid-18th century, and predicted to result from the four IPCC emissions scenarios, also expressed as equivalent carbon dioxide concentrations



The contribution from each of the human-made greenhouse gases to the change in radiative forcing from 1980 to 1990. The contribution from ozone may also be significant, but cannot be quantified at present.

amount that is radiatively equivalent to about a 50% increase in carbon dioxide, although carbon dioxide itself has risen by only 26%; other gases have made up the rest.

The contributions of the various gases to the total increase in climate forcing during the 1980s is shown above as a pie diagram; carbon dioxide is responsible for about half the decadal increase. (Ozone, the effects of which may be significant, is not included)

How can we evaluate the effect of different greenhouse gases?

To evaluate possible policy options, it is useful to know the relative radiative effect (and, hence, potential climate effect) of equal emissions of each of the greenhouse gases. The concept of relative **Global Warming Potentials (GWP)** has been developed to take into account the differing times that gases remain in the atmosphere.

This index defines the time-integrated warming effect due to an instantaneous release of unit mass (1 kg) of a given greenhouse gas in today's atmosphere, relative to that of carbon dioxide. The relative importances will change in the future as atmospheric composition changes because, although radiative forcing increases in direct proportion to the concentration of CFCs, changes in the other greenhouse gases (particularly carbon dioxide) have an effect on forcing which is much less than proportional.

The GWPs in the following table are shown for three time horizons, reflecting the need to consider the cumulative effects on climate over various time scales. The longer time horizon is appropriate for the cumulative effect; the shorter timescale will indicate the response to emission changes in the short term. There are a number of practical difficulties in devising and calculating the values of the GWPs, and the values given here should be considered as preliminary. In addition to these direct effects, there are indirect effects of human-made emissions arising from chemical reactions between the various

GLOBAL WARMING POTENTIALS

The warming effect of an emission of 1kg of each gas relative to that of CO_2

These figures are best estimates calculated on the basis of the present day atmospheric composition

	Time Horizon		
	20 yr	100 yr	500 yr
Carbon dioxide	1	1	1
Methane (including indirect)	63	21	9
Nitrous oxide	270	290	190
CFC-11	4500	3500	1500
CFC-12	7100	7300	4500
HCFC-22	4100	1500	510

Global Warming Potentials for a range of CFCs and potential replacements are given in the full text

THE RELATIVE CUMULATIVE CLIMATE EFFECT OF 1990 MAN-MADE EMISSIONS

	GWP (100yr horizon)	1990 emissions (Tg)	Relative contribution over 100yr
Carbon dioxide	1	26000†	61%
Methane*	21	300	15%
Nitrous oxide	290	6	4%
CFCs	Various	0.9	11%
HCFC-22	1500	0.1	0.5%
Others*	Various		8.5%

*These values include the indirect effect of these emissions on other greenhouse gases via chemical reactions in the atmosphere. Such estimates are highly model dependent and should be considered preliminary and subject to change. The estimated effect of ozone is included under "others". The gases included under "others" are given in the full report.

† 26 000 Tg (teragrams) of carbon dioxide = 7 000 Tg (=7 Gt) of carbon

constituents. The indirect effects on stratospheric water vapour, carbon dioxide and tropospheric ozone have been included in these estimates.

The table indicates, for example, that the effectiveness of methane in influencing climate will be greater in the first few decades after release, whereas emission of the longer-lived nitrous oxide will affect climate for a much longer time. The lifetimes of the proposed CFC replacements range from 1 to 40 years; the longer lived replacements are still potentially effective as agents of climate change. One example of this, HCFC-22 (with a 15 year lifetime), has a similar effect (when released in the same amount) as CFC-11 on a 20 year timescale; but less over a 500 year timescale.

The table shows carbon dioxide to be the least effective greenhouse gas per kilogramme emitted, but its contribution to global warming, which depends on the product of the GWP and the amount emitted, is largest. In the example in the box below, the effect over 100 years of emissions of greenhouse gases in 1990 are shown relative to carbon dioxide. This is illustrative; to compare the effect of different emission projections we have to sum the effect of emissions made in future years

GAS	MAJOR CONTRIBUTOR?	LONG LIFETIME?	SOURCES KNOWN?
Carbon dioxide	yes	yes	yes
Methane	yes	no	semi-quantitatively
Nitrous oxide	not at present	yes	qualitatively
CFCs	yes	yes	yes
HCFCs, etc	not at present	mainly no	yes
Ozone	possibly	no	qualitatively

There are other technical criteria which may help policymakers to decide, in the event of emissions reductions being deemed necessary, which gases should be considered. Does the gas contribute in a major way to current, and future, climate forcing? Does it have a long lifetime, so earlier reductions in emissions would be more effective than those made later? And are its sources and sinks well enough known to decide which could be controlled in practice? The table opposite illustrates these factors.

How much do we expect climate to change?

It is relatively easy to determine the direct effect of the increased radiative forcing due to increases in greenhouse gases. However, as climate begins to warm, various processes act to amplify (through positive feedbacks) or reduce (through negative feedbacks) the warming. The main feedbacks which have been identified are due to changes in water vapour, sea-ice, clouds and the oceans.

The best tools we have which take the above feedbacks into account (but do not include greenhouse gas feedbacks) are three-dimensional mathematical models of the climate system (atmosphere-ocean-ice-land), known as General Circulation Models (GCMs). They synthesise our knowledge of the physical and dynamical processes in the overall system and allow for the complex interactions between the various components. However, in their current state of development, the descriptions of many of the processes involved are comparatively crude. Because of this, considerable uncertainty is attached to these predictions of climate change, which is reflected in the range of values given; further details are given in a later section.

The estimates of climate change presented here are based on

i) the "best estimate" of equilibrium climate sensitivity (i.e the equilibrium temperature change due to a doubling of carbon dioxide in the atmosphere) obtained from model simulations, feedback analyses and observational considerations (see later box: "What tools do we use?")

ii) a "box diffusion upwelling" ocean-atmosphere climate model which translates the greenhouse forcing into the evolution of the temperature response for the prescribed climate sensitivity. (This simple model has been calibrated against more complex atmosphere-ocean coupled GCMs for situations where the more complex models have been run).

How quickly will global climate change?

a. If emissions follow a Business-as-Usual pattern

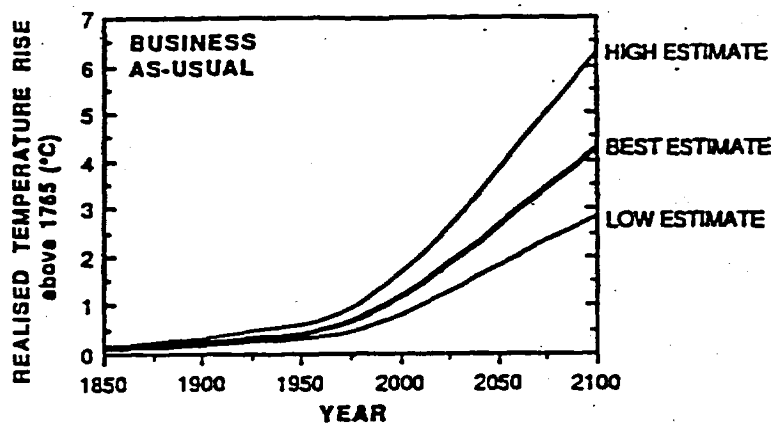
Under the IPCC Business-as-Usual (Scenario A) emissions of greenhouse gases, the average rate of increase of global mean temperature during the next century is estimated to be about 0.3°C per decade (with an uncertainty range of 0.2°C to 0.5°C). This will result in a likely increase in global mean temperature of about 1°C above the present value (about 2°C above that in the pre-industrial period) by 2025 and 3°C above today's (about 4°C above pre-industrial) before the end of the next century.

The projected temperature rise out to the year 2100, with high, low and best-estimate climate responses, is shown in the diagram below. Because of other factors which influence climate, we would not expect the rise to be a steady one.

The temperature rises shown above are **realised** temperatures; at any time we would also be **committed** to a further temperature rise toward the equilibrium temperature (see box: "Equilibrium and Realised Climate Change"). For the BaU "best estimate" case in the year 2030, for example, a further 0.9°C rise would be expected, about 0.2°C of which would be realised by 2050 (in addition to changes due to further greenhouse gas increases); the rest would become apparent in decades or centuries.

Even if we were able to stabilise emissions of each of the greenhouse gases at present day levels from now on, the temperature is predicted to rise by about 0.2°C per decade for the first few decades.

The global warming will also lead to increased global average precipitation and evaporation of a few percent by 2030. Areas of sea-ice and snow are expected to diminish.

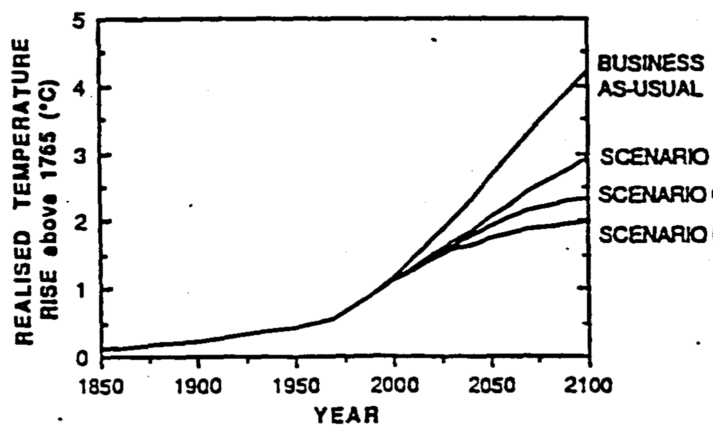


Simulation of the increase in global mean temperature from 1850-1990 due to observed increases in greenhouse gases, and predictions of the rise between 1990 and 2100 resulting from the Business-as-Usual emissions.

b. If emissions are subject to controls

Under the other IPCC emission scenarios which assume progressively increasing levels of controls, average rates of increase in global mean temperature over the next century are estimated to be about 0.2°C per decade (Scenario B), just above 0.1°C per decade (Scenario C) and about 0.1°C per decade (Scenario D). The results are illustrated opposite with the Business-as-Usual case for comparison. Only the best-estimate of the temperature rise is shown in each case.

The indicated range of uncertainty in global temperature rise given above reflects a subjective assessment of uncertainties in the calculation of climate response, but does not include those due to the transformation of emissions to concentrations, nor the effects of greenhouse gas feedbacks.



Simulations of the increase in global mean temperature from 1850-1990 due to observed increases in greenhouse gases, and predictions of the rise between 1990 and 2100 resulting from the IPCC Scenario B,C and D emissions, with the Business-as-Usual case for comparison.

What tools do we use to predict future climate, and how do we use them?

The most highly developed tool which we have to predict future climate is known as a **general circulation model or GCM**. These models are based on the laws of physics and use descriptions in simplified physical terms (called parameterisations) of the smaller-scale processes such as those due to clouds and deep mixing in the ocean. In a climate model an atmospheric component, essentially the same as a weather prediction model, is coupled to a model of the ocean, which can be equally complex.

Climate forecasts are derived in a different way from weather forecasts. A weather prediction model gives a description of the atmosphere's state up to 10 days or so ahead, starting from a detailed description of an initial state of the atmosphere at a given time. Such forecasts describe the movement and development of large weather systems, though they cannot represent very small scale phenomena; for example, individual shower clouds.

To make a climate forecast, the climate model is first run for a few (simulated) decades. The statistics of the model's output is a description of the model's simulated climate which, if the model is a good one, will bear a close resemblance to the climate of the real atmosphere and ocean. The above exercise is then repeated with increasing concentrations of the greenhouse gases in the model. The differences between the statistics of the two simulations (for example in mean temperature and interannual variability) provide an estimate of the accompanying climate change.

The long term change in **surface air temperature** following a doubling of carbon dioxide (referred to as the **climate sensitivity**) is generally used as a benchmark to compare models. The range of results from model studies is 1.9 to 5.2°C. Most results are close to 4.0°C but recent studies using a more detailed but not necessarily more accurate representation of cloud processes give results in the lower half of this range. Hence the models results do not justify altering the previously accepted range of 1.5 to 4.5°C.

Although scientists are reluctant to give a single best estimate in this range, it is necessary for the presentation of climate predictions for a choice of best estimate to be made. Taking into account the model results, together with observational evidence over the last century which is suggestive of the climate sensitivity being in the lower half of the range, (see section: "Has man already begun to change global climate?") a value of climate sensitivity of 2.5°C has been chosen as the best estimate. Further details are given in Section 5 of the report.

In this Assessment, we have also used much simpler models, which simulate the behaviour of GCMs, to make predictions of the evolution with time of global temperature from a number of emission scenarios. These so-called box-diffusion models contain highly simplified physics but give similar results to GCMs when globally averaged.

A completely different, and potentially useful, way of predicting patterns of future climate is to search for periods in the past when the global mean temperatures were similar to those we expect in future, and then use the past spatial patterns as **analogues** of those which will arise in the future. For a good analogue, it is also necessary for the forcing factors (for example, greenhouse gases, orbital variations) and other conditions (for example, ice cover, topography, etc.) to be similar; direct comparisons with climate situations for which these conditions do not apply cannot be easily interpreted. Analogues of future greenhouse-gas-changed climates have not been found.

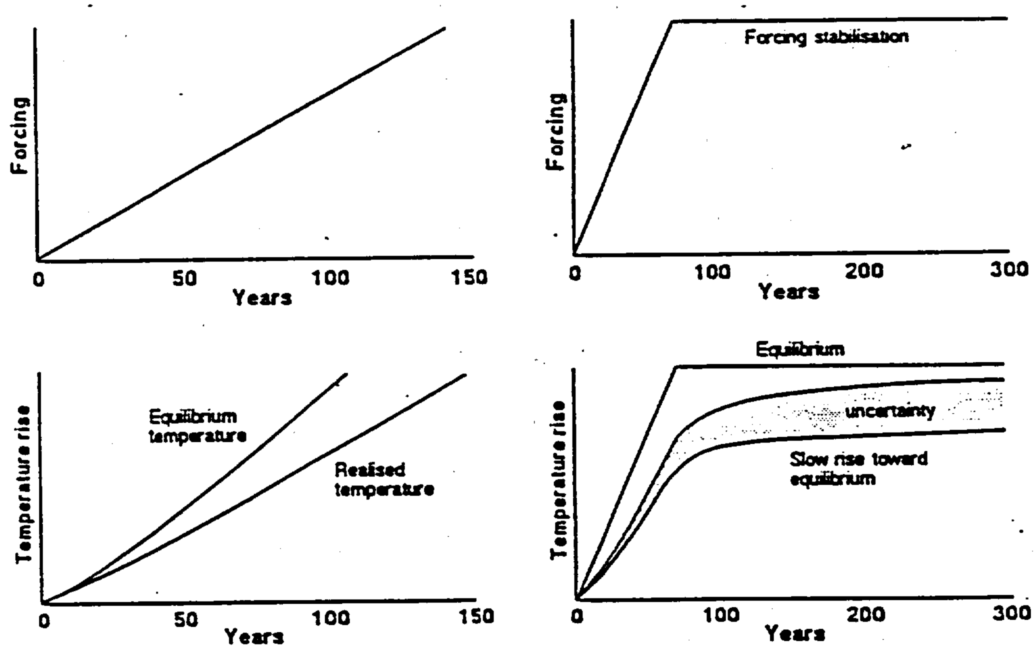
We cannot therefore advocate the use of palaeo-climates as predictions of regional climate change due to future increases in greenhouse gases. However, palaeo-climatological information can provide useful insights into climate processes, and can assist in the validation of climate models.

Equilibrium and realised climate change

When the radiative forcing on the earth-atmosphere system is changed, for example by increasing greenhouse gas concentrations, the atmosphere will try to respond (by warming) immediately. But the atmosphere is closely coupled to the oceans, so in order for the air to be warmed by the greenhouse effect, the oceans also have to be warmed; because of their thermal capacity this takes decades or centuries. This exchange of heat between atmosphere and ocean will act to slow down the temperature rise forced by the greenhouse effect.

In a hypothetical example where the concentration of greenhouse gases in the atmosphere, following a period of constancy, rises suddenly to a new level and remains there, the radiative forcing would also rise rapidly to a new level. This increased radiative forcing would cause the atmosphere and oceans to warm, and eventually come to a new, stable, temperature. A commitment to this **equilibrium** temperature rise is incurred as soon as the greenhouse gas concentration changes. But at any time before equilibrium is reached, the actual temperature will have risen by only part of the equilibrium temperature change, known as the realised temperature change.

Models predict that, for the present day case of an increase in radiative forcing which is approximately steady, the realised temperature rise at any time is about 50% of the committed temperature rise if the climate sensitivity (the response to a doubling of carbon dioxide) is 4.5°C and about 80% if the climate sensitivity is1.5°C. If the forcing were then held constant, temperatures would continue to rise slowly, but it is not certain whether it would take decades or centuries for most of the remaining rise to equilibrium to occur



What will be the patterns of climate change by 2030?

Knowledge of the global mean warming and change in precipitation is of limited use in determining the impacts of climate change, for instance on agriculture. For this we need to know changes regionally and seasonally.

Models predict that surface air will warm faster over land than over oceans, and a minimum of warming will occur around Antarctica and in the northern North Atlantic region.

There are some continental-scale changes which are consistently predicted by the highest resolution models and for which we understand the physical reasons. The warming is predicted to be 50-100% greater than the global mean in high northern latitudes in winter, and substantially smaller than the global mean in regions of sea ice in summer. Precipitation is predicted to increase on average in middle and high latitude continents in winter (by some 5 - 10% over 35-55°N).

Five regions, each a few million square kilometres in area and representative of different climatological regimes, were selected by IPCC for particular study (see map below). In the box below are given the changes in temperature, precipitation and soil moisture, which are predicted to occur by 2030 on the Business-as-Usual scenario, as an average over each of the five regions. There may be considerable variations within the regions. In general, confidence in these regional estimates is low, especially for the changes in precipitation and soil moisture, but they are examples of our best estimates. We cannot yet give reliable regional predictions at the smaller scales demanded for impacts assessments.

How will climate extremes and extreme events change?

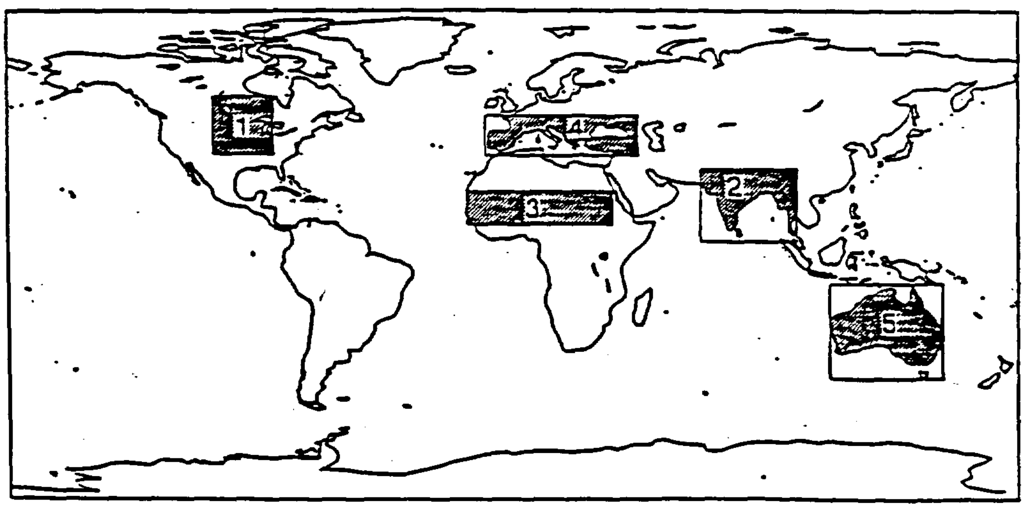
Changes in the variability of weather and the frequency of extremes will generally have more impact than changes in the mean climate at a particular location. With the possible exception of an increase in the number of intense showers, there is no clear evidence that weather variability will change in the future. In the case of temperatures, assuming no change in variability, but with a modest increase in the mean, the number of days with temperatures above a given value at the high end of the distribution will increase substantially. On the same assumptions, there will be a decrease in days with temperatures at the low end of the distribution. So the number of very hot days or frosty nights can be substantially changed without any change in the variability of the weather. The number of days with a minimum threshold amount of soil moisture (for viability of a certain crop, for example) would be even more sensitive to changes in average precipitation and evaporation.

If the large scale weather regimes, for instance depression tracks or anticyclones, shift their position, this would effect the variability and extremes of weather at a particular location, and could have a major effect. However, we do not know if, or in what way, this will happen.

Will storms increase in a warmer world?

Storms can have a major impact on society. Will their frequency, intensity or location increase in a warmer world?

Tropical storms, such as typhoons and hurricanes, only develop at present over seas that are warmer than about 26°C. Although the area of sea having temperatures over this critical value



Map showing the locations and extents of the five areas selected by IPCC

ESTIMATES FOR CHANGES BY 2030

(IPCC Business-as-Usual scenario; changes from **pre-industrial**)

The numbers given below are based on high resolution models, scaled to be consistent with our best estimate of global mean warming of 1.8°C by 2030. For values consistent with other estimates of global temperature rise, the numbers below should be reduced by 30% for the low estimate or increased by 50% for the high estimate. Precipitation estimates are also scaled in a similar way.

Confidence in these regional estimates is low

Central North America (35°-50°N 85°-105°W)
The warming varies from 2 to 4°C in winter and 2 to 3°C in summer. Precipitation increases range from 0 to 15% in winter whereas there are decreases of 5 to 10% in summer. Soil moisture decreases in summer by 15 to 20%.

Southern Asia (5°-30°N 70°-105°E)
The warming varies from 1 to 2°C throughout the year. Precipitation changes little in winter and generally increases throughout the region by 5 to 15% in summer. Summer soil moisture increases by 5 to 10%.

Sahel (10°-20°N 20°W-40°E)
The warming ranges from 1 to 3°C. Area mean precipitation increases and area mean soil moisture decreases marginally in summer. However, throughout the region, there are areas of both increase and decrease in both parameters throughout the region.

Southern Europe (35°-50°N 10°W- 45°E)
The warming is about 2°C in winter and varies from 2 to 3°C in summer. There is some indication of increased precipitation in winter, but summer precipitation decreases by 5 to 15%, and summer soil moisture by 15 to 25%.

Australia (12°-45°S 110°-115°E)
The warming ranges from 1 to 2°C in summer and is about 2°C in winter. Summer precipitation increases by around 10%, but the models do not produce consistent estimates of the changes in soil moisture. The area averages hide large variations at the sub-continental level.

will increase as the globe warms, the critical temperature itself may increase in a warmer world. Although the theoretical maximum intensity is expected to increase with temperature, climate models give no consistent indication whether tropical storms will increase or decrease in frequency or intensity as climate changes; neither is there any evidence that this has occurred over the past few decades.

Mid-latitude storms, such as those which track across the North Atlantic and North Pacific, are driven by the equator-to-pole temperature contrast. As this contrast will probably be weakened in a warmer world (at least in the northern hemisphere), it might be argued that mid-latitude storms will also weaken or change their tracks, and there is some indication of a general reduction in day-to-day variability in the mid-latitude storm tracks in winter in model simulations, though the pattern of changes vary from model to model. Present models do not resolve smaller-scale disturbances, so it will not be possible to assess changes in storminess until results from higher resolution models become available in the next few years.

Climate change in the longer term

The foregoing calculations have focussed on the period up to the year 2100; it is clearly more difficult to make calculations for years beyond 2100. However, while the timing of a predicted increase in global temperatures has substantial uncertainties, the prediction that an increase will eventually occur is more certain. Furthermore, some model calculations that have been extended beyond 100 years suggest that, with continued increases in greenhouse climate forcing, there could be significant changes in the ocean circulation, including a decrease in North Atlantic deep water formation.

Other factors which could influence future climate

Variations in the output of **solar energy** may also affect climate. On a decadal time-scale solar variability and changes in greenhouse gas concentration could give changes of similar magnitudes. However the variation in solar intensity changes sign so that over longer timescales the increases in greenhouse gases are likely to be more important. **Aerosols** as a result of volcanic eruptions can lead to a cooling at the surface which may oppose the greenhouse warming for a few years following an eruption. Again, over longer periods the greenhouse warming is likely to dominate.

Human activity is leading to an increase in aerosols in the lower atmosphere, mainly from sulphur emissions. These have two effects, both of which are difficult to quantify but which may be significant particularly at the regional level. The first is the direct effect of the aerosols on the radiation scattered and absorbed by the atmosphere. The second is an indirect effect whereby the aerosols affect the microphysics of clouds leading to an increased cloud reflectivity. Both these effects might lead to a significant regional cooling; a decrease in emissions of sulphur might be expected to increase global temperatures.

Because of long-period couplings between different components of the climate system, for example between ocean and atmosphere, the earth's climate would still vary without being perturbed by any external influences. This **natural variability** could act to add to, or subtract from, any human-made warming; on a century timescale this would be less than changes expected from greenhouse gas increases.

How much confidence do we have in our predictions?

Uncertainties in the above climate predictions arise from our imperfect knowledge of:

- future rates of human-made emissions
- how these will change the atmospheric concentrations of greenhouse gases
- the response of climate to these changed concentrations

Firstly, it is obvious that the extent to which climate will change depends on the rate at which greenhouse gases (and other gases which affect their concentrations) are emitted. This in turn will be determined by various complex economic and sociological factors. Scenarios of future emissions were generated within IPCC WGIII and are described in the annex.

Secondly, because we do not fully understand the sources and sinks of the greenhouse gases, there are uncertainties in our calculations of future concentrations arising from a given emissions scenario. We have used a number of models to calculate concentrations and chosen a best estimate for each gas. In the case of carbon dioxide, for example, the concentration increase between 1990 and 2070 due to the Business-as-Usual emissions scenario spanned almost a factor of two between the highest and lowest model result (corresponding to a range in radiative forcing change of about 50%)

Furthermore, because natural sources and sinks of greenhouse gases are sensitive to a change in climate, they may substantially modify future concentrations (see earlier section: "Greenhouse gas feedbacks"). It appears that, as climate warms, these feedbacks will lead to an overall increase, rather than decrease, in natural greenhouse gas abundances. For this reason, climate change is likely to be greater than the estimates we have given.

Thirdly, climate models are only as good as our understanding of the processes which they describe, and this is far from perfect. The ranges in the climate predictions given above reflect the uncertainties due to model imperfections; the largest of these is cloud feedback (those factors affecting the cloud amount and distribution and the interaction of clouds with solar and terrestrial radiation), which leads to a factor of two uncertainty in the size of the warming. Others arise from the transfer of energy between the atmosphere and ocean, the atmosphere and land surfaces, and between the upper and deep layers of the ocean. The treatment of sea-ice and convection in the models is also crude. Nevertheless, for reasons given in the box below, we have substantial confidence that models can predict at least the broad-scale features of climate change.

Furthermore, we must recognise that our imperfect understanding of climate processes (and corresponding ability to model them) could make us vulnerable to surprises; just as the human-made ozone hole over Antarctica was entirely unpredicted. In particular, the ocean circulation, changes in which are thought to have led to periods of comparatively rapid climate change at the end of the last ice age, is not well observed, understood or modelled.

Will the climate of the future be very different?

When considering future climate change, it is clearly essential to look at the record of climate variation in the past. From it we can learn about the range of natural climate variability, to see how it compares with what we expect in the future, and also look for evidence of recent climate change due to man's activities.

Climate varies naturally on all time scales from hundreds of millions of years down to the year to year. Prominent in the Earth's history have been the 100,000 year glacial-interglacial cycles when climate was mostly cooler than at present. Global surface temperatures have typically varied by 5-7°C through these cycles, with large changes in ice volume and sea level, and temperature changes as great as 10-15°C in some

Confidence in predictions from climate models

What confidence can we have that climate change due to increasing greenhouse gases will look anything like the model predictions? Weather forecasts can be compared with the actual weather the next day and their skill assessed; we cannot do that with climate predictions. However, there are several indicators that give us some confidence in the predictions from climate models.

When the latest atmospheric models are run with the present atmospheric concentrations of greenhouse gases and observed boundary conditions their simulation of present climate is generally realistic on large scales, capturing the major features such as the wet tropical convergence zones and mid-latitude depression belts, as well as the contrasts between summer and winter circulations. The models also simulate the observed variability; for example, the large day-to-day pressure variations in the middle latitude depression belts and the maxima in interannual variability responsible for the very different character of one winter from another both being represented. However, on regional scales (2,000km or less), there are significant errors in all models.

Overall confidence is increased by atmospheric models' generally satisfactory portrayal of aspects of variability of the atmosphere, for instance those associated with variations in sea surface temperature. There has been some success in simulating the general circulation of the ocean, including the patterns (though not always the intensities) of the principal currents, and the distributions of tracers added to the ocean.

Atmospheric models have been coupled with simple models of the ocean to predict the equilibrium response to greenhouse gases, under the assumption that the model errors are the same in a changed climate. The ability of such models to simulate important aspects of the climate of the last ice age generates confidence in their usefulness. Atmospheric models have also been coupled with multilayer ocean models (to give coupled ocean-atmosphere GCMs) which predict the gradual response to increasing greenhouse gases. Although the models so far are of relatively coarse resolution, the large scale structures of the ocean and the atmosphere can be simulated with some skill. However, the coupling of ocean and atmosphere models reveals a strong sensitivity to small scale errors which leads to a drift away from the observed climate. As yet, these errors must be removed by adjustments to the exchange of heat between ocean and atmosphere. There are similarities between results from the coupled models using simple representations of the ocean and those using more sophisticated descriptions, and our understanding of such differences as do occur gives us some confidence in the results.

middle and high latitude regions of the northern hemisphere. Since the end of the last ice age, about 10,000 years ago, global surface temperatures have probably fluctuated by little more than 1°C. Some fluctuations have lasted several centuries, including the Little Ice Age which ended in the nineteenth century and which appears to have been global in extent.

The changes predicted to occur by about the middle of the next century due to increases in greenhouse gas concentrations from the Business-as-Usual emissions will make global mean temperatures higher than they have been in the last 150,000 years.

The rate of change of global temperatures predicted for Business-as-Usual emissions will be greater than those which have occured naturally on earth over the last 10,000 years, and the rise in sea level will be about three to six times faster than that seen over the last 100 years or so.

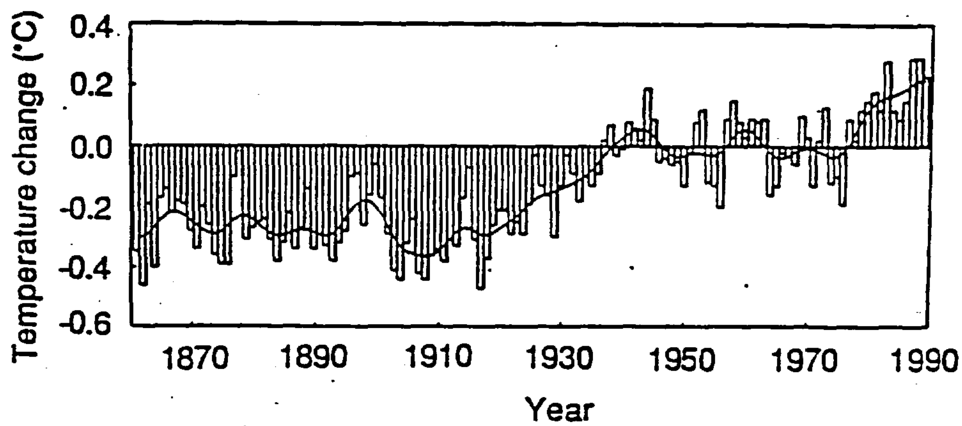
Has man already begun to change the global climate?

The instrumental record of surface temperature is fragmentary until the mid-nineteenth century, after which it slowly improves. Because of different methods of measurement, historical records have to be harmonised with modern observations, introducing some uncertainty. Despite these problems we believe that a real warming of the globe of 0.3°C - 0.6°C has taken place over the last century; any bias due to urbanisation is likely to be less than 0.05°C.

Moreover since 1900 similar temperature increases are seen in three independent data sets: one collected over land and two over the oceans. The figure below shows current estimates of smoothed global mean surface temperature over land and ocean since 1860. Confidence in the record has been increased by their similarity to recent satellite measurements of mid-tropospheric temperatures.

Although the overall temperature rise has been broadly similar in both hemispheres, it has not been steady, and differences in their rates of warming have sometimes persisted for decades. Much of the warming since 1900 has been concentrated in two periods, the first between about 1910 and 1940 and the other since 1975; the five warmest years on record have all been in the 1980s. The northern hemisphere cooled between the 1940s and the early 1970s when southern hemisphere temperatures stayed nearly constant. The pattern of global warming since 1975 has been uneven with some regions, mainly in the northern hemisphere, continuing to cool until recently. This regional diversity indicates that future regional temperature changes are likely to differ considerably from a global average.

The conclusion that global temperature has been rising is strongly supported by the retreat of most mountain glaciers of the world since the end of the nineteenth century and the fact that global sea level has risen over the same period by an average of 1 to 2mm per year. Estimates of thermal expansion of the oceans, and of



Global mean combined land-air and sea-surface temperatures, 1861 - 1989, relative to the average for 1951-80.

increased melting of mountain glaciers and the ice margin in West Greenland over the last century, show that the major part of the sea level rise appears to be related to the observed global warming. This apparent connection between observed sea level rise and global warming provides grounds for believing that future warming will lead to an acceleration in sea level rise.

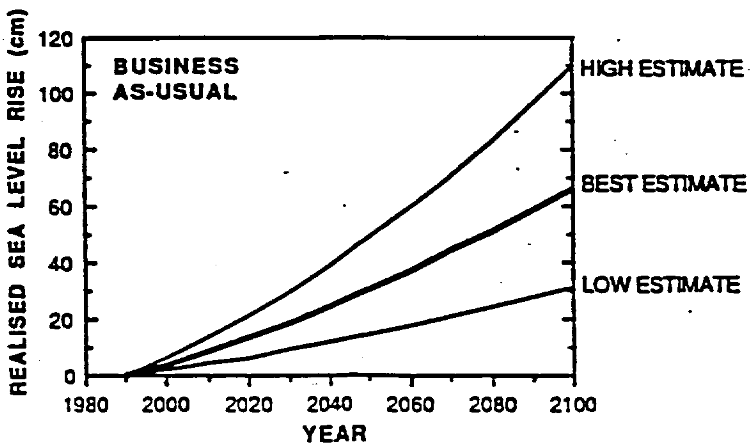
The size of the warming over the last century is broadly consistent with the predictions of climate models, but is also of the same magnitude as natural climate variability. If the sole cause of the observed warming were the human-made greenhouse effect, then the implied climate sensitivity would be near the lower end of the range inferred from the models. The observed increase could be largely due to natural variability; alternatively this variability and other man-made factors could have offset a still larger man-made greenhouse warming. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more, when the commitment to future climate change will then be considerably larger than it is today.

Global-mean temperature alone is an inadequate indicator of greenhouse-gas-induced climatic change. Identifying the causes of any global-mean temperature change requires examination of other aspects of the changing climate, particularly its spatial and temporal characteristics - the man-made climate change "signal". Patterns of climate change from models such as the northern hemisphere warming faster than the southern hemisphere, and surface air warming faster over land than over oceans, are not apparent in observations to date. However, we do not yet know what the detailed "signal" looks like because we have limited confidence in our predictions of climate change patterns. Furthermore, any changes to date could be masked by natural variability and other (possibly man-made) factors, and we do not have a clear picture of these.

How much will sea level rise ?

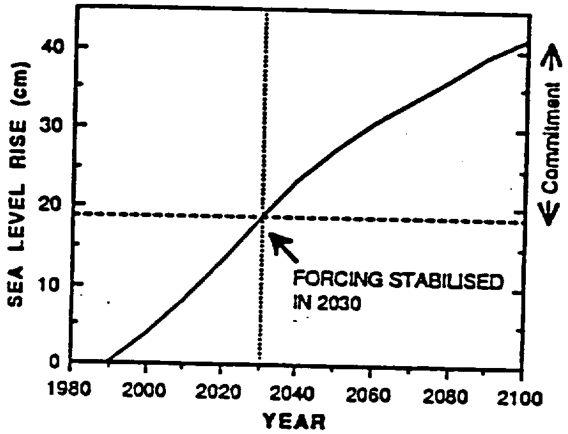
Simple models were used to calculate the rise in sea level to the year 2100; the results are illustrated below. The calculations necessarily ignore any long-term changes, unrelated to greenhouse forcing, that may be occurring but cannot be detected from the present data on land ice and the ocean. The sea-level rise expected from 1990-2100 under the IPCC Business as Usual emissions scenario is shown below. An average rate of global mean sea level rise of about 6cm per decade over the next century (with an uncertainty range of 3 - 10 cm per decade). The predicted rise is about 20cm in global mean sea level by 2030, and 65cm by the end of the next century. There will be significant regional variations.

The best estimate in each case is made up mainly of positive contributions from thermal expansion of the oceans and the melting of glaciers. Although, over the next 100 years, the effect of the Antarctic and Greenland ice sheets is expected to be small, they make a major contribution to the uncertainty in predictions.



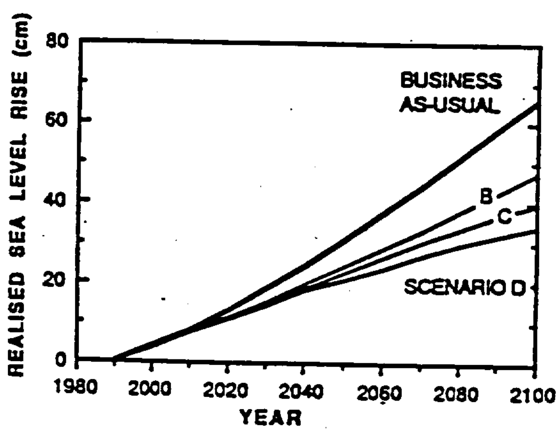
Sea level rise predicted to result from Business-as-Usual emissions, showing the best-estimate and range

Even if greenhouse forcing increased no further, there would still be a commitment to a continuing sea level rise for many decades and even centuries, due to delays in climate, ocean and ice mass responses. As an illustration, if the increases in greenhouse gas concentrations were to suddenly stop in 2030, sea level would go on rising from 2030 to 2100, by as much again as from 1990-2030, as shown in the diagram below.



Commitment to sea level rise in the year 2030. The curve shows the sea level rise due to Business-as-Usual emissions to 2030, with the additional rise that would occur in the remainder of the century even if climate forcing was stabilised in 2030.

Predicted sea level rises due to the other three emissions scenarios are shown below, with the Business-as-Usual case for comparison; only best-estimate calculations are shown.



Model estimates of sea-level rise from 1990-2100 due to all four emissions scenarios.

The West Antarctic Ice Sheet is of special concern. A large portion of it, containing an amount of ice equivalent to about 5m of global sea level, is grounded far below sea level. There have been suggestions that a sudden outflow of ice might result from global warming and raise sea level quickly and substantially. Recent studies have shown that individual ice streams are changing rapidly on a decade-to- century timescale; however this is not necessarily related to climate change. Within the next century, it is not likely that there will be a major outflow of ice from West Antarctica due directly to global warming.

Any rise in sea level is not expected to be uniform over the globe. Thermal expansion, changes in ocean circulation, and surface air pressure will vary from region to region as the world warms, but in an as yet unknown way. Such regional details await further development of more realistic coupled ocean atmosphere models. In addition, vertical land movements can be as large or even larger than changes in global mean sea level; these movements have to be taken into account when predicting local change in sea level relative to land.

The most severe effects of sea-level rise are likely to result from extreme events (for example, storm surges) the incidence of which may be affected by climatic change.

What will be the effect of climate change on ecosystems?

Ecosystem processes such as photosynthesis and respiration are dependent on climatic factors and carbon dioxide concentration in the short term. In the longer term, climate and carbon dioxide are among the factors which control ecosystem structure, i.e., species composition, either directly by increasing mortality in poorly adapted species, or indirectly by mediating the competition between species. Ecosystems will respond to local changes in temperature (including its rate of change), precipitation, soil moisture and extreme events. Current models are unable to make reliable estimates of changes in these parameters on the required local scales.

Photosynthesis captures atmospheric carbon dioxide, water and solar energy and stores them in organic compounds which are then used for subsequent plant growth, the growth of animals or the growth of microbes in the soil. All of these organisms release carbon dioxide via respiration into the atmosphere. Most land plants have a system of photosynthesis which will respond positively to increased atmospheric carbon dioxide ("the carbon dioxide fertilization effect") but the response varies with species. The effect may decrease with time when restricted by other ecological limitations, for example, nutrient availability. It should be emphasized that the carbon content of the terrestrial biosphere will increase only if the forest ecosystems in a state of maturity will be able to store more carbon in a warmer climate and at higher concentrations of carbon dioxide. We do not yet know if this is the case.

The response to increased carbon dioxide results in greater efficiencies of water, light and nitrogen use. These increased efficiencies may be particularly important during drought and in arid/semi-arid and infertile areas.

Because species respond differently to climatic change, some will increase in abundance and/or range while others will decrease. Ecosystems will therefore change in structure and composition. Some species may be displaced to higher latitudes and altitudes, and may be more prone to local, and possibly even global, extinction; other species may thrive.

As stated above, ecosystem structure and species distribution are particularly sensitive to the rate of change of climate. We can deduce something about how quickly global temperature has changed in the past from paleoclimatological records. As an example, at the end of the last glaciation, within about a century, temperature increased by up to 5°C in the North Atlantic region, mainly in Western Europe. Although during the increase from the glacial to the current interglacial temperature simple tundra ecosystems responded positively, a similar rapid temperature increase applied to more developed ecosystems could result in their instability.

Deforestation and Reforestation

Man has been deforesting the Earth for millennia. Until the early part of the century, this was mainly in temperate regions, more recently it has been concentrated in the tropics. Deforestation has several potential impacts on climate: through the carbon and nitrogen cycles (where it can lead to changes in atmospheric carbon dioxide concentrations), through the change in reflectivity of terrain when forests are cleared, through its effect on the hydrological cycle (precipitation, evaporation and runoff) and surface roughness and thus atmospheric circulation which can produce remote effects on climate.

It is estimated that each year about 2 Gt of carbon (GtC) is released to the atmosphere due to tropical deforestation. The rate of forest clearing is difficult to estimate; probably until the mid-20th century, temperate deforestation and the loss of organic matter from soils was a more important contributor to atmospheric carbon dioxide than was the burning of fossil fuels. Since then, fossil fuels have become dominant; one estimate is that around 1980, 1.6 GtC was being released annually from the clearing of tropical forests, compared with about 5 GtC from the burning of fossil fuels. If all the tropical forests were removed, the input is variously estimated at from 150 to 240 GtC; this would increase atmospheric carbon dioxide by 35 to 60 ppmv.

To analyse the effect of reforestation we assume that 10 million hectares of forests are planted each year for a period of 40 years, ie 4 million km2 would then have been planted by 2030, at which time 1GtC would be absorbed annually until these forests reach maturity. This would happen in 40-100 years for most forests. The above scenario implies an accumulated uptake of about 20GtC by the year 2030 and up to 80GtC after 100 years. This accumulation of carbon in forests is equivalent to some 5-10% of the emission due to fossil fuel burning in the Business-as-Usual scenario.

Deforestation can also alter climate directly by increasing reflectivity and decreasing evapotranspiration. Experiments with climate models predict that replacing all the forests of the Amazon Basin by grassland would reduce the rainfall over the basin by about 20%, and increase mean temperature by several degrees.

What should be done to reduce uncertainties, and how long will this take?

Although we can say that some climate change is unavoidable, much uncertainty exists in the prediction of global climate properties such as the temperature and rainfall. Even greater uncertainty exists in predictions of regional climate change, and the subsequent consequences for sea level and ecosystems. The key areas of scientific uncertainty are:

- **clouds:** primarily cloud formation, dissipation, and radiative properties, which influence the response of the atmosphere to greenhouse forcing;
- **oceans:** the exchange of energy between the ocean and the atmosphere, between the upper layers of the ocean and the deep ocean, and transport within the ocean, all of which control the rate of global climate change and the patterns of regional change;
- **greenhouse gases:** quantification of the uptake and release of the greenhouse gases, their chemical reactions in the atmosphere, and how these may be influenced by climate change.
- **polar ice sheets:** which affect predictions of sea level rise

Studies of land surface hydrology, and of impact on ecosystems, are also important.

To reduce the current scientific uncertainties in each of these areas will require internationally coordinated research, the goal of which is to improve our capability to observe, model and understand the global climate system. Such a program of research will reduce the scientific uncertainties and assist in the formulation of sound national and international response strategies.

Systematic long-term **observations** of the system are of vital importance for understanding the natural variability of the Earth's climate system, detecting whether man's activities are changing it, parametrising key processes for models, and verifying model simulations. Increased accuracy and coverage in many observations are required. Associated with expanded observations is the need to develop appropriate comprehensive global information bases for the rapid and efficient dissemination and utilization of data. The main observational requirements are:

i) the maintenance and improvement of observations (such as those from satellites) provided by the World Weather Watch Programme of WMO

ii) the maintenance and enhancement of a programme of monitoring, both from satellite-based and surface-based instruments, of key climate elements for which accurate observations on a continuous basis are required, such as the distribution of important atmospheric constituents, clouds, the earth's radiation budget, precipitation, winds, sea surface temperatures and terrestrial ecosystem extent, type and productivity.

iii) the establishment of a global ocean observing system to measure changes in such variables as ocean surface topography, circulation, transport of heat and chemicals, and sea-ice extent and thickness.

iv) the development of major new systems to obtain data on the oceans, atmosphere and terrestrial ecosystems using both satellite-based instruments and instruments based on the surface, on automated instrumented vehicles in the ocean, on floating and deep sea buoys, and on aircraft and balloons.

v) the use of paleoclimatological and historical instrumental records to document natural variability and changes in the climate system, and subsequent environmental response.

The **modelling** of climate change requires the development of global models which couple together atmosphere, land, ocean and ice models and which incorporate more realistic formulations of the relevant processes and the interactions between the different components. Processes in the biosphere (both on land and in the ocean) also need to be included. Higher spatial resolution than is currently generally used is required if regional patterns are to be predicted. These models will require the largest computers which are planned to be available during the next decades.

Understanding of the climate system will be developed from analyses of observations and of the results from model simulations. In addition, detailed studies of particular processes will be required through targetted observational campaigns. Examples of such field campaigns include combined observational and small scale modelling studies for different regions, of the formation, dissipation, radiative, dynamical and microphysical properties of clouds, and ground-based (ocean and land) and aircraft measurements of the fluxes of greenhouse gases from specific ecosystems. In particular, emphasis must be placed on field experiments that will assist in the development and improvement of sub-grid-scale parametrizations for models.

The required program of research will require unprecedented international cooperation, with the World Climate Research Programme (WCRP) of the World Meteorological Organization and International Council of Scientific Unions (ICSU), and the International Geosphere-Biosphere Programme (IGBP) of ICSU both playing vital roles. These are large and complex endeavours that will require the involvement of all nations, particularly the developing countries. Implementation of existing and planned projects will require increased financial and human resources; the latter requirement has immediate implications at all levels of education, and the international community of scientists needs to be widened to include more members from developing countries.

The WCRP and IGBP have a number of ongoing or planned research programs, that address each of the three key areas of scientific uncertainty. Examples include:

- **clouds:**
  International Satellite Cloud Climatology Project (ISCCP);
  Global Energy and Water Cycle Experiment (GEWEX).
- **oceans:**
  World Ocean Circulation Experiment (WOCE);
  Tropical Oceans and Global Atmosphere (TOGA).
- **trace gases:**
  Joint Global Ocean Flux Study (JGOFS);
  International Global Atmospheric Chemistry (IGAC);
  Past Global Changes (PAGES).

As research advances, increased understanding and improved observations will lead to progressively more reliable climate predictions. However considering the complex nature of the problem and the scale of the scientific programmes to be undertaken we know that rapid results cannot be expected. Indeed further scientific advances may expose unforeseen problems and areas of ignorance.

Timescales for narrowing the uncertainties will be dictated by progress over the next 10-15 years in two main areas:

- Use of the fastest possible computers, to take into account coupling of the atmosphere and the oceans in models, and to provide sufficient resolution for regional predictions.
- Development of improved representation of small scale processes within climate models, as a result of the analysis of data from observational programmes to be conducted on a continuing basis well into the next century.

Annex

EMISSIONS SCENARIOS FROM WORKING GROUP III OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

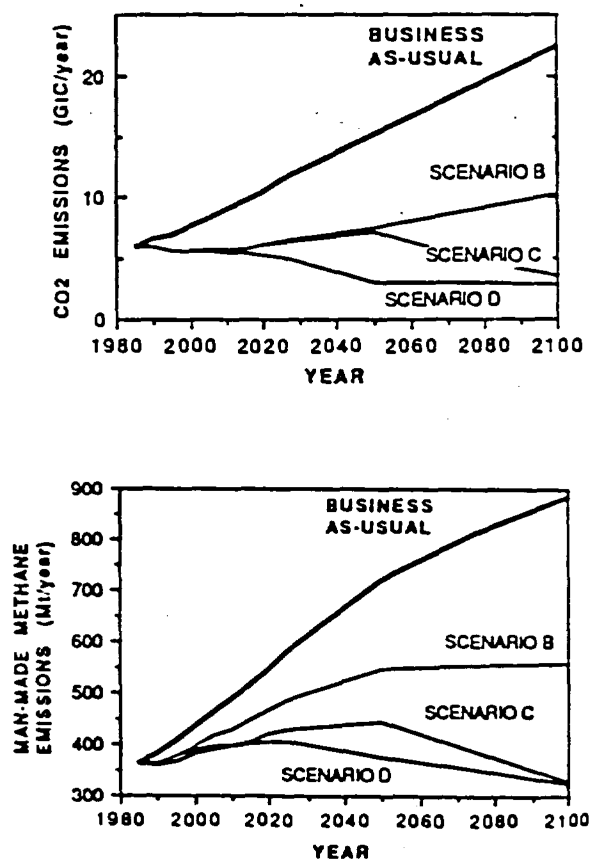
The Steering Group of the Response Strategies Working Group requested the USA and the Netherlands to develop emissions scenarios for evaluation by the IPCC Working Group I. The scenarios cover the emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), carbon monoxide (CO) and nitrogen oxides (NO_x) from the present up to the year 2100. Growth of the economy and population was taken common for all scenarios. Population was assumed to approach 10.5 billion in the second half of the next century. Economic growth was assumed to be 2-3% annually in the coming decade in the OECD countries and 3-5 % in the Eastern European and developing countries. The economic growth levels were assumed to decrease thereafter. In order to reach the required targets, levels of technological development and environmental controls were varied.

In the **Business-as-Usual scenario** (Scenario A) the energy supply is coal intensive and on the demand side only modest efficiency increases are achieved. Carbon monoxide controls are modest, deforestation continues until the tropical forests are depleted and agricultural emissions of methane and nitrous oxide are uncontrolled. For CFCs the Montreal Protocol is implemented albeit with only partial participation. Note that the aggregation of national projections by IPCC Working Group III gives higher emissions (10 - 20%) of carbon dioxide and methane by 2025.

In **Scenario B** the energy supply mix shifts towards lower carbon fuels, notably natural gas. Large efficiency increases are achieved. Carbon monoxide controls are stringent, deforestation is reversed and the Montreal Protocol implemented with full participation.

In **Scenario C** a shift towards renewables and nuclear energy takes place in the second half of next century. CFCs are now phased out and agricultural emissions limited.

For **Scenario D** a shift to renewables and nuclear in the first half of the next century reduces the emissions of carbon dioxide, initially more or less stabilizing emissions in the industrialized countries. The scenario shows that stringent controls in industrialized countries combined with moderated growth of emissions in developing countries could stabilize atmospheric concentrations. Carbon dioxide emissions are reduced to 50% of 1985 levels by the middle of the next century.



Emissions of carbon dioxide and methane (as examples) to the year 2100, in the four scenarios developed by IPCC Working Group III.

WMO

UNEP

Intergovernmental Panel on Climate Change

Policymakers Summary

of the

Potential Impacts of Climate Change

Report from Working Group II to IPCC

June 1990

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Executive summary

The IPCC Working Groups on scientific analysis (Working Group I), impacts (Working Group II) and response strategies (Working Group III) were established in November 1988 and proceeded to work in parallel under instructions from IPCC. The responsibility of Working Group II is to describe the environmental and socio-economic implications of possible climate changes over the next decades caused by increasing concentrations of greenhouse gases.

The report of Working Group II is based on the work of a number of subgroups, using independent studies which have used different methodologies. Based on the existing literature, the studies have used several scenarios to assess the potential impacts of climate change. These have the features of:

(i) an effective doubling of CO_2 in the atmosphere between now and 2025 to 2050 for a 'business-as-usual' scenario;

(ii) a consequent increase of global mean temperature in the range of 1.5°C to 4°-5°C;

(iii) an unequal global distribution of this temperature increase, namely a smaller increase of half the global mean in the tropical regions and a larger increase of twice the global mean in the polar regions; and

(iv) a sea-level rise of about 0.3-0.5 m by 2050 and about 1 m by 2100, together with a rise in the temperature of the surface ocean layer of between 0.2° and 2.5°C.

These scenarios pre-date, but are in line with, the recent assessment of Working Group I which, for a 'business-as-usual' scenario (scenario A in Working Group I Report) has estimated the magnitude of sea-level rise at about 20 cm by 2030 and about 65 cm by the end of the next century. Working Group I has also predicted the increase in global mean temperatures to be about 1°C above the present value by 2025 and 3°C before the end of the next century.

Any predicted effects of climate change must be viewed in the context of our present dynamic and changing world. Large-scale natural events such as El Niño can cause significant impacts on agriculture and human settlement. The predicted population explosion will produce severe impacts on land use and on the demands for energy, fresh water, food and housing, which will vary from region to region according to national incomes and rates of development. In many cases, the impacts will be felt most severely in regions already under stress, mainly the developing countries. Human-induced climate change due to continued uncontrolled emissions will accentuate these impacts. For instance, climate change, pollution and ultra-violet-B radiation from ozone depletion can interact, reinforcing their damaging effects on materials and organisms. Increases in atmospheric concentrations of greenhouse gases may lead to irreversible change in the climate which could be detectable by the end of this century.

Comprehensive estimates of the physical and biological effects of climate change at the regional level are difficult. Confidence in regional estimates of critical climatic factors is low. This is particularly true of precipitation and soil moisture, where there is considerable disagreement between various general circulation model and palaeoanalog results. Moreover, there are several scientific uncertainties regarding the relationship between climate change and biological effects and between these effects and socioeconomic consequences.

This report does not attempt to anticipate any adaptation, technological innovation or any other measures to diminish the adverse effects of climate change that will take place in the same time frame. This is especially important for heavily managed sectors, eg agriculture, forestry and public health. This is one of the responsibilities of Working Group III.

Finally, the issue of timing and rates of change need to be considered; there will be lags between:

i) emissions of greenhouse gases and doubling of concentrations;

ii) doubling of greenhouse gas concentrations and changes in climate;

iii) changes in climate and resultant physical and biological effects; and

iv) changes in physical and ecological effects and resultant socioeconomic (including ecological) consequences. The shorter the lags, the less the ability to cope and the greater the socioeconomic impacts.

There is uncertainty related to these time lags. The changes will not be steady and surprises cannot be ruled out. The severity of the impacts will depend to a large degree on the rate of climate change.

Despite these uncertainties, Working Group II has been able to reach some major conclusions, which are:

Agriculture and forestry

Sufficient evidence is now available from a variety of different studies to indicate that changes of climate would have an important effect on agriculture and livestock. Studies have not yet conclusively determined whether, on average, global agricultural potential will increase or decrease. Negative impacts could be felt at the regional level as a result of changes in weather and pests associated with climate change, and changes in ground-level ozone associated with pollutants, necessitating innovations in technology and agricultural management practices. There may be severe effects in some regions, particularly decline in production in regions of high present-day vulnerability that are least able to adjust. These include Brazil, Peru, the Sahel Region of Africa, Southeast Asia, the Asian region of the USSR and China. There is a possibility that potential productivity of high and mid latitudes may increase because of a prolonged growing season, but it is not likely to open up large new areas for production and it will be mainly confined to the Northern Hemisphere.

Patterns of agricultural trade could be altered by decreased cereal production in some of the currently high-production areas, such as Western Europe, southern US, parts of South America and western Australia. Horticultural production in mid-latitude regions may be reduced. On the other hand, cereal production could increase in northern Europe. Policy responses directed to breeding new plant cultivars, and agricultural management designed to cope with changed climate conditions, could lessen the severity of regional impacts. On balance, the evidence suggests that in the face of estimated changes of climate, food production at the global level can be maintained at essentially the same level as would have occurred without climate change; however, the cost of achieving this is unclear. Nonetheless, climate change may intensify difficulties in coping with rapid population growth. An increase or change in UV-B radiation at ground level resulting from the depletion of stratospheric ozone will have a negative impact on crops and livestock.

The rotation period of forests is long and current forests will mature and decline during a climate in which they are increasingly more poorly adapted. Actual impacts depend on the physiological adaptability of trees and the host-parasite relationship. Large losses from both factors in the form of forest declines can occur. Losses from wildfire will be increasingly extensive. The climate zones which control species distribution will move poleward and to higher elevations. Managed forests require large inputs in terms of choice of seedlot and spacing, thinning and protection. They provide a variety of products from fuel to food. The degree of dependency on products varies among countries, as does the ability to cope with and to withstand loss. The most sensitive areas will be where species are close to their biological limits in terms of temperature and moisture. This is likely to be, for example, in semi-arid areas. Social stresses can be expected to increase and consequent anthropogenic damage to forests may occur. These increased and non-sustainable uses will place more pressure on forest investments, forest conservation and sound forest management.

Natural terrestrial ecosystems

Natural terrestrial ecosystems could face significant consequences as a result of the global increases in the atmospheric concentrations of greenhouse gases and the associated climatic changes. Projected changes in temperature and precipitation suggest that climatic zones could shift several hundred kilometres towards the poles over the next fifty years. Flora and fauna would lag behind these climatic shifts, surviving in their present location and, therefore, could find themselves in a different climatic regime. These regimes may be more or less hospitable and, therefore, could increase productivity for some species and decrease that of others. Ecosystems are not expected to move as a single unit, but would have a new structure as a consequence of alterations in distribution and abundance of species.

The rate of projected climate changes is the major factor determining the type and degree of climatic impacts on natural terrestrial ecosystems. These rates are likely to be faster than the ability of some species to respond and responses may be sudden or gradual.

Some species could be lost owing to increased stress leading to a reduction in global biological diversity. Increased incidence of disturbances such as pest outbreaks and fire are likely to occur in some areas and these could enhance projected ecosystem changes.

Consequences of CO_2 enrichment and climate change for natural terrestrial ecosystems could be modified by other environmental factors, both natural and man-induced (eg by air pollution).

Most at risk are those communities in which the options for adaptability are limited (eg montane, alpine, polar, island and coastal communities, remnant vegetation, and heritage sites and reserves) and those communities where climatic changes add to existing stresses.

The socioeconomic consequences of these impacts will be significant, especially for those regions of the globe where societies and related economies are dependent on natural terrestrial ecosystems for their welfare. Changes in the availability of food, fuel, medicine, construction materials and income are possible as these ecosystems are changed. Important fibre products could also be affected in some regions.

Hydrology and water resources

Relatively small climate changes can cause large water resource problems in many areas, especially arid and semi-arid regions and those humid areas where demand or pollution has led to water scarcity. Little is known about regional details of greenhouse-gas-induced hydrometeorological change. It appears that many areas will have increased precipitation, soil moisture and water storage, thus altering patterns of agricultural, ecosystem and other water use. Water availability will decrease in other areas, a most important factor for already marginal situations, such as the Sahelian zone in Africa. This has significant implications for agriculture, for water storage and distribution, and for generation of hydroelectric power. In some limited areas, for example, under the assumed scenario of a 1°C to 2°C temperature increase, coupled with a 10% reduction in precipitation, a 40-70% reduction in annual runoff could occur. Regions such as Southeast Asia, that are dependent on unregulated river systems, are particularly vulnerable to hydrometeorological change. On the other hand, regions such as the western USSR and western United States that have large regulated water resource systems are less sensitive to the range of hydrometeorological changes in the assumed greenhouse scenario.

In addition to changes in water supply, water demand may also change through human efforts to conserve, and through improved growth efficiency of plants in a higher CO_2 environment. Net socioeconomic consequences must consider both supply and demand for water. Future design in water resource engineering will need to take possible impacts into account when considering structures with a life span to the end of the next century. Where precipitation increases, water management practices, such as urban storm drainage systems, may require upgrading in capacity. Change in drought risk represents potentially the most serious impact of climate change on agriculture at both regional and global levels.

Human settlements, energy, transport, and industrial sectors, human health and air quality

The most vulnerable human settlements are those especially exposed to natural hazards, eg coastal or river flooding, severe drought, landslides, severe wind storms and tropical cyclones. The most vulnerable populations are in developing countries, in the lower income groups, residents of coastal lowlands and islands, populations in semi-arid grasslands, and the urban poor in squatter settlements, slums and shanty towns, especially in megacities. In coastal lowlands such as in Bangladesh, China and Egypt, as well as in small island nations, inundation due to sea-level rise and storm surges could lead to significant movements of people. Major health impacts are possible, especially in large urban areas, owing to changes in availability of water and food and increased health problems due to heat stress spreading of infections. Changes in precipitation and temperature could radically alter the patterns of vector-borne and viral diseases by shifting them to higher latitudes, thus putting large populations at risk. As similar events have in the past, these changes could initiate large migrations of people, leading over a number of years to severe disruptions of settlement patterns and social instability in some areas.

Global warming can be expected to affect the availability of water resources and biomass, both major sources of energy in many developing countries. These effects are likely to differ between and within regions with some areas losing and others gaining water and biomass. Such changes in areas which lose water may jeopardise energy supply and materials essential for human habitation and energy. Moreover, climate change itself is also likely to have different effects between regions on the availability of other forms of renewable energy such as wind and solar power. In developed countries some of the greatest impacts on the energy, transport and industrial sectors may be determined by policy responses to climate change such as fuel regulations, emission fees or policies promoting greater use of mass transit. In developing countries, climate-related changes in the availability and price of production resources such as energy, water, food and fibre may affect the competitive position of many industries.

Global warming and increased ultra-violet radiation resulting from depletion of stratosphere ozone may produce adverse impacts on air quality such as increases in ground-level ozone in some polluted urban areas. An increase of UV-B radiation intensity at the earth's surface would increase the risk of damage to the eye and skin and may disrupt the marine food chain.

Oceans and coastal zones

Global warming will accelerate sea-level rise, modify ocean circulation and change marine ecosystems, with considerable socioeconomic consequences. These effects will be added to present trends of rising sea-level, and other effects that have already stressed coastal resources, such as pollution and over-harvesting. A 30-50 cm sea-level rise (projected by 2050) will threaten low islands and coastal zones. A 1 m rise by 2100 would render some island countries uninhabitable, displace tens of millions of people, seriously threaten low-lying urban areas, flood productive land, contaminate fresh water supplies and change coastlines. All of these impacts would be exacerbated if droughts and storms become more severe. Coastal protection would involve very significant costs. Rapid sea-level rise would change coastal ecology and threaten many important fisheries. Reductions in sea ice will benefit shipping, but seriously impact on ice-dependent marine mammals and birds.

Impacts on the global oceans will include changes in the heat balance, shifts in ocean circulation which will affect the capacity of the ocean to absorb heat and CO_2, and changes in upwelling zones associated with fisheries. Effects will vary by geographic zones, with changes in habitats, a decrease in biological diversity and shifts in marine organisms and productive zones, including commercially important species. Such regional shifts in fisheries will have major socioeconomic impacts.

Seasonal snow cover, ice and permafrost

The global areal extent and volume of elements of the terrestrial cryosphere (seasonal snow cover, near-surface layers of permafrost and some masses of ice) will be substantially reduced. These reductions, when reflected regionally, could have significant impacts on related ecosystems and social and economic activities. Compounding these impacts in some regions is that, as a result of the associated climatic warming positive feedbacks, the reductions could be sudden rather than gradual.

The areal coverage of seasonal snow and its duration are projected to decrease in most regions, particularly at mid-latitudes, with some regions at high latitudes possibly experiencing increases in seasonal snow cover. Changes in the volume of snow cover, or the length of the snow cover season, will have both positive and negative impacts on regional water resources (as a result of changes in the volume and the timing of runoff from snowmelt); on regional transportation (road, marine, air and rail); and on recreation sectors.

Globally, the ice contained in glaciers and ice sheets is projected to decrease, with regional responses complicated by the effect of increased snowfall in some areas which could lead to accumulation of ice. Glacial recession will have significant implications for local and regional water resources, and thus impact on water availability and on hydroelectric power potential. Glacial recession and loss of ice from ice sheets will also contribute to sea-level rise.

Permafrost, which currently underlies 20-25% of the land mass of the Northern Hemisphere, could experience significant degradation within the next 40-50 years. Projected increases in the thickness of the freeze-thaw (active) layer above the permafrost and a recession of permafrost to higher latitudes and altitudes could lead to increases in terrain instability, erosion and landslides in those areas which currently contain permafrost. As a result, overlying ecosystems could be significantly altered and the integrity of man-made structures and facilities reduced, thereby influencing existing human settlements and development opportunities.

Future action

The results of the Working Group II studies highlight our lack of knowledge, particularly at the regional level and in areas most vulnerable to climate change. Further national and international research is needed on:

- regional effects of climate change on crop yields, livestock productivity and production costs;
- identification of agricultural management practices and technology appropriate for changed climate;
- factors influencing distribution of species and their sensitivity to climate change;
- initiation and maintenance of integrated monitoring systems for terrestrial and marine ecosystems;
- intensive assessment of water resources and water quality, especially in arid and semi-arid developing countries and their sensitivity to climate change;
- regional predictions of changes in soil moisture, precipitation, surface and subsurface runoff regimes and their interannual distributions as a result of climate change;
- assessment of vulnerability of countries to gain or loss of energy resources, particularly biomass and

hydroelectric power in developing countries;

- adaptability of vulnerable human populations to heat stress and vector-borne and viral diseases;

- global monitoring of sea-level changes, particularly for island countries;

- identification of populations and agricultural and industrial production at risk in coastal areas and islands;

- better understanding of the nature and dynamics of ice masses and their sensitivity to climate change;

- integration of climate change impact information into the general planning process, particularly in developing countries; and

- development of methodology to assess sensitivity of environments and socioeconomic systems to climate change.

- Some of these topics are already being covered by existing and proposed programs and these will need continuing support. In particular, there are three core projects of the International Geosphere-Biosphere Program, namely:

  Land-Ocean Interactions in the Coastal Zone

  Biosphere Aspects of the Hydrological Cycle

  Global Change Impact on Agriculture and Society

  that will provide valuable data in the coming years.

Scenarios

Any changes which take place as the results of increasing emissions must be viewed against a background of changes which are already occurring and which will continue to occur as a result of other factors such as:

- Natural changes - these include long-term changes which are driven by solar and tectonic factors, and short-to-medium term changes which are driven by ocean and atmospheric circulation patterns.
- Population increase - the predicted world population is expected to be above 10 billion by the middle of the next century; this growth will be unevenly distributed on a regional basis and will impact on already vulnerable areas.
- Land use changes - the clearing of forests for new agricultural production, together with more intensive use of existing agricultural land, will contribute to land degradation and increase demands for water resources.

In an ideal world, Working Group I would have had the time to produce scenarios for emission-induced climate change which could have been used as a basis for the analyses of this Working Group. However, this was precluded because work proceeded in parallel. As a result, and in order to complete its work in time, Working Group II has used a number of scenarios based on existing models in the literature.

The scenarios generally have the following features:

(i) an effective doubling of CO_2 in the atmosphere over pre-industrial levels between now and 2025 to 2050 for a 'business-as-usual' scenario, with no changes to present policy;

(ii) an increase of mean global temperature in the range 1.5°C to 4.5°C corresponding to the effective doubling of CO_2;

(iii) an unequal global distribution of this temperature increase, namely half the global mean in the tropical regions and twice the global mean in the polar regions;

(iv) a sea-level rise of about 0.3 to 0.5 m by 2050 and about 1 m by 2100, together with a rise in temperature of the surface ocean layer of between 0.2° and 2.5°.

These scenarios can be compared with the recent assessment of Working Group I which, for a 'business as usual' scenario, has predicted the increase in global temperatures to be about 1°C above the present value by 2025 and 3°C before the end of next century. However, it has also estimated the magnitude of sea-level rise to be about 20 cm by 2030 and about 65 cm by the end of next century. Nevertheless, the impacts based on 1-2 m rise serve as a warning of the consequences of continued uncontrolled emissions.

The smaller rise does not lessen the anxiety, for their continued existence, of the small island countries, particularly the Pacific and Indian Oceans and the Caribbean, or of the larger populations in low-lying coastal areas such as Bangladesh. It is difficult to predict the regional effects of sea-level rise with any certainty. Significant variations of sea-level already occur for a variety of reasons, while there are considerable shifts in land levels associated with tectonic plate movements which can also lead to rises and falls.

The scenarios of Working Group II are derived both from General Circulation Models and from palaeoanalog techniques. Palaeoclimate analogs are proposed by Soviet scientists as a means by which climate changes can be assessed. The methodology assumes that past warm geologic intervals provide insight into possible future climate conditions. The General Circulation Models, developed by Western scientists, are based on three-dimensional mathematical representations of the physical processes in the atmosphere and the interactions of the atmosphere with the earth's surface and the oceans. There is considerable scientific debate about the merits and demerits of each of these, as discussed in the report of Working Group I.

The palaeoclimate scenarios used by Soviet scientists are based on three warm geological periods with estimated future levels of concentration of CO_2 applied to them. The details of these are shown in Table 1. While these are superficially similar to the predictions of the general circulation model approach for different CO_2 concentrations, the factors which caused the climate changes in geologic times are not clear. Nevertheless, they have been used to make predictions of climate change of regions in the USSR.

The General Circulation Models are, in their current state of development, comparatively crude in their description of many of the processes involved. However they can be used to simulate regional changes resulting from a range of concentrations of CO_2 in the atmosphere. Working Group I has favoured the general circulation model approach in producing its predictions of temperature rise and precipitation changes. In its report, estimates for 2030 have been given for central North America, southern Asia, Sahel, southern Europe and Australia. These are reproduced in Table 2 and are broadly similar to those used by Working Group II.

Despite the current uncertainties, both techniques have been used by Working Group II in the development of regional impacts to assist policy makers. There are problems with prediction of regional precipitation since there is disagreement between various general circulation model outputs as a result of simplifications to the representation of complex physical processes. Current research is seeking to improve the general circulation model approach and to increase resolution to enable better regional predictions. There are also problems with the palaeoanalog approach which yields differing scenarios for precipitation from the general circulation model approach. This leads to different assessments of impact on water resources and agriculture. Soviet scientists are working to validate their techniques and improve regional scenarios.

It should be noted that, in many situations, the overall impact is determined more by the changes in the magnitude and frequency of extreme events than by changes in the average. This is especially the case for tropical storms and droughts. The assessment of Working Group I of possible climate changes suggests a low probability of increased frequency of extreme events. However, it is entirely possible that shifts in climate regimes will result in changes in frequency in certain regions.

Table 1 Palaeoclimate analogs used by Soviet scientists

Period	Analogue (year)	Temperature (difference from present)	Past CO_2 concn. (ppm)	Assumed CO_2 concn. (ppm)
Holocene Optimum	2000	+1	280	380
Eemian Interglacial	2025	+2	280	420
Pliocene	2050	+4	500-600	560

Table 2 Estimates for regional changes by Working Group I
(IPCC Business-as-Usual scenario; changes from pre-industrial)

The estimates are based on high resolution models, scaled to give a global mean warming of 1.8°C consistent with the best estimate (2.5°C) of climate response to greenhouse gases. With the low estimate value of 1.5°C, these values should be reduced by 30%; with a high estimate of 4.5°C, they should be increased by 50%. Confidence on these estimates is low.

Central North America (35°-50°N 85°-105°W)
The warming varies from 2° to 4°C in winter and 2° to 3°C in summer. Precipitation increase range from 0% to 15% in winter, whereas there are decreases of 5% to 10% in summer. Soil moisture decreases in summer by 15% to 20%.

Southern Asia (5°-30°N 70°-105°E)
The warming varies from 1° to 2°C throughout the year. Precipitation changes little in winter and generally increases throughout the region by 5% to 15% in summer. Summer soil moisture increases by 5% to 10%.

Sahel (10°-20°N 20°W-40°E)
The warming ranges from 1° to 3°C. Area mean precipitation increases and area mean soil moisture decreases marginally in summer. However, there are areas of both increase and decrease in both parameters throughout the region, which differ from model to model.

Southern Europe (30°-50°N 10°W-45°E)
The warming is about 2°C in winter and varies from 2° to 3°C in summer. There is some indication of increased precipitation in winter, but summer precipitation decreases by 5% to 15%, and summer soil moisture by 15% to 25%.

Australia (12°-45°S 110°-155°E)
The warming ranges from 1° to 2° in summer and is about 2°C in winter. Summer precipitation increases by around 10%, but the models do not produce consistent estimates of the changes in soil moisture. The area averages hide large variations at the subcontinental level.

An issue of importance not considered in any detail is the impact of possible response strategies (developed by Working Group III) on the scenarios used here. Thus, a major change in energy production from fossil fuel to nuclear or renewable energy sources could drastically alter our assessments. Further, changes in agricultural practice could dramatically alter yields of particular crops in certain regions. These impacts of response strategies require much additional work.

Despite all these uncertainties, it is possible to make assessments of potential impacts of climate change by considering the sensitivity of natural systems to significant variations. These are summarised in the following sections under: agriculture and forestry; terrestrial ecosystems; hydrology and water resources; human settlement, energy, transport, industry, human health and air quality; world ocean and coastal zones; seasonal snow cover, ice and permafrost.

Summary of findings

Potential impacts of climate change on agriculture, land use and forestry

Potential impacts on agriculture

Major findings

- Sufficient evidence is now available from a variety of different studies to indicate that changes of climate would have an important effect on agriculture, including livestock. Yet the fact that there are major uncertainties regarding likely effects in specific regions should be a cause for concern. Studies have not yet conclusively determined whether, on average, global agricultural potential will increase or decrease.

- Negative impacts could be felt at the regional level as a result of changes in weather, diseases, pests and weeds associated with climate change, necessitating innovation in technology and agriculture management practices. There may be severe effects in some regions, particularly in regions of high present-day vulnerability that are least able to adjust technologically to such effects.

- There is a possibility that potential productivity of high and mid-latitudes may increase because of a prolonged growing season, but it is not likely to open up large new areas for production, and will be largely confined to the Northern Hemisphere.

- On balance, the evidence is that in the face of estimated changes of climate, food production at the global level can be maintained at essentially the same level as would have occurred without climate change; but the cost of achieving this is unclear. Nonetheless, climate changes may intensify difficulties in coping with rapid population growth.

Principal issues

Magnitudes of possible dislocation

Under the estimate of changes in productive potential for the changes of climate outlined in this report, the cost of producing some mid-latitude crops, such as maize and soybean, could increase, reflecting a small net decrease in the global food production capability of these crops. Rice production could, however, increase if available moisture increased in Southeast Asia, but these effects may be limited by increased cloudiness and temperature. The average global increase in overall production costs due to climate change could thus be small.

Much depends on the possible benefits of the so-called 'direct' effects of increased CO_2 on crop yield. If plant productivity were substantially enhanced and more moisture were available in some major production areas, then world production of staple cereals could increase relative to demand. If, on the contrary, there is little beneficial direct CO_2 effect and climate changes are negative for agricultural potential in all or most of the major food-exporting areas, then the average costs of world agricultural production due to climate change could increase significantly.

Most vulnerable regions and sectors

On the basis of both limited resource capacity in relation to present-day population and possible future diminution of the agricultural resource base as a consequence of reduced crop-water availability, two broad sets of regions appear most vulnerable to climate change: (i) some semi-arid, tropical and subtropical regions (such as western Arabia, the Maghreb, western West Africa, Horn of Africa and southern Africa, eastern Brazil), and (ii) some humid tropical and equatorial regions (such as Southeast Asia and Central America).

In addition, certain regions that are currently net exporters of cereals could also be characterised by reduced productive potential as a result of climate changes. Any decrease in production in these regions could markedly affect future global food prices and patterns of trade. These regions might include, for example, Western Europe, southern US, parts of South America, and Western Australia.

Effect of altered climate extremes

Relatively small changes in the mean values of rainfall and temperature can have a marked effect on the frequency of extreme levels of available warmth and moisture. For example, the number of very hot days which can cause damaging heat stress to temperate crops and livestock could increase significantly in some regions as a result of a 1°C to 2°C increase in mean annual temperatures. Similarly, reduction in average levels of soil moisture as a result of higher rates of evapotranspiration could increase substantially the number of days below a minimum threshold of water availability for given crops.

Although at present we know little about how the frequency of extreme events may alter as a result of climate change, the potential impact of concurrent drought or heat stress in the major food-exporting regions of the world could be severe. In addition, relatively small decreases in rainfall, changes in rainfall distribution or increases in evapotranspiration could markedly increase the probability, intensity and duration of drought in currently drought-prone (and often food-deficient) regions. Increase in drought risk represents potentially the most serious impact of climate change on agriculture at both the regional and global level.

Effects on crop growth potential, land degradation, pests and diseases

Higher levels of atmospheric CO_2 are expected to enhance the growth rate of some staple cereal crops, such as wheat and rice, but not of others such as millet, sorghum and maize. The use of water by crop plants may also be more efficient under higher CO_2 levels. However, it is not clear how far the potentially beneficial 'direct' effects of enhanced atmospheric CO_2 will be manifested in the farmer's field.

Warming is likely to result in a poleward shift of thermal limits of agriculture, which may increase productive potential in high-latitude regions. But soils and terrain may not enable much of this potential to be realised. Moreover, shifts of moisture limits in some semi-arid and sub-humid regions could lead to significant reductions of potential with serious implications for regional food supplies in some developing countries. Horticultural production in mid-latitude regions may be reduced owing to insufficient accumulated winter chilling. The impact of climate change will be far greater for long-lived horticultural fruit crops, with long establishment periods, than for annual crops where new cultivars can quickly replace others.

Temperature increases may extend the geographic range of some insect pests, diseases and weeds, allowing their expansion to new regions as they warm and become suitable habitats. Changes in temperature and precipitation may also influence soil characteristics.

Regional impacts

Impacts on potential yields are likely to vary greatly according to types of climate change and types of agriculture.

In the northern mid-latitude regions, where summer drying may reduce productive potential (eg in the south and central US and in southern Europe), yield potential is estimated to fall by 10-30% under an equilibrium 2 x CO_2 climate by the middle of the next century. Towards the northern edge of current core producing regions, however, warming may enhance productive potential in climatic terms. When combined with direct CO_2 effects, increased climatic potential could be substantial - though in actuality it may be limited by soils, terrain and land use.

There are indications that warming could lead to an overall reduction of cereal production potential in North America and to southern Europe, but increased potential in northern Europe. Warming could allow increased agricultural output in regions near the northern limit of current production in the USSR and North America, but output in the southern areas of these regions could only increase if corresponding increases in soil moisture were to occur; this is at present uncertain.

Little is known about likely impacts in semi-arid and humid tropical regions, because production potential here largely depends on crop-water availability, and the regional pattern of possible changes in precipitation is unclear at present. It is prudent, however, to assume that crop-water availability could decrease in some regions. Under these circumstances there could be substantial regional dislocation of access to food.

Adaptation in agriculture

In some parts of the world, climatic limits to agriculture are estimated to shift poleward by 200-300 km per degree of warming. The warming-induced upwards shift in thermal zones above mountain slopes could be in the order of 150-200 m.

Agriculture has an ability to adjust, within given economic and technological constraints, to a limited rate and range of climate change. This capability varies greatly between regions and sectors, but no thorough analysis of adaptive capacity has yet been conducted for the agriculture sector.

In some currently highly variable climates, farmers may be more adaptable than those in regions of more equable climate. But in developing economies, and particularly in some marginal types of agriculture, this intrinsic adaptive capability may be much lower. It is important to establish in more detail the nature of this adaptability and thus help to determine critical rates and ranges of climatic change that would exceed those that could be accommodated by adjustments within the system.

Recommendations for action

This study has emphasised the inadequacy of our present knowledge. It is clear that more information on potential impacts would help to identify the full range of potentially useful responses and assist in determining which of these may be most valuable.

Some priorities for future research may be summarised as follows:

- Improved knowledge is needed of effects of changes in climate on crop yields and livestock productivity in different regions and under varying types of management. To date, less than a dozen detailed regional studies have been completed, and these are insufficient as a basis for generalising about effects on food production at the regional or world scale. Further research in vulnerable regions in particular should be encouraged.

- Improved understanding of the effects of changes in climate on other physical processes is needed: for example on rates of soil erosion and salinisation; on soil nutrient depletion; on pests, diseases and soil microbes, and their vectors; on hydrological conditions as they affect irrigation water availability.

- An improved ability is required to 'scale-up' our understanding of effects on crops and livestock, effects on farm production, on village production, and on national and global food supply. This is particularly important because policies must be designed to respond to impacts at the national and global levels. Further information is needed on the effects of changes in climate on social and economic conditions in rural areas (eg employment and income, equity considerations, farm infrastructure, and support services).

- Further information is needed on the range of potentially effective technical adjustments at the farm and village level (eg irrigation, crop selection, fertilising etc) and on the economic and political constraints on such adjustments. In particular, it is recommended that national and international centres of agricultural research consider the potential value of new research programs aimed at identifying or developing cultivars and management practices appropriate for altered climates.

- Further information is needed on the range of potentially effective policy responses at regional, national and international levels (eg reallocation of land use, plant breeding, improved agricultural extension schemes, large-scale water transfers etc).

Potential impacts on managed forests and the forest sector

All impacts referred to in this section reflect the current uncertainty in the extent of warming, and levels and distribution of precipitation. They reflect the consensus that anthropogenic change is occurring; the direction is towards higher temperatures, with the extent affected by latitude and continentality.

The distinction between managed and unmanaged forests is often unclear, but it is taken here to be one of degree in the intensity of human intervention. In managed forests, harvesting takes place and the forests are renewed, replaced or restructured in such a way that actual physical inputs are needed to achieve goals.

Managed forests are quite distinct from the unmanaged forests. They supply a wide variety of products and are found in a wide variety of countries with different social, physical and political environments. The intensity of forest management may not necessarily parallel the degree of economic development; different countries depend to different degrees on the products from forests.

Therefore the severity of the impacts will vary among countries as will the ability to respond. In tropical countries the managed forests characteristically employ exotic species, whereas in the northern countries greater reliance is placed on indigenous species.

Biophysical effects on forest ecosystems

Impacts on forest ecosystems will be at the tree and microsite levels, at the stand/watershed level and at the regional level. Impacts on individual trees include tolerance of drought and winds, the possible effects of altered seasonality (active vs dormant stages), altered photosynthetic rates and increased water use efficiency. At the microsite level, moisture may be limited and biological soil processes may be enhanced. Forest renewal will be adversely affected if there is a shortage of moisture at the critical establishment phase.

On stand levels, insects and diseases can be expected to cause significant losses to forests and these losses can be expected to increase with increasing change. Fire severity will increase, and while managed forests may have less fuel available than unmanaged ecosystems, this will not lessen the incidence of fire, nor will it affect the weather conditions giving rise to the rates of spread or the extent of the areas burned. Developed countries can barely cope with the current state and the extent of areas burned seem to be rising. The incidence of fire may be less in the tropics as the climate there changes less, but many plantations are in semi-arid zones and will be suffer adverse impacts. Costs associated with flooding, resulting from rising sea-levels and disruption of weather patterns, can be expected. There will be problems in using the lower quality wood grown under stress and large costs associated with moving processing facilities and infrastructure as the wood supply zones move northward. The most important feature of these costs and disruptions from a global point of view is that the changes will differ among countries and that some countries are better able than others to cope with the impacts.

Major forest-type zones and species ranges could shift significantly as a result of climate change. Results of several Northern Hemisphere studies show that both high-latitude and low-latitude boundaries of temperate and northern forests (and tree species) may shift hundreds of kilometres poleward. In contrast, studies in the Southern Hemisphere suggest that Australian species could adapt and grow at temperatures much warmer than those of their natural distribution.

At the stand level, the following effects of climate change on forests are likely: increased mortality owing to physical stress; increased susceptibility to and infestations of insects and diseases; increased susceptibility to and incidences of fire; changed stand growth rates, both increases and decreases; more difficult stand establishment by both natural and artificial regeneration; and changed composition of species.

Two broad types of forests are likely to be sensitive to a changing climate: (i) boreal forests, where stands are mainly even-aged and often temperature-limited, and where temperature changes are expected to be large; and (ii) forests in arid and semi-arid regions where increased temperatures and stable or decreasing precipitation could render sites inhospitable to the continued existence of current forest stands. However, there could be compensating effects of faster growth owing to higher ambient CO_2.

Socioeconomic implications

All countries use forests for heating, cooking and food. The degree to which people are dependent on these, however, varies widely. Forest ecosystem changes and tree distribution have no regard for political or administrative boundaries. Managed forests have, by definition, high levels of investment in them; some countries are better able than others to tolerate the risk to, and possible loss, of these investments.

Intensively managed forests have high inputs from choice of species, sites, spacing, tending, thinning, fertilisation and protection. These interventions are costly and some countries may not be able to supply the inputs necessary to establish, maintain and protect the investments.

Increased protection costs will be unevenly borne and could encourage poorer countries to accelerate harvesting, reduce rotation periods and engage in other practices, which may not be sustainable. More data are needed on these secondary and insidious effects of climate change. Associated disruptions in the social fabric of many countries may impact adversely on forests, as instances of arson or other damage as do now.

The socioeconomic implications of shifts in the ranges of tree species will be influenced by the fact that climate will probably change much faster than tree species can naturally respond (eg through migration).

Moreover, new sites may not be hospitable, having evolved over thousands of years under other climatic and vegetative regimes. The suitability of new ranges and the actual composition and growth patterns of forests under new climates will have no regard for non-ecological boundaries such as watersheds, ownerships, parks, nature reserves and recreation areas.

It is concluded that climate change could more likely exacerbate most current and near-term issues and tensions rather than relieve them. This finding is very dependent on the assumption that during the next 30-50 years, in response to climate change, forests everywhere in the world will be prone to some measure and form of decline. These changes will be taking place at the same time as a substantial increase in population with increased demands. If, on the other hand, forests in some regions are largely unaffected by climate change, or actually experience increased growth rates, then perhaps most of the issues and tensions could be at least partly relieved.

Adaptation

Much can be done to reduce the susceptibility of socioeconomic systems to climate-induced forest declines. Appropriate measures include the whole array of forest-management tools, to be chosen and implemented as local conditions warrant, but some may be detrimental to other indicators, for example, wildlife or recreation.

For wood supply, the forest-products industry can move processing technology towards new kinds and qualities of fibre, and plan new mills in areas improving in wood-supply potential. Governments can support efforts in economic diversification in forest-based communities, and engage in improved long-range planning for future changes in land potential for forestry. The provision of recreational facilities is another example of an important forest-based economic sector. Governments and private firms must anticipate how forested landscapes might change, and plan accordingly to divest themselves of the old facilities and invest in the new.

Recommendations for action

The ability to deal with climate change and the forest sector is related to the amount of knowledge available. There are uncertainties to be considered: for instance, in the future, will the same tensions and issues have similar high priority? Studies of the socioeconomic impacts must be global in scope, international in organisation, institutional in focus and historical in breadth. We need regional climate scenarios and better information on stand-level responses, the biological relationship between species and sites and the inherent variability of species. Changing climates demonstrate the need for strategies in active management in the forest sector. Even better knowledge is needed of the potential role of forest management in mitigating impacts and exploiting opportunities from climate change.

A major impact, of which there is evidence now, will be considerable apprehension on the part of the general public, particularly those dependent on the forest sector for their livelihood. Public cooperation in the implementation of decisions will be required for dealing with a problem which has biological rather than ideological solutions.

Research on the socioeconomic impacts of climate change must focus on the transitional climates occurring over the next several decades, not only at specific points in time. This reflects the way people live - in specific localities and in real time. It makes sense to prepare for serious impacts by implementing policies which are biologically sustainable, even if the eventual changes are minimal.

Examining biogeochemical changes on a global scale is complex enough; adding humans as a variable factor complicates the issue even more. Nevertheless, humans are the critical element in the study of ecological systems. We must consider the institutional imperatives and the economic and political influences on people in different nations, together with the cultural diversity that distinguishes and may dominate our actions.

The nature and temporal/spatial distribution of climate change itself is highly uncertain, as are the various ways by which a changing climate could influence forests and their growing sites, and the various repercussions this might have on our uses of forests. Moreover, the means by which society might cope with the changing environmental and socioeconomic conditions, in a context in which those conditions are rapidly changing quite independently of climate change, are largely unexplored so far.

The following major research and assessment initiatives should be developed and pursued in the near future (early 1990s) to begin to shed light on the impacts discussed in this section: (i) more secure regional climate scenarios; (ii) simulation of impacts of climate change on managed forest stands; (iii) modelling studies for better understanding of matches between species and sites; (iv) analyses of the potential role of forest management in mitigating undesirable impacts and capitalising on desirable impacts of climate change; (v) regional analyses of potential disruption of wildlife habitat and the recreational potential of forests due to forest-structure changes brought on by climate change; (vi) regional analyses of potential socioeconomic repercussions of fluctuations in timber supply due to climate change on rural communities, industrial concerns, markets and trade in forest products, and governments. (vii) synthesis studies of the policy possibilities for the forest sector to prepare for climate change; and (viii) periodical assessment of the destruction of tropical forests using remote sensing.

Potential impacts of climate change on natural terrestrial ecosystems and the socioeconomic consequences

Major findings

- Global increases in the atmospheric concentration of greenhouse gases and related climatic changes will have significant consequences for natural terrestrial ecosystems and related socioeconomic systems.

- Climatic zones could shift several hundred kilometres towards the poles. Flora and fauna would lag behind these climatic shifts, surviving in their present location; they would therefore find themselves in a different climatic regime.

- The rate of projected climatic changes is the major factor determining the type and degree of climatic impacts on natural terrestrial ecosystems. These rates are likely to be faster than the ability of some species to respond and these responses may be sudden or gradual.

- New climatic regimes may be less hospitable under some circumstances (eg towards lower latitudes and lower altitudes) and may be more hospitable under others (eg towards higher latitudes). Vegetation zone changes are projected to be greatest where the land is classified as polar desert, tundra and boreal forest.

- Ecosystems are not expected to move as a single unit, but would have a new structure as a consequence of alterations in species distributions and abundance.

- Some species could be lost owing to increased stresses leading to a reduction in global biological diversity, whereas other species may thrive as stresses decrease.

- Most sensitive are those communities in which the options for adaptability are limited (eg montane, alpine, polar, island and coastal communities, remnant vegetation, and heritage sites and reserves) and those communities where climatic change add to existing stresses.

- Increased incidents of disturbances such as pest outbreaks and fire are likely to occur in some areas and these could enhance projected ecosystem changes.

- The direct effects of increased atmospheric concentrations of CO_2 may increase plant growth, water use efficiency and tolerance to salinity, though this positive effect could be reduced over time by ecosystem feed-backs. Enhanced levels of air pollution could also reduce this positive effect.

- Socioeconomic consequences of these impacts will be significant, especially for those regions of the globe where societies and related economies are dependent on natural terrestrial ecosystems for their welfare. Changes in the availability of food, fuel, medicine, construction materials and income are possible as these ecosystems are affected. Important fibre products, recreation and tourism industries could also be affected in some regions.

Principal issues

The projected changes in climate will present these ecosystems with a climate warmer than that experienced during their recent evolution and there will be warming at a rate 15-40 times faster than past glacial-interglacial transitions. This combination of relatively large and fast changes in climate will cause disruption of ecosystems, allowing some species to expand their ranges while others will become less viable and, in some cases, may disappear.

Current knowledge does not allow a comprehensive and detailed analysis of all aspects of the impacts of climate change on natural terrestrial ecosystems. It is possible, however, to make some plausible implications. All estimates presented below are based on scenarios of enhanced atmospheric concentrations of greenhouse gases and related changes in global climate. It is impossible to evaluate the consequences of change in climatic variability since the required climatic analyses are not available.

Particularly sensitive species

The species which are particularly sensitive to climatic changes are:

- species at the edge of (or beyond) their optimal range;
- geographically localised species (eg those found on islands, on mountain peaks, in remnant vegetation patches in rural areas, and in parks and reserves);
- genetically impoverished species;
- specialised organisms with specific niches;
- poor dispersers;
- more slowly reproducing species; and
- localised populations of annual species.

This would suggest that montane and alpine, polar, island and coastal communities, and heritage sites and reserves are particularly at risk, since their component species may not be able to survive or adapt to climate change because of the limited number of adaptive options available to them.

Changes in the boundaries of vegetation zones

Projected changes in global temperature of 1.5°-4.5°C and changes in precipitation will result in the movement of the boundaries of vegetation zones, and will impact on their floristic composition and associated animal species. Boundaries (eg boreal-tundra, temperate forests, grasslands etc) are expected to shift several hundreds of kilometres over the next 50 years. Real rates of the movement of species, however, will be restricted by limits on their ability to disperse and the presence of barriers to dispersion; they will, therefore, average approximately 10-100 m/year.

Both coniferous and broad-leaved thermophilic tree species will find favourable environments much further poleward than their current limits. In the northern parts of the Asian USSR, the boundary of the zone will move northward 40°-50° of latitude (500-600 km). The tundra zone is expected to disappear from the north of Eurasia.

Expected changes in precipitation will allow species to extend their boundaries equatorward. As a result, broad-leaved species range will expand and these ecosystems will be more maritime in terms of species composition. The forest steppe subzone in the European USSR will change while in southern portions of western Siberia the forest-steppe boundary could move up to 200 km.

In the semi-arid, arid and hyper-arid ecoclimatic zones of the Mediterranean, greenhouse-gas-induced climate change will reduce plant productivity and result in desertification of the North African and Near Eastern steppes owing to increased evapotranspiration. The upper limit of the deserts would migrate under the influence of climate change and most likely extend into the area that currently corresponds to the lower limits of the Semi-Arid Zone (ie foothills of the high, Mid and Tell Atlas and Tunisian Dorsal in Northern Africa, and of the main mountain ranges of the Near-Middle East: Taurus, Lebanon, Alaoui, Kurdistan, Zagros and Alborz).

The impact of climate changes on the present tropical and temperate rainforest is uncertain. For example, almost all of Tasmania is expected to become, at best, climatically 'marginal' in terms of temperate rainforests, largely owing to a rise in winter temperatures suggested by climate scenarios. This increase in temperature is unlikely to have a direct effect on the forest, but may facilitate the invasion of less frost-tolerant species.

Changes within ecosystems

Projected greenhouse-gas-induced climate changes will profoundly affect hydrologic relationships in natural terrestrial ecosystems, both directly by altering inputs of precipitation, runoff, soil moisture, snow cover and melt, and evapotranspiration, as well as indirectly by altering sea and lake levels which influence water levels in coastal and shoreline ecosystems.

The seasonality of rainfall also affects its impact. A lengthening of the dry season or, conversely, an increase in ground-water table levels could both accentuate salinisation problems. In Mediterranean and semi-arid climates, where evapotranspiration exceeds precipitation for long periods and increased percolation from vegetation clearing or excessive irrigation may have raised the water table, surface soil salinisation can be a major problem. Such salinisation can kill all but the most halophytic vegetation, increase soil erosion and reduce water quality. Salinisation is already a problem in many Mediterranean and semi-arid regions (eg coastal Western Australia, the Mediterranean, subtropical Africa) and is a major cause of increased desertification.

Greenhouse-gas-induced climatic changes will affect the structure and composition of natural terrestrial ecosystems as a result of altered relationships within these ecosystems, perhaps leading to the introduction of new species.

Given the new associations of species that could occur as climate changes, many species will face 'exotic' competitors for the first time. Local extinctions may occur as climate change causes increased frequencies of droughts and fires, and invasion of species. One species that might spread, given such conditions, is *Melaleuca quinquenervia*, a bamboo-like Australian plant. This species has already invaded the Florida Everglades, forming dense monotypic stands where drainage and frequent fires have dried the natural marsh community.

Pests and pathogens, in some cases, are expected to increase their ranges as a result of climate change and, in the case of insects, their population densities. This could place at risk the health of ecosystems, and thereby play an important role in determining future vegetation and animal distributions

Pest outbreaks can also be expected as a result of the increased stress and mortality of standing vegetation resulting from a combination of climate-driven stressors. An example from New Zealand concerns hard beech (*Nothofagus truncata*). A 3°C rise in temperature would increase annual respiratory carbon losses by 30%; such a loss exceeds the total annual amount allocated to stem and branch growth for this species. With insufficient reserves to replace current tissue, the tree is weakened, and becomes more susceptible to pathogens and insects. Following repeated drought episodes, several (*Nothofagus*) species succumbed to defoliation insects. This would be exacerbated by non-induced climate change.

Since wetlands, particularly seasonal wetlands in warmer regions, provide habitat for the breeding and growth of vectors of a number of serious diseases such as malaria, filariasis and schistosomiasis, an increase in average temperature and any change in the distribution of seasonal wetlands will alter the temporal and spatial distribution of these diseases.

Higher temperatures and changed precipitation may well lead to increased drought frequency and fire risk in many forested areas. Coupled with probably increased fuel density because of the direct effects of increased ambient CO_2 on forest understorey, this could lead to increased exposure of forests to fire, which would tend to accelerate changes in ecosystem composition under conditions of changing climate.

In areas with a distinct wet and dry season (parts of the tropic, and all of the Mediterranean-climate regions), change in the amount of precipitation in rainy months could alter fuel loads by influencing growth. The altered fuel loads, along with changes in precipitation, could affect fire intensities during the dry season. A shift towards a slightly wetter climate during the summer rainy season could increase fuel loadings in most of the subtropical and temperate woodlands of Mexico, which would suggest increased fire frequencies.

Global biological diversity is expected to decrease with possible socioeconomic consequences as a result of climate change; however, some local increases may also result, especially over the longer term. The resulting impacts on biological diversity are dependent on the balance between changes in species interactions and adaptation through migration.

Warming could set off a chain of extinctions by eliminating keystone herbivores or their functional counterparts in other ecosystems. For example, in the 100 years following the disappearance of elephants in the Hluhluwe Game reserve in Natal, several species of antelope have been extirpated and populations of open country grazers, such as wildebeest and waterbuck, have been greatly reduced.

The direct effects of increased atmospheric concentrations of CO_2 may increase the rate of plant growth; however, man-induced changes in the chemical composition of the atmosphere (eg ozone) and ecosystem feedbacks could reduce this positive effect over time.

Recommendations for action

While the specific impacts of global warming on any one region or a single species are to some degree matters of conjecture, there are some clear conclusions that can be made. Natural terrestrial ecosystems will change in make-up and shift in location, and those species which can adapt and shift will survive. The sensitive species, especially those for which options are limited, will dwindle and disappear.

Examination of the environmental impacts of climate change on natural terrestrial ecosystems and the associated socioeconomic consequences is in its infancy. The studies that have been carried out are limited; only specific regions and sectors have been examined. Further limiting this work is that, for the most part, existing studies have taken a narrow view of the problem and not looked at it from a multi-disciplinary perspective. In addition, most of the studies have examined the effects of climate change on current social, economic and environmental systems and have not considered social and economic adjustments nor impacts and consequences during ecosystem transitional periods.

These limitations can be addressed by:

- assembling relevant inventories of species and ecosystems;
- initiating and maintaining integrated monitoring programs;
- gathering information on relative species and ecosystems sensitivities to climate change;
- initiating and supporting regional national and international research and impacts programs; and
- educating resource managers and the public about the potential consequences of climatic change for natural terrestrial ecosystems.

Potential impacts of climate change on hydrology and water resources

Major findings

- For many watersheds worldwide, especially those in arid and semi-arid regions, runoff is very sensitive to small changes and variations in climate. For example, 1°C to 2°C temperature increase coupled with a 10% reduction in precipitation could conceivably produce a 40-70% reduction in annual runoff.
- Based on empirical data and hydrological models, annual runoff appears to be more sensitive to changes in precipitation than to changes in temperature. However, in regions where seasonal snowfall and snowmelt are a major part of the total water supply, the monthly distribution of runoff and soil moisture is more sensitive to temperature than to precipitation.
- The construction of hypothetical scenarios provides a range of runoff responses and the characteristics of those responses for particular areas. However, credible forecasts for any specific region, sufficient to designate either direction or magnitude of change, are not yet available. We can conduct warm sensitivity analysis using General Circulation Models while the scientific basis slowly improves.

- Vulnerabilities in present water uses (ie where demand exceeds firm yield) and conflicts among current uses are likely to be exacerbated by global warming in most arid and semi-arid regions.

- The regions that appear to be at greatest risk, in terms of serious threats to sustaining the population are: Africa - Maghreb, Sahel, the north of Africa, southern Africa; Asia - western Arabia, Southeast Asia, the Indian subcontinent; North America - Mexico, Central America, southwest US; South America - parts of eastern Brazil; Europe - Mediterranean zone.

- The relative degree of water management (storage versus mean annual flow) is a primary determinant in adapting to changes in the mean annual variability.

- It is essential that future design of water resource engineering take into account that climate is a non-stationary process, and that structures with a design life of 50 to more than 100 years should be designed to accommodate climatic and hydrometeorological conditions which may exist over the entire life of the structure.

Principal issues

If worthwhile estimates of water resources conditions, appropriate for planning and policy formulation, are to be produced, then studies must include estimates on the frequency, intensity and duration of potential future hydrologic events. This is especially critical for evaluating effects on agriculture, the design of water resource management systems, and for producing reasonably accurate water supply estimates.

In many instances it can be expected that changes in hydrologic extremes in response to global warming will be more significant than changes in hydrologic mean conditions. Thus, attention must be focused on changes in the frequency and magnitude of floods and droughts in evaluating the societal ramifications of water resource changes.

Initial water resource planning and policy making will continue to be implemented even in the face of uncertainty about global change. Clarification and specification of the useful information about the various methods for estimating future change must be made available to the management community.

Regional impacts

Continental/national

Based on palaeoclimatic analogs coupled with physically based water-balance models, annual runoff over the whole of the USSR is projected to rise, although runoff is expected to decrease slightly in the forest steppe and southern forest zones. In any case, winter runoff is expected to increase in the regions with snowfall and snowmelt. Serious flooding problems could arise in many northern rivers of the USSR.

An assessment of all the river basins in the US shows that the arid and semi-arid regions of the US would be most severely affected by global warming, even though there is a high degree of water control. The competing uses of agricultural irrigation, municipal water supply, and generation of hydroelectric power, have stressed even the present system. All other regions in the US will probably suffer adverse water-resource impacts to some degree, whether for generation of hydroelectric power, municipal water supply shortages, or agricultural irrigation.

An assessment of the general circulation model studies for the nations of the European Economic Community (EEC) indicates that precipitation and runoff may increase in the northern nations, possibly causing flooding problems in low-lying countries. The Mediterranean countries of the EEC may experience a decline in runoff, thereby increasing the already serious and frequent water supply shortages occurring in that region. It is most probable that agriculture will suffer the most adverse effects.

In Japan, prolonged periods of droughts and shorter periods of intense precipitation may be likely. Current storage capacity is limited and a large proportion of the population is located on floodplains. Water demand can be expected to increase, which will seriously stress the existing water management system.

An increase in precipitation and consequent flooding, along with overloads of stormwater/sewerage systems leading to degradation of surface water quality, is possible in New Zealand.

The UK can expect an increase in mean annual runoff over most of the country, but with a stronger seasonal variation in peak flows, imposing the need for redesigning existing water management systems.

River basins and critical environments

Runoff in the Volga River basin, after undergoing an initial decrease through the year 2000, is expected to increase after that year.

Studies indicate that hydrological conditions in the Sahelian zone are very sensitive to climatic conditions, especially precipitation. Research suggests, for example, that a 20% to 30% decrease in precipitation could lead to a 15% to 59% reduction in runoff. As for potential changes in water resources in the future, it can be said that the situation is very uncertain. Therefore, additional comprehensive studies of this problem, which is very important for the region, are required.

A study of the Sacramento-San Joaquin River basin showed how a highly managed water resource system, dependent on snowmelt-generated runoff, would be affected by global warming. Air temperature increases changed the timing and increased the magnitude of snowmelt-generated runoff by 16% to 81%, severely stressing the flood-control capabilities of existing reservoirs. However, summer runoff decreases of 30% to 68%, coupled with soil moisture decreases of 14% to 36% and a doubling of water demand by the year 2020, suggest that serious water use conflicts and periodic shortages are a distinct possibility for this system.

In the Murray-Darling basin of Australia, the use of spatial analogs indicates that precipitation could decrease by 40% to 50%. However, based on general circulation model outputs, the summer-dominant rainfall area of Australia will possibly expand to encompass 75% of the continent by 2035. Runoff could double on the Darling River.

A water supply-demand stochastically-based sensitivity analysis was conducted for the Delaware River basin, a highly urbanised watershed in the northeastern US. Basin-wide estimates of annual runoff indicate a possible decrease of 9% to 25%. Also, the probability of drought increases substantially throughout the basin. The Delaware River supplies a large percentage of New York City's water supply, which is already operating below its safe yield. Reduced flows in the Delaware River would threaten the city of Philadelphia's water supply intakes in the estuarine portion of the river through upstream movement of the freshwater-saltwater interface.

Large lakes/seas

The Caspian Sea is the largest closed water body in the world. It receives nearly 80% of its runoff from the Volga River and will respond to the initial decrease in projected Volga River flows to the year 2000, but will increase thereafter. This will greatly improve the severely degraded water quality and ecological conditions in the Sea.

Based on general circulation model results, the Great Lakes are expected to incur net basin runoff decreases of 23% to 51% under an effective doubling of CO_2 scenario. Generation of hydroelectric power, the very important commercial navigational uses, and lake water quality which is due to thermal stratification, are expected to be adversely affected.

The Aral Sea would continue to experience water-quality degradation by polluted irrigation return flows, as the precipitation-runoff increases projected for the area would not be enough to compensate for increased expansion of irrigated agriculture.

Recommendations for action

The most essential need is for more reliable and detailed (both in space and time) estimates of future climatic conditions. These estimates must be regionally specific and provide information on both the frequency and magnitude of events. Increased understanding of relations between climatic variability and hydrologic response must be developed. Such work should include the development of methods for translating climate model information into a form that provides meaningful input data to watershed and water resource system models.

Areas particularly vulnerable to even small changes in climate must be identified worldwide. Vulnerabilities must be ascertained considering both natural and anthropogenic conditions and potential changes.

Intensive assessments of water resource sensitivities are necessary in developing countries, especially those located in environmentally sensitive arid and semi-arid regions, where the potential for conflicts associated with low water resource system development and rapidly increasing water demands is high.

Studies are needed that produce improved procedures for operating water management systems in consideration of climate uncertainty. A related aspect of this work is the development of design criteria for engineered structures that specifically incorporate estimates of climatic variability and change.

Very little is currently known about the effects of climate change on water quality. Although concerns about water quality are becoming increasingly important, the separation of human-induced versus climate-induced changes in water quality is a very difficult problem. Specifically, there is an immediate need to identify those aspects of this problem that hold the most promise for yielding credible evaluations of climatic effects on water quality.

Potential impacts of climate change on human settlement, the energy, transport and industrial sectors, human health and air quality

Major findings

- Throughout the world the most vulnerable populations are farmers engaged in subsistence agriculture, residents of coastal lowlands and islands, populations in semi-arid grasslands and the urban poor in slums in shanty towns, especially in megacities - those with several millions of inhabitants.

- Climate change and even a modest global sea-level rise can be expected to prove disruptive to human settlement in many vulnerable coastal areas of some island nations and communities where drought, floods and changed agricultural growing conditions have affected water resources, energy, public health and sanitation, and industrial or agricultural production.

- Global warming can be expected to cause a significant shift in the permafrost zone; such rapid change will prove quite disruptive to roads, railways, buildings, oil and gas pipelines, mining facilities and infrastructure in the permafrost region.

- Global warming can be expected to affect the availability of water resources and biomass, both major energy sources in a large number of developing countries. Such changes in areas which lose water may jeopardise energy supply and materials essential for human habitation and energy. Climate change will also affects the regional distribution of other renewable energy resources such as wind and solar power.

- Vector-borne and viral diseases such as malaria, schistosomiasis and dengue can be expected under warmer climatic conditions to shift to higher latitudes.

- Should severe weather, such as tropical cyclones, occur more frequently or become more intense as a result of climate changes, human settlement and industry may be seriously affected, with large loss of human life.

Principal issues

The impact on developing countries, many of which lack resources for adaptation, may be particularly disruptive. Understanding likely impacts of climate change on human settlement, energy, transport, industry and human health in such countries should be a high priority, together with reinforcing indigenous capability to design and implement strategies to reduce adverse impacts of climate change.

The impacts of climate change on human settlement and related socioeconomic activity, including the energy, transport and industry sectors, will differ regionally, depending on regional distribution of changes in temperature, precipitation, soil moisture, patterns of severe storm, and other possible manifestations of climate change. As the general circulation model scenarios provided by Working Group I have indicated, changes in some of these climatic characteristics may differ considerably among regions. In addition, the vulnerability to change in climate of human settlement and related economic activity varies considerably among regions and within regions. For example, coastal areas may generally be more vulnerable to climate change than inland areas within the same region.

Development of effective strategies to respond to climate change will require much better capability to predict and detect regional climate change and occurrence of severe meteorological phenomena. A major issue is that of timing. For example, a sea-level rise of 0.5 m over 50 years would have substantially different impacts than the same rise over 100 years. Not only are present-value costs for adaptation measures vastly different, but also much of the present-day infrastructure would have undergone replacement in the longer time period.

Human settlement

A principal difficulty in determining the impact of climate change on human habitat is the fact that many other factors, largely independent of climate change, are also important. One can reliably predict that certain developing countries will be extremely vulnerable to climate changes because they are already at the limits of their capacity to cope with climatic events. These include populations in low-lying coastal regions and islands, subsistence farmers, populations in semi-arid grasslands, and the urban poor.

The largest impacts on humanity of climate change may be on human settlement, with the existence of entire countries such as the Maldives, Tuvalu, and Kiribati imperilled by a rise of only a few metres in sea-levels and populous river delta and coastal areas of such countries as Egypt, Bangladesh, India, China and Indonesia, threatened by inundation from even a moderate global sea-level rise. Coastal areas of such industrialised nations as the United States and Japan will also be threatened, although these nations are expected to have the requisite resources to cope with this challenge. The Netherlands has demonstrated how a small country can effectively marshall resources to deal with such a threat.

Besides flooding of coastal areas, human settlement may be jeopardised by drought, which could impair food supplies and the availability of water resources. Water shortages caused by irregular rainfall may especially affect developing countries, as seen in the case of the Zambezi river basin. Biomass is the principal source of energy for most of the countries of sub-Saharan Africa, and changed moisture conditions in some areas, reducing this biomass, could pose grave problems for domestic energy production and construction of shelter.

Although there has been only a handful of city-specific studies, they suggest that climate change could prove costly to major urban areas in developed nations. A study has projected that an effective CO_2 doubling could produce a major water shortfall for New York City equal to 28% to 42% of the planned supply in the Hudson River Basin, requiring a $3 billion project to skim Hudson River flood waters into additional reservoirs.

Although in the permafrost region global warming may result in expansion of human settlement poleward, thawing of the permafrost may also disrupt infrastructure and transport and adversely affect stability of existing buildings and conditions for future construction.

The gravest effects of climate change may be those on human migration as millions are displaced by shoreline erosion, coastal flooding and severe drought. Many areas to which they flee are likely to have insufficient health and other support services to accommodate the new arrivals. Epidemics may sweep through refugee camps and settlements, spilling over into surrounding communities. In addition, resettlement often causes psychological and social strains, and this may affect the health and welfare of displaced populations.

Energy

Among the largest potential impacts of climate change on the developing world are the threats in many areas to biomass, a principal source of energy in most sub-Saharan African nations and many other developing countries. More than 90% of the energy in some African countries depends on biomass energy (fuelwood). Owing to uncertainties in water resource projections derived from current climate models, it is very difficult to provide reliable regional projections of future moisture conditions in these countries. Drier conditions could be expected in some countries or regions, and in those situations energy resources could be severely impaired. There could be possible compensating effects of faster growth of fuelwood due to higher ambient CO_2. Analysis of this situation should be a top priority for energy planners.

In addition to affecting the regional distribution of water and biomass, climate-related changes in cloud cover, precipitation and wind circulation intensity will affect the distribution of other forms of potential renewable energy such as solar and wind power. Understanding these impacts on hydro, biomass, solar and wind energy is particularly important because renewable energy sources are playing a significant role in the energy planning of many countries. This could become an increasingly important concern in developing countries, many of which are facing serious economic pressures from the need to import conventional energy resources.

Developing countries, including many in Africa, depend significantly on hydroelectric power. By changing water resource availability, climate change may make some present hydroelectric power facilities obsolete and future energy planning more troubled, although others may benefit from increased runoff.

Major studies to date of the likely impact of global warming on the energy sector in developed countries are confined largely to six countries: Canada, the Federal Republic of Germany, Japan, the UK, the USSR and the US. Generally, they show differing overall aggregate impacts, depending on how much energy use is related to residential and office heating and cooling. Climate warming will increase energy consumption for air-conditioning and, conversely, lower it for heating.

In addition, the energy sector may be affected by response strategies against global warming, such as a policy on emission stabilisation. This may be among the most significant energy sector impacts in many developed countries, enhancing opportunities for technologies that produce low quantities of greenhouse gases. Controversy on the way to obtain CO_2-free energy has already risen, particularly the options of increased reliance on nuclear power or hydroelectric power, weighed against related safety and environmental concerns. Energy sector changes in both developing and developed countries may have broad economic impacts affecting regional employment, migration and patterns of living.

Transport

Generally, the impacts of climate change on the transport sector appear likely to be quite modest, with two exceptions. Ultimately, the greatest impact of climate change on the transport sector in developed countries would appear to be changes produced by regulatory policies or consumer shifts designed to reduce transport-related emissions of greenhouse gases. Because of the importance of the transport sector as a source of greenhouse gases, it is already being targeted as a major source of potential reductions in greenhouse gas emissions, with potentially added constraints on private automobile traffic, automotive fuel and emissions, and increased use of efficient public transport.

A second large impact on the transport sector concerns inland shipping, where changes in water levels of lakes and rivers may seriously affect navigation and the costs of barge and other transport. Studies to date, focused entirely on the Great Lakes region of Canada and the US, have shown quite large potential impacts. Climate scenarios have shown a likely drop of lake levels of as much as 2.5 m resulting from an effective CO_2 doubling. Such changes could increase shipping costs, but the shipping season could be longer than at present due to decreased ice. Lake and river levels may rise in some other regions with potentially enhanced opportunities for shipping.

Generally, impacts on roads appear likely to be quite modest, except in coastal areas where highways or bridges may be endangered by sea-level rise or in mountainous regions where potentially increased intensity in rainfall might pose the risk of mudslides. Studies in Atlantic Canada and Greater Miami, US, indicate that highway infrastructure costs could prove very costly in such exposed coastal areas. Reduced snow and ice and lessened threat of frost heaves should generally produce highway maintenance savings as suggested by a study of Cleveland, Ohio, US.

Impacts on railways appear likely to be modest, although heat stress on tracks could increase summertime safety concerns on some railways and reduce operational capability during unusually hot periods. Dislocations due to flooding may increase.

There has been little analysis of likely impacts on ocean transport. The greatest effect would appear likely to be some jeopardy to shipping infrastructure such as ports and docking facilities, threatened both by sea-level rise and storm surge. Some climate projections indicate the possibility that tropical cyclone intensity may increase. This could have adverse implications for ocean shipping and infrastructure. On the other hand, decreased sea ice could provide greater access to northern ports and even enable regular use of the Arctic Ocean for shipping. Moderate sea-level rise could also increase the allowable draught for ships using shallow channels.

There is a strong need for analysis of likely impacts of climate change for the transport sector in developing countries, as efficiency of the transport sector is likely to be an essential element in the ability of countries to respond to climate change.

Industry

Studies of likely impacts of climate change on the industrial sector tend to be concentrated heavily on certain sectors such as recreation and only on a handful of developed countries, principally Australia, Canada, Japan, the UK and the US. There is very little analysis of the likely impacts of climate change on industry in developing countries, although there is some evidence to suggest that industry of developing countries may be particularly vulnerable to climate change. An especially important factor is the likely change in the production map of primary products as a result of climate change.

Changes in the regional and global availability and cost of food and fibre may significantly affect the competitiveness and viability of such derivative industries as food processing, forest and paper products, textiles and clothing. Climate change may be expected to have impacts on the availability and cost of food, fibre, water and energy which would differ markedly from region to region.

Just as the motor vehicle and the energy sectors are likely to be influenced by regulatory decisions and shifts in consumer patterns emanating from concerns about limiting greenhouse gas emissions, heavy manufacturing may face readjustment to new situations such as transboundary siting constraints and international mechanisms for development and transfer of new technology. Efficiency in the use of energy may become an even more significant competitive factor in steel, aluminium and other metal industries, and automotive manufacturing. Public concerns about limiting greenhouse gas emissions may also create opportunities for energy conservation or for industries based on 'clean technology'. Studies of likely impacts of climate change on industry tend to be clustered in the recreational sector, where direct impacts of climate change are more ascertainable.

With sufficient lead time, industry may be able to adjust to many of the changes accompanying global warming. Shortages of capital in developing countries which may be vulnerable to flood, drought or coastal inundation may, however, constrain such industry's ability to design effective response strategies.

Human health

Humans have a great capacity to adapt to climatic conditions. However, adaptations have occurred over many thousands of years. The rate of projected climatic changes suggest that the cost of future adaptation may be significant.

A greater number of heatwaves could increase the risk of excess mortality. Increased heat stress in summer is likely to increase heat-related deaths and illnesses. Generally, the increase in heat-related deaths would be likely to exceed the number of deaths avoided by reduced severe cold in winter. Global warming and stratospheric ozone depletion appear likely to worsen air pollution conditions, especially in many heavily populated and polluted urban areas. Climate change-induced alterations in photochemical reaction rates among chemical pollutants in the atmosphere may increase oxidant levels, adversely affecting human health.

There is a risk that increased ultraviolet-B radiation resulting from depletion of the stratospheric ozone layer could raise the incidence of skin cancer, cataracts and snow blindness. The increased skin cancer risks are expected to rise most among fair-skinned Caucasians in high-latitude zones.

Another major effect of global warming may be the movement poleward in both hemispheres of vector-borne diseases carried by mosquitoes and other parasites. Parasitic and viral diseases have the potential for increase and reintroduction in many countries.

Changes in water quality and availability may also affect human health. Drought-induced famine and malnutrition have enormous consequences for human health and survival.

The potential scarcity in some regions of biomass used for cooking, and the growing difficulty in securing safe drinking water because of drought, may increase malnutrition in some developing countries.

Air pollution

SO_x, NO_x and auto-exhaust controls are already being implemented to improve air quality in urban areas in some developed countries. Concerns about possible energy penalties and overall implications of such control measures for greenhouse gas emissions will need to be incorporated in future planning. Moreover, global warming and stratospheric ozone depletion appear likely to aggravate tropospheric ozone problems in polluted urban areas. The tropospheric temperature rise induced by the enhanced greenhouse effect could change homogeneous and heterogeneous reaction rates, solubility to cloud water, emission from marine, soil and vegetative surfaces, and deposition to plant surfaces of various atmospheric gases, including water vapour and methane. A change in water vapour concentration will lead to changes in the concentration of HO_x radicals and H_2O_2, which are important for the oxidation of SO_2 and NO_x in the atmosphere. The predicted change of the patterns of cloud cover, stability in the lower atmosphere, circulation and precipitation, could concentrate or dilute pollutants, and change their distribution patterns and transformation rates in regional or local sectors. A change in aerosol formation by atmospheric conversion from NO_x, and SO_2 and windblown dust from arid land could lead to changes in visibility and albedo. Material damage caused by acidic and other types of air pollutants may be aggravated by higher levels of humidity.

Ultraviolet-B radiation

Besides the human health implications of increased ultraviolet-B radiation already discussed, such radiation may also significantly affect terrestrial vegetation, marine organisms, air quality and materials. Increased ultraviolet-B radiation may adversely affect crop yields. There are some indications that increased solar ultraviolet-B radiation which penetrates into the ocean surface zone where some marine organisms live, may adversely affect marine phytoplankton, potentially reducing marine productivity and affecting the global food supply. Increased ultraviolet-B radiation can also be expected to accelerate degradation of plastic and other coating used outdoors. The enhanced greenhouse effect is expected to decrease stratospheric temperatures and this may affect the state of the stratospheric ozone layer.

Recommendations for action

- Assessment of the vulnerability of countries, especially in the developing world, to gain or loss of energy resources such as hydroelectric power, biomass, wind and solar, and an examination of available substitutes under new climate conditions, should be a high priority.

- Research is critically needed into the adaptability of vulnerable human populations, especially the elderly and the sick, to the occurrence of increased heat stress as well as the potential for vector-borne and viral diseases to shift geographically.

- Policy makers should give priority to the identification of population and agricultural and industrial production at risk in coastal areas subject to inundation from sea-level rise of various magnitudes and to storm surge.

- It is important that developing countries have the capability to assess climate change impacts and to integrate this information into their planning. The world community should assist countries in conducting such assessments and work to create indigenous climate-change impact assessment capabilities in such countries.

Potential impacts of climate change on the world ocean and coastal zones

Major findings

The projected global warming will cause sea-level rise, modify ocean circulation, and cause fundamental changes to marine ecosystems, with considerable socioeconomic consequences.

Sea-level is already rising on average of over 6 cm per 50 years, with important regional variations because of local geological movements. The Greenland and perhaps the Antarctic ice sheets may still be responding to changes since the last glaciation. Fisheries and various coastal resources are presently under growing stress from pollution, exploitation and development, creating serious problems for populations dependent on them. Impacts from the enhanced greenhouse effect, which have been considered by the IPCC, will be added to these present trends.

A 20-30 cm sea-level rise (projected by the year 2050) poses problems for the low-lying island countries and coastal zones, destroying productive land and the freshwater lens. Protecting these areas entails considerable cost.

A 1 m sea-level rise (the maximum projected by the year 2100) would eliminate several sovereign states, displace populations, destroy low-lying urban infrastructure, inundate productive lands, contaminate freshwater supplies and alter coastlines. These effects could not be prevented except at enormous cost. The severity would vary among coastal regions and would depend on the actual rate of rise.

Coastal ecology is affected by the rate of sea-level rise. Too rapid a rise could reduce or eliminate many coastal ecosystems, drown coral reefs, reduce biological diversity and disrupt the life cycles of many economically and culturally important species.

Erosion of wetlands and increasing availability of organic matter from sea-level rise can increase estuarine and near-shore productivity for some decades.

Global warming will change the thermal budget of the World Ocean and shift the global ocean circulation. Changes in ocean circulation, including high-latitude deep water formation, will affect the capacity of the ocean as a sink of atmospheric heat and CO_2. Upwellings of nutrient-rich waters associated with major fisheries are also expected to change, causing a decrease in primary production in open ocean upwelling zones and an increase in primary production in coastal upwelling zones. The expected impacts will include chemical changes in biogeochemical cycles such as the global carbon cycle which affects the rate of accumulation of atmospheric CO_2.

Adverse ecological and biological consequences will vary by geographic zones of the world's oceans. The loss of habitat will cause changes in biological diversity, redistribution of marine organisms and a shift in the ocean production zones.

A simultaneous rise in both water temperature and sea-level may lead to the redistribution of commercially important species and benthic organisms. Changes in fisheries production may well balance globally in the long term, but there could be important regional shifts in areas of fisheries, with major socioeconomic impacts.

Shipping and ocean transportation will benefit from less sea ice and small increases in depth in harbours, but some ice-dependent marine mammals and birds will lose migratory and hunting routes and the essential habitats.

Increase in ultraviolet-B radiation can have widespread effects on biological and chemical processes, on life in the upper layer of the open ocean, on corals, and on wetlands. These impacts are of concern but not well understood.

Impacts of sea-level rise on coastal zones

The magnitude and rate of sea-level rise will determine the ability of social and natural ecosystems to adapt to the rise. Direct effects of the rise are straightforward: inundation of low-lying coastal areas; erosion and recession of sandy shorelines and wetlands; increased tidal range and estuarine salt-front intrusion; increases in sedimentation in the zone of tidal excursion; and increase in the potential for salt water contamination of coastal freshwater acquifers. The predicted changes in climate may also affect the frequency and intensity of coastal storms and hurricanes, which are the major determinants of coastal geomorphic features and extreme high sea-level events.

The socioeconomic impacts of these direct physical effects are uncertain and more difficult to assess, and are region- and site-specific. There are three general impact categories that encompass the physical effects:

- threatened populations in low-lying areas and island nations.
- alteration and degradation of the biophysical properties of beaches, estuaries and wetlands.
- inundation, erosion and recession of barrier beaches and shoreline.

Threatened populations in low-lying areas and island nations

The most important socioeconomic impact of sea-level rise is the inundation of intensely utilised and densely populated coastal plains. A 1 m rise would produce a coastline recession of several kilometres in a number of countries. Other countries have a substantial proportion of land area between 1 m and 5 m above sea-level, with high density coastal populations. For example, a 1 m sea-level rise could inundate 12-15% of Egypt's arable land and 14% of Bangladesh's net cropped area, displacing millions of inhabitants.

Sea-level rise would also expose a greater proportion of low-lying areas to coastal storm flooding from storm surges. Densely populated urban areas could be protected at great cost, but less densely populated areas stretched out along the coastline could not be protected. In these situations, large-scale resettlement might be necessary. Another consequence of sea-level rise is greater incursion of salt water into freshwater estuarine areas, along with larger tidal excursion. This would reduce the freshwater portion of estuarine rivers, especially during drought periods, adversely affecting municipal and industrial freshwater supplies, and could contaminate coastal groundwater acquifers, which also supply water for municipal purposes in many areas. Many estuarine areas across the world, with large population centres, would be affected, particularly those where a decrease in net freshwater runoff is also projected as a consequence of global warming.

Finally, as sea-level rises, much of the infrastructure in low-lying urban areas would be affected, requiring major engineering design adjustments and investments. In particular, stormwater drainage and sewerage systems of many cities will be affected. Coastal protection structures, highways, power plants and bridges may require redesign and reinforcement to withstand increased flooding, erosion, storm surges, wave attack and sea-water intrusion.

Alteration of the biophysical properties of estuaries and wetlands

An accelerated rise in sea-level could severely redistribute coastal wetlands. Salt, brackish and fresh marshes as well as mangrove and other swamps would be lost to inundation and erosion; others would transform and adapt to the new hydrologic and hydraulic regime or would migrate inland through adjacent lowlands not impeded by protective structures. The value of these wetlands as habitat for wildlife would be impaired during the transitional period and their biodiversity may decrease. Although many wetlands have kept pace or have increased in area under the historic rate of sea-level rise owing to sediment entrapment and peat formation, vertical accretion of wetlands has not been observed to occur at rates comparable to those projected for sea-level rise in the next century.

Wetlands are vital to the ecology and economy of coastal areas. Their biological productivity is equal to or exceeds that of any other natural or agricultural system, although little of that productivity may be available to marsh animals and coastal fisheries. Over half the species of commercially important fishes in the southeastern US use salt marshes as nursery grounds. Wetlands also serve as sinks for pollutants and provide a degree of protection from floods, storms and high tides. Based on these functions, marshes can provide a present value to society of as much as $US5500/acre or over $US10,000/ha.

Coastal wetlands and estuaries are important to many species. If sea-level rise is too rapid, natural succession of the coastal ecology will not take place and will lead to great disruption in life cycles. In the short term, production of fisheries could rise as marshes flood, die and decompose, thus improving fisheries habitat in some cases and providing more nutrients. Further nutrients will become available from the leaching of soils and peat which become more frequently flooded. This temporary increase in productivity appears to be happening now in the southeast US where sea-level rise is compounded by land subsidence. However, this temporary benefit for fisheries may be balanced by negative impacts on birds and other wildlife as the habitat area is decreased. In the longer term, by 2050 the overall impact on fisheries and wildlife is likely to be negative.

While considering potential changes in the biogeochemical cycles of chemicals from sea-level rise, it should be noted that (i) growth of nitrogen and phosphorus concentrations on a regional scale (in subpolar and mid latitudes, in the Bering Sea in particular) would result from flooding of coastal areas and from soil erosion; and (ii) many pesticides which are presently held in sediments could be released into the marine environment by coastal flooding.

The combination of climatic changes will cause coastal ecosystems to move inland, unless humankind intervenes, and poleward. Also, if sea-level rise is rapid, as predicted, productivity will probably fall, but there may be some decades during which wetlands-based productivity increases before it falls. Once the ocean begins to stabilise at its new level (if this were to occur in the foreseeable future), productivity will begin to decrease.

Inundation and recession of barrier islands, coral atolls and other shorelines

Sea-level rise would cause inundation and recession of all types of shorelines, especially low-lying coastal areas. Many beaches have very small gradients of 1:100 or less. A 1 m rise in sea-level would inundate 100 m of beach. Additional shoreline recession would result from normal erosive processes including storm surges and wave attack. The potential destruction of coral atolls is perhaps most significant, because these island areas serve both as contained human habitats as well as important ecological habitats with high biodiversity. Unlike continental areas with receding coastlines, where areas for resettlement are available landward of the coasts, coral islands have very limited possibilities. If the rate of sea-level rise exceeds the maximum rate of vertical coral growth (8 mm/yr), then inundation and erosive processes begin to dominate, leading to the demise of the coral atoll. However, if the rate of sea-level rise is small, then coral growth may be able to keep pace. Although there are engineering solutions for retarding erosion and protecting against storm damage of continental coasts, coral atolls cannot be effectively protected.

Barrier beaches are important for human use, both for subsistence and recreation, and as protection for lagoons and mainland areas from coastal storms. Coastal areas have always been hazardous. Societies have adapted to or sought to control the most extreme conditions resulting from natural climate variability. The loss of habitable coastal areas, which are typically densely populated will undoubtedly lead to large-scale resettlement. Since most commercial and subsistence fisheries are de facto located in the very same vulnerable areas, the impacts are twofold: reduction in ecological (wetlands) habitat that sustains fish populations, coupled with increased threats to habitable coastal areas. Many areas around the globe, comprising thousands of kilometres of shoreline and affecting millions of people would be adversely affected by a rise of 1 m, or even 0.5 m. For the most part, prevention of the primary physical effects is not economical for most of the threatened coastline. Therefore, the prospect for adverse impacts should be considered to be extremely important and virtually irreversible.

Impacts on the World Ocean

Global climate warming can change the physical, chemical and biological processes in the oceans, and affect productivity of the oceans and fisheries. Effective CO_2 doubling could lead to an increase of sea-surface temperature by 0.2°-2°C and to changed heat balance components. Impacts will differ among geographic zones.

In addition, an increase in atmospheric CO_2 could cause an increase in sea-water acidity up to 0.3 pH and elevation of the lysocline (because of solution of additional amounts of $CaCO_3$). These processes might be accompanied by a decrease in the stability of the complexes of trace metals with aquatic humus, strengthening the toxic impacts of these substances on marine organisms as well as a change in the conditions of accumulation of deposits.

Coastal ecosystems will be exposed to the most severe impact owing to a water temperature increase and, especially, to sea-level rise. Disturbances by hydrological and hydrochemical conditions in these regions will be accompanied by a shift of feeding zones of many commercial fish species and benthic organisms, a change in the trophic structure of coastal communities and, as a consequence, a decrease in their productivity. At the first stage, as the flux of nutrient increases, in the process of land flooding, a certain increase in the productivity of coastal areas might be observed.

A change in heat balance and the circulation system in the oceans will produce a direct effect on the productivity of marine ecosystems. Taking into consideration the fact that 45% of the total annual production is in the zones of oceanic and coastal upwellings and subpolar regions, a change in these regions would determine the future productivity of the oceans.

According to the results of numerical experiments with the use of General Circulation Models of the atmosphere-ocean system, as well as palaeo-oceanographical data, the global warming would be accompanied by a weakening of the intensity of oceanic upwellings because of a decrease in the meridional temperature gradient. This process will involve a decrease in the productivity of these ecosystems. However, some increase in the intensity of coastal upwellings as a result of increasing temperature difference between land and water surface, would partially compensate for the reduction of oceanic upwellings. Besides, an increase in the temperature at high latitudes will be accompanied by an increase in their productivity. As a result of the above changes, a redistribution of productive zones will probably occur. This could lead to disturbances in the trophic structure of marine ecosystems and to a change in the conditions of the formation of the stocks of commercial fishes.

An increase in the zone of the area of warm equatorial and tropical waters would cause the movement of pelagic and benthic communities of these areas to the boreal and temperate regions. This circumstance might significantly affect the structure of world fisheries. Under conditions of climate warming, the intensification of biodegradation processes will occur by up to 30-50% in the zone of high latitudes. This factor, along with the expected increase of ultraviolet-B radiation, resulting from the depletion of the ozone layer, could accelerate bacterial and photochemical degradation of pollutants and reduction of their 'residence time' in the marine environment. Ecological and biological consequences of climate changes will vary among geographic zones. A regional approach is needed to study the biogeochemical carbon cycle, especially in the most productive and vulnerable ecosystems of the ocean.

The highly productive subpolar and polar ecosystems of the Bering Sea, Arctic Seas and Southern Ocean are important to study because the high-latitude areas will see the greatest changes. These areas are important to the total global carbon cycle in the ocean, in climate-forming processes, in fisheries, and in marine mammal and bird production.

International investigations, for example those planned for the region of the Bering Sea, will contribute to the determination of the role of subpolar ecosystems in the formation of earth's climate, as well as to a more comprehensive study of possible ecological impacts of global warming on the ocean, in particular on fisheries.

Many fisheries and marine mammal populations are heavily stressed from fishing pressure. Climate changes will increase stress and the chance of collapse. However, for some species, the new climate may be more advantageous to their well-being.

One benefit of warming will be the reduction of sea ice and thus improved access for shipping. However, there are ecological concerns. Land animals use sea ice for migratory and hunting routes, while for many species of marine mammals (eg seals, polar bears, penguins) sea ice is an essential part of their habitat. Thus, reduction of the amount or duration of ice can cause difficulties for such animals. Moderate rises in sea-level, provided they are insufficient to threaten port installations, may prove to be beneficial by increasing the allowable draught of ships in shallow ports and channels.

Recommendations for action

- Identification and assessment of the risks to coastal areas and islands and living resources of a 0.3-0.5 m rise in sea-level.

- Assessment of potential leaching of toxic chemicals with sea-level rise.

- Improvement of the methods for analysing the major components of oceanic branch of carbon cycle (the carbonate system and organic carbon).

- Assessment of the possible impacts of increased UV-B radiation from stratospheric ozone depletion on oceanic and estuarine ecosystems.

- Determination of ecological impacts of Arctic and Antarctic sea ice reductions.

- Development of methodologies to assess the impacts on living marine resources, and socioeconomic impacts, of changes in the ocean and coastal zone.

- Development and implementation of multinational systems to detect and monitor expected environmental and socioeconomic impacts of ocean and coastal zone changes.

Impacts of climate change on seasonal snow cover, ice and permafrost, and socioeconomic consequences

Major findings

- The global areal extent and volume of the terrestrial cryosphere (seasonal snow cover, near-surface layers of permafrost and some masses of ice) will be substantially reduced. These reductions, when reflected regionally, could have significant impacts on related ecosystems and social and economic activities.

- Thawing and reduction in the areal extent of the terrestrial cryosphere can enhance global warming (positive feedback on climate warming) through changes in the global and local radiation and heat balances, and the release of greenhouse gases. This positive feedback could increase the rate of global warming and, in some regions, could result in changes that are sudden rather than gradual. The possibility of relatively rapid changes, increases the potential significance of the associated impacts.

- The areal coverage of seasonal snow and its duration are projected to decrease in most regions, particularly at mid latitudes, with some regions at high latitudes in the Arctic and Antarctic possibly experiencing increases in seasonal snow cover.

- Decreases in seasonal snow cover can have both positive and negative socio-economic consequences owing to impacts on regional water resources, winter transportation and winter recreation.

- Globally, the ice contained in glaciers and ice sheets is projected to decrease. Regional responses, however, are complicated by the effect of increased snowfall in some areas which could lead to accumulation of ice. Glacial recession will have significant implications for local and regional water resources and thus impact on water availability and on hydroelectric power potential. Enhanced melt rates of glaciers may initially increase the flow of melt-waters; however, flows will decrease and eventually be lost as glacial ice mass decreases. Glacial recession and loss of ice from ice sheets will also contribute to sea-level rise.

- Degradation of permafrost is expected with an increase in the thickness of the seasonal freeze-thaw (active) layer and a recession of permafrost to higher latitudes and higher altitudes. The thickness of the active layer is expected to increase by 1 m over the next 40-50 years. Although major shifts are expected in climatic zones, recession of permafrost will significantly lag behind, receding only 25-50 km during the next 40-50 years. These changes could lead to increases in terrain instability, erosion and landslides in those areas which are currently underlaid by permafrost.

- The socioeconomic consequences of these changes in permafrost could be significant. Ecosystems which are underlaid by permafrost could be substantially altered owing to terrain disturbances and changes in the availability of water. The integrity of existing and planned structures and associated facilities and infrastructure could be reduced by changes in the underlying permafrost. Retrofitting or redesigning would be required at a minimum; however, in some situations the associated terrain disruptions and/or costs (environmental, social and economic) may be too large, necessitating abandonment. Development opportunities could also be affected in areas where the risks associated with developing in an area susceptible to permafrost degradation are assessed as too high.

- The terrestrial cryosphere, because of its relative responsiveness to climate and climatic changes, provides an effective means of monitoring and detecting climatic change.

- Lack of sufficient data and gaps in the understanding of associated processes limits more quantitative assessments at this time.

Principal issues

The terrestrial component of the cryosphere consists of seasonal snow cover, mountain glaciers, ice sheets, and frozen ground, including permafrost and seasonally frozen ground. These elements of the terrestrial cryosphere currently cover approximately 41 million km^2 with seasonal snow cover covering as much as 62% of the Eurasian continent and virtually all of North America north of 35° latitude.

Projected changes in climate will dramatically reduce the areal extent and volume of these elements of the terrestrial cryosphere. This has implications not only with respect to changes in the availability of fresh water, changes in sea-level and in terrain characteristics, but also for societies and related economic systems which have come to depend on, or are limited by, the existence of a terrestrial cryosphere.

Feedback mechanisms are an important factor in understanding the impacts of climatic change on the terrestrial cryosphere. Reduced areal coverage of these elements and degradation of permafrost as a result of climatic warming can enhance warming through changes in surface characteristics and release of greenhouse gases.

The impacts of socioeconomic consequences of changes in the terrestrial cryosphere will depend to a large extent on the rate at which the changes occur. Where the rate of change is quick or sudden, environment and associated social and economic systems will have little time to adapt. Under these circumstances the impacts and socioeconomic consequences could be large.

Seasonal snow cover

General Circulation Models indicate that in most parts of the Northern and Southern Hemispheres the area of snow cover is expected to decrease as a result of increased temperature and, in most regions, a corresponding decrease in total mass of the snow. Areas where snow cover is projected to increase include latitudes south of 60°S and higher elevations of inland Greenland and Antarctica (though the latter is, and will remain, largely a cold desert).

A reduction in the areal snow coverage and in the length of the snow cover season will result in a positive climatic feedback, increasing global warming as a result of the greater amount of solar radiation that a snow-free surface can absorb relative to one that is snow-covered.

Loss of snow cover has both negative and positive socioeconomic consequences. Decreases in snow cover will result in increased risks of damages and losses for those systems which rely on snow as protection (ie insulation) from cold winter climates. Included are agricultural crops such as winter wheat, trees and shrubs, hibernating animals, and construction and maintenance of municipal infrastructures.

Reductions in both the temporal and spatial coverage of seasonal snow cover will have significant ramifications for water resources as the amount of water available for consumptive (eg potable and irrigation water) and non-consumptive (eg hydroelectric power and waste management) uses decreases. Particularly sensitive are those areas such as the Alps and Carpathians, the Altai mountains of Central Asia, the Syr Dar'ya and Amu Dar'ya region of the USSR, the Rocky Mountains and the North American Great Plains, all of which are dependent on snowmelt for the majority of their spring and summer water resources.

Changes in snow cover will also affect tourism and recreation-based industries and societies, particularly winter recreation sports such as skiing. Projected climate change could eliminate a $50 million per annum ski industry in Ontario, Canada.

From a positive impacts perspective, reductions of seasonal snow cover will reduce expenditures on snow removal and will increase access opportunities and ease transportation problems. A reduction in snow cover, however, will also have adverse impacts for transportation in those areas which rely on snow roads in winter. Inability to use snow roads will result in the necessity of using other more costly methods of transportation.

Ice sheets and glaciers

The relationships between climate and ice sheets and glaciers are complex, and because of relatively limited monitoring and research, not fully understood at this time. Increased temperatures generally result in increased ablation and, hence, a decrease in ice mass. Conversely, increased snowfall usually increases ice mass. Since projected changes in climate for some ice-covered regions include both increases in temperature and snowfall, understanding the impact of climatic changes on glaciers and ice sheets must consider the combined impact.

The bulk of the earth's ice mass is stored in the Antarctic ice sheet, divided between an eastern portion resting on continental crust and a large western portion which is underlaid both by continental crust and ocean. Much of the remaining ice mass is contained in the Greenland ice sheet, with smaller quantities stored in glaciers throughout the world.

Although observed data are limited, it is estimated that both Antarctic and Greenland ice sheets are at present roughly in equilibrium, with annual gains close to annual losses. There is some evidence that suggests that the Greenland ice sheet has been thickening since the late 1970s, which has been attributed to new snow accumulations on the ice sheet.

Greenhouse-gas-induced climatic change will tend gradually to warm these sheets and bring them out of balance with the new climate regime. Change in ice-sheet volume is likely to be slow, however, with significant loss unlikely to occur until after 2100. Calculations for Greenland suggest that a 3% loss of ice volume in the next 250 years is possible, based on the projected changes in climate. In the case of the Antarctic ice sheet the situation is more complex. The mass of the eastern ice sheet is expected to remain virtually the same or increase slowly as a result of expected increases in precipitation and temperatures. In contrast, the western ice sheet, like other marine ice sheets is inherently unstable. Climatic warming could cause groundline retreat and rapid dispersal of ice into the surrounding ocean by way of relatively fast-flowing ice streams. These changes in behaviour could lead to collapse of a portion of the western Antarctic ice sheet which, depending on the amount of ice involved, could have a dramatic impact on sea-level and the surrounding environment.

The response of glaciers to climatic change will depend on their type and geographic location. In general, however, they have been shrinking for the last 100 years and are expected to continue to do so in response to projected changes in climate. In Austria a 3°C warming by 2050 is projected to cause a reduction by about one-half in the extent of alpine glaciers. Melting of glaciers in the Soviet arctic archipelagoes may result in their disappearance in 150-250 years. In contrast, an assessment of mountain glaciers in the temperate zone of Eurasia indicates that up to 2020 these glaciers will, in general, remain essentially unchanged, with increased precipitation compensating for increased melt.

Ice sheet and glacier melting will result in higher sea-levels. Observations over the last century indicate that levels have been rising between 1-3 mm/year primarily as a result of mass loss from alpine glaciers. Current projections suggest an accelerated rise with greenhouse gas warming to a most probable rise of 65 cm by the end of the next century.

Glacial melting can act as a negative feedback to regional and global warming, with heat extracted from the air to melt glacial ice and snow, thereby reducing the degree of warming.

The melting of glaciers will also alter regional hydrologic cycles. In New Zealand it has been estimated that a 3°C increase in temperature would, in the short term, increase glacier-fed river flow in some western rivers, increasing hydroelectric power generation by 10%. Another effect of glacier retreat is possible increased debris flows. Large amounts of debris masses on steep slopes will become exposed as a result of glacial retreat and, therefore, would be unstable and vulnerable to the effects of erosion. Landslides would result, leading to burial of structures, traffic routes and vegetation. Obstructions of river flows and increased sediment loads resulting in changes in water quantity (eg local floods and reduced flows downstream) and water quality would also be likely to occur as a result of debris flows.

Permafrost

Permafrost is the part of the terrestrial cryosphere consisting of ground (soil and rock) that remains at or below freezing throughout the year. It usually contains ice which can take a variety of forms from ice held in soil pores to massive bodies of more or less pure ice many metres thick. The presence of this ice in the ground makes it behave uniquely as an earth material, and makes its properties vulnerable to climatic warming.

At present about 20-25% of the land surface of the earth contains permafrost, primarily in the polar regions but also in the alpine areas at lower latitudes. It occupies approximately 10.7 million km^2 in the USSR, 5 million km^2 in Canada, 2 million km^2 in China and 1.5 million km^2 in Alaska. Present and past climate is the major determinant of permafrost occurrence and characteristics; however, a variety of other factors is also important, for example, the properties of the soil, and overlying terrain, vegetation and snow cover.

Permafrost is usually present where the mean annual air temperature is less than -1°C. At temperatures near this value it is discontinuous in extent (discontinuous permafrost zone). Both its extent and thickness increase at progressively higher latitudes where temperatures are lower. It has been found to extend to depths of approximately 1000 m or more in parts of Canada, approximately 1500 m in the USSR and 100-250 m in China.

Permafrost can also exist in seabeds. There is extensive ice-bound material in the continental shelf beneath the Arctic Ocean; however, this permafrost is commonly relict (ie it formed under past conditions and would not form under current ones).

Permafrost is to a large extent inherently unstable since it exists so close to its melting point. Most responsive to changes in climate would be those portions nearest the surface. Climate warming would thicken the active layer, leading to a decrease in soil stability. This permafrost degradation would lead to thaw settlement of the surface (thermokarst), ponding of surface water, slope failures (landslides) and increased soil creep. This terrain instability would result in major concerns for the integrity and stability of roads, pipelines, airfields, dams, reservoirs and other facilities in areas which contain permafrost. Terrain instability of the surface layer can also occur as a result of permafrost degradation in alpine areas, such as the Alps. This instability could result in dangerous debris falls from thawed rocks and mudflows.

Slope failures, thermokarst and loss of near-surface moisture, as the increased depth of the active layer moved limited water supplies further from the surface, would have detrimental effects on vegetation and could lead to significant decreases in plant populations. In the longer term, permafrost degradation would allow the growth of deeper rooted, broadleaved species and the establishment of denser forest of coniferous species. Wildlife could also be affected through changes in terrain, surface hydrology and food availability. Loss of species and habitats can be expected, especially where wetlands dry out or areas are flooded as a result of melt.

Assessment of the effects of climate change on permafrost in any particular location must consider factors other than temperature, eg changes in summer rainfall and snow cover. In general, however, the projected warming during the next several decades would significantly deepen the active layer and initiate a northward retreat of permafrost. It is expected that a 2°C global warming would shift the southern boundary of the climatic zone currently associated with permafrost over most of Siberia north and northeast by at least 500-700 km. The southern extent of permafrost will lag behind this, moving only 25-50 km in the next 40-50 years (up to 10% reduction in an area underlaid by continuous permafrost). The depth of the active layer is expected to increase by 1 m during the next 40-50 years. Projected changes in permafrost in Canada are of similar magnitude.

The melting of permafrost would result in the release of methane and, to a lesser extent, CO_2 from previously frozen biological material and from gas hydrates. The extent to which this will enhance the greenhouse effect is uncertain, but could be about 1°C by the middle of the next century.

The socioeconomic impacts of permafrost degradation will be mixed. Maintenance costs of existing northern facilities such as buildings, roads and pipelines will tend to rise with abandonment and relocation needed in some cases. Change in current construction practices will be necessary, as may be changes in sanitary waste disposal. Benefits from climate warming and permafrost melt are likely for agriculture, forestry, and hunting and trapping.

Recommendations for action

Projected greenhouse-gas-induced changes in climate will lead to ablation of global ice masses. Uncertainty exists, however, regarding how this global response will be reflected at the regional/local level and how the individual ice masses and seasonal ice and snow will respond. The most important effects of climatic change at high latitudes and elevated regions will be on and through changes in the terrestrial cryosphere. Furthermore, the terrestrial cryosphere is particularly suited for early detection of the effects of climate change. These two points necessitate a better understanding of the nature and dynamics of these ice masses and the factors that control them. This will require:

- establishment or enhancement of integrated, systematic observation programs commensurate with research on the use of more efficient ground-based systems and remote sensing technologies designed to provide baseline information and trends;
- concurrent monitoring of those facilities, structures and natural resources that are at risk owing to projected changes in the terrestrial cryosphere;
- establishment of new guidelines and procedures for design and construction practices that consider the impacts of climatic changes on permafrost;
- research, including international cooperative efforts, on the relationships between components of the terrestrial cryosphere and climate in conjunction with other determining factors, including feedback mechanisms;
- refinement of existing climate-terrestrial cryosphere models;
- impacts assessments nationally and regionally that will provide data and information on the impacts of climate change on areas in which components of the terrestrial cryosphere occur and the resulting socioeconomic consequences;
- assessment of the needs for protected areas (natural reserves) for affected species and habitats; and
- development and distribution of relevant educational material and information on climatic changes, their impacts on the terrestrial cryosphere and socioeconomic consequences, as well as a wider distribution of research results.

Summary of major future actions

The results of the Working Group II studies highlight our lack of knowledge, particularly at the regional level and in areas most vulnerable to climate change. Further national and international research is needed on:

- regional effects of climate change on crop yields, livestock productivity and production costs;
- identification of agricultural management practices and technology appropriate for changed climate;
- factors influencing distribution of species and their sensitivity to climate change;
- initiation and maintenance of integrated monitoring systems for terrestrial and marine ecosystems;
- intensive assessment of water resources and water quality, especially in arid and semi-arid developing countries and their sensitivity to climate change;
- regional predictions of changes in soil moisture, precipitation, surface and subsurface runoff regimes and their interannual distributions as a result of climate change;
- assessment of vulnerability of countries to gain or loss of energy resources, particularly biomass and hydroelectric power in developing countries;
- adaptability of vulnerable human populations to heat stress and vector-borne and viral diseases;
- a global monitoring of sea-level changes, particularly for island countries;
- identification of populations and agricultural and industrial production at risk in coastal areas and islands;
- better understanding of the nature and dynamics of ice masses and their sensitivity to climate change;
- integration of climate change impact information into the general planning process, particularly in developing countries; and
- development of methodology to assess sensitivity of environments and socioeconomic systems to climate change.
- Some of these topics are already being covered by existing and proposed programs and these will need continuing support. In particular, there are three core projects of the International Geosphere-Biosphere Program, namely:

  Land-Ocean Interactions in the Coastal Zone

  Biosphere Aspects of the Hydrological Cycle

  Global Change Impact on Agriculture and Society

that will provide valuable data in the coming years.

Concluding remarks

Human-induced climate change can have profound consequences for the world's social, economic and natural systems. Each country should take steps to understand the impacts on its population and land resources resulting from such a change, and the consequences of sea-level rise, the changed character of atmospheric circulation and the resulting changes in typical weather patterns, reduction of freshwater resources, increased ultraviolet-B radiation and spreading of pests and diseases. These can affect the potential of food and agricultural production and adversely affect human health and well-being.

Too rapid a change in climate may not allow species to adapt and, thus, biodiversity could be reduced. This reduction could occur equally as well in the cryosphere regions, where melting of sea ice could accelerate, and in the equatorial regions where sea surface temperatures could increase. Traditional cost-benefit analyses do not allow for assessment of these risks. Although substantial scientific uncertainty remains concerning the precise time, location and nature of particular impacts, it is inevitable, under the scenario developed by Working Group I, that in the absence of major preventive and adaptive actions by humanity, significant and potentially disruptive changes in the earth's environment will occur.

The world community recognises the need to undertake certain actions to reduce and mitigate the impact of climate change. Specific measures should follow the assessments of potential impact on the biosphere and on human activity, and a comparison of the net costs of adaptation and mitigation measures. Some of these impacts, such as sea-level rise, are likely to proceed slowly but steadily while others such as shifts in climate zones - which will affect the occurrence of such events as floods, droughts and severe storms - may occur unpredictably. Regions and nations differ considerably in their vulnerability to such changes and subsequent impacts. Generally human activity in developing countries is more vulnerable than that in developed countries to the disruption associated with climate change. Global warming and its impact must not widen the gap between developed and developing countries.

The capacity of developing nations to adapt to likely climate changes and to minimise their own contributions to it through greenhouse gas emissions, is constrained by their limited resources, by their debt problems and by their difficulties in developing their economies on a sustainable and equitable basis. These countries will need assistance in developing and implementing appropriate response options (including consideration of technological development and transfer, additional financial assistance, public education and information). As they possess greater resources to cope with climate change, developed countries must recognise the need to assist developing countries to assess and deal with the potential impacts of climate change.

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INTERGOVERNMENTAL PANEL ON
CLIMATE CHANGE

POLICYMAKERS SUMMARY

OF THE

FORMULATION OF RESPONSE STRATEGIES

Report Prepared for IPCC
by Working Group III

June 1990

POLICYMAKERS SUMMARY OF THE REPORT OF WORKING GROUP III OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (RESPONSE STRATEGIES WORKING GROUP)

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CHAIRMAN'S INTRODUCTION

The First Plenary Meeting of Working Group III of the IPCC, the Response Strategies Working Group (RSWG), was held in Washington, 30 January - 2 February 1989. This meeting was largely organizational (see Figure 1), and it was not until after a subsequent RSWG Officers Meeting in Geneva, 8-12 May 1989, that the real work by the four RSWG subgroups, the Emissions Scenarios Task Force (Task A), and "Implementation Measures" Topic Coordinators (Task B) began.

The Second RSWG Plenary Session was held in Geneva, from 2 to 6 October 1989, to discuss the implementation measures: 1) public education and information;
2) technology development and transfer; 3) financial measures; 4) economic measures; and 5) legal measures, including elements of a framework climate convention. A consensus was reached on five topical papers dealing with these measures, with the understanding that they would be "living documents" subject to further modification as new information and developments might require.

The Third Plenary Meeting of RSWG, held in Geneva, 5-9 June 1990, achieved three objectives:

1) It reached consensus on the attached "policy summary", the first interim report of the RSWG.

2) It completed final editing and accepted the reports of the four RSWG subgroups, of the coordinators of Task A, and of the coordinators of the five Task B topical papers. These documents comprise the underlying material for the consensus report of this meeting, the policymakers summary; they are not themselves the product of a RSWG plenary consensus although many governments participated in their formulation.

Finally,

3) The Working Group agreed to submit comments on its suggested future work programme to the RSWG Chairman by 1 July 1990, for transmission to the Chair of the IPCC. There was general agreement that the work of the RSWG should continue.

The primary task of the RSWG was, in the broad sense, technical, not political. The charge of IPCC to RSWG was to lay out as fully and fairly as possible a set of response policy options and the factual basis for those options.

Consistent with that charge, it was <u>not</u> the purpose of the RSWG to select or recommend political actions, much less to carry out a negotiation on the many difficult policy questions that attach to the climate change issue, although clearly the information might tend to suggest one or another option. Selection of options for implementation is appropriately left to the policymakers of governments and/or negotiation of a convention.

The work of RSWG continues. The Energy and Industry Subgroup has, since the June RSWG Plenary Meeting, held another very productive meeting in London, the results of which are not reflected in this report.

It should be noted that quantitative estimates provided in the report regarding CFCs, including those in Scenario A (Business as Usual), generally do not reflect decisions made in June 1990 by the Parties to the Montreal Protocol. Those decisions

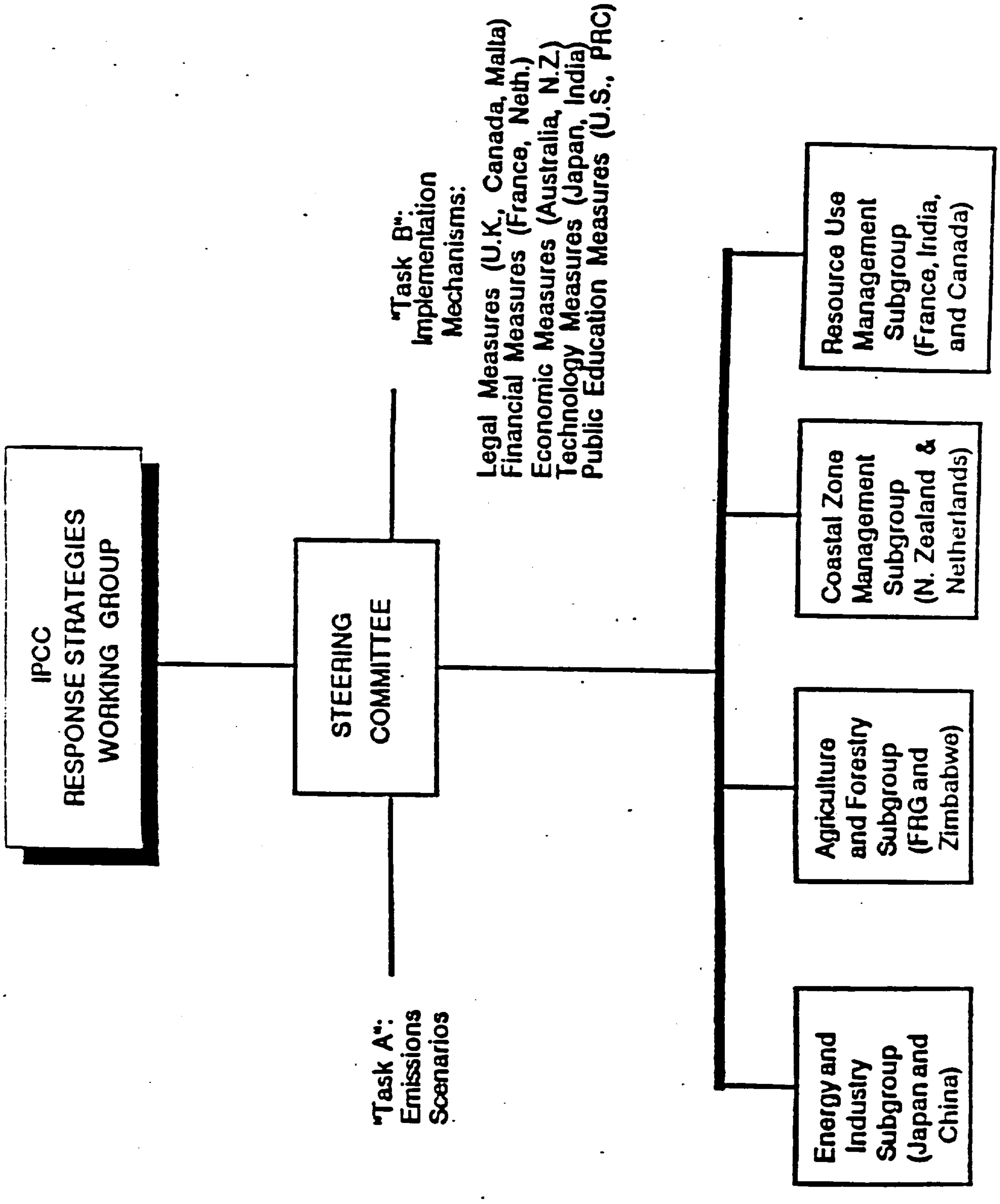
IPCC
RESPONSE STRATEGIES
WORKING GROUP
STEERING
COMMITTEE
"Task A":
Emissions
Scenarios
"Task B":
Implementation
Mechanisms:
Legal Measures (U.K., Canada, Malta)
Financial Measures (France, Neth.)
Economic Measures (Australia, N.Z.)
Technology Measures (Japan, India)
Public Education Measures (U.S., PRC)
Energy and Industry Subgroup (Japan and China)
Agriculture and Forestry Subgroup (FRG and Zimbabwe)
Coastal Zone Management Subgroup (N. Zealand & Netherlands)
Resource Use Management Subgroup (France, India, and Canada)

Figure 1.

accelerate the timetable to phase out production and consumption of CFCs, halons, carbon tetrachloride and methyl chloroform.

It should further be noted that quantitative estimates of forestry activities (e.g., deforestation, biomass burning, including fuel wood, and other changes in land-use practices), as well as agricultural and other activities, provided in the Report continue to be reviewed by experts.

Two specific items of unfinished business submitted to RSWG by the Ministers at the November 1989 meeting in Noordwijk are the consideration of the feasibility of achieving: (1) targets to limit or reduce CO_2 emissions, including e.g. a 20 percent reduction of CO_2 emission levels by the year 2005; (2) a world net forest growth of 12 million hectares a year in the beginning of the next century. The RSWG hopes to complete this analysis before the Second World Climate Conference in November of this year.

The subgroup chairs and topic coordinators took the responsibility for completing their individual reports and, along with their respective governments, contributed generously of their time and resources to that end.

The RSWG Policymakers Summary is the culmination of the first year of effort by this body. The RSWG has gone to considerable lengths to insure that the summary accurately reflects the work of the various subgroups and tasks. Given the very strict time schedule under which the RSWG was asked to work, this first report can only be a beginning.

Frederick M. Bernthal
Chairman,
Response Strategies Working Group

EXECUTIVE SUMMARY

Working Group III (Response Strategies Working Group) was tasked to formulate appropriate response strategies to global climate change. This was to be done in the context of the work of Working Group I (Science) and Working Group II (Impacts) which concluded that:

"We are certain emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluoro-carbons (CFCs) and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface.

"The longer emissions continue at present day rates, the greater reductions would have to be for concentrations to stabilize at a given level.

"The long-lived gases would require immediate reductions in emissions from human activities of over 60% to stabilize their concentrations at today's levels.

"Based on current model results, we predict under the IPCC Business-as-Usual emissions of greenhouse gases, a rate of increase of global mean temperature during the next century of about 0.3°C per decade (with an uncertainty range of 0.2°C to 0.5°C per decade), greater than that seen over the past 10,000 years; under the same scenario, we also predict an average rate of global mean sea level rise of about 6 cm per decade over the next century (with an uncertainty range of 3 - 10 cm per decade).

"There are many uncertainties in our predictions particularly with regard to the timing, magnitude and regional patterns of climate change.

"Ecosystems affect climate, and will be affected by a changing climate and by increasing carbon dioxide concentrations. Rapid changes in climate will change the composition of ecosystems; some species will benefit while others will be unable to migrate or adapt fast enough and may become extinct. Enhanced levels of carbon dioxide may increase productivity and efficiency of water use of vegetation.

"In many cases, the impacts will be felt most severely in regions already under stress, mainly the developing countries.

"The most vulnerable human settlements are those especially exposed to natural hazards, e.g., coastal or river flooding, severe drought, landslides, severe storms and tropical cyclones".

Any responses will have to take into account the great diversity of different countries' situations and their responsibility for and negative impacts on different countries and consequently would require a wide variety of responses. Developing countries for example are at widely varying levels of development and face a broad range of different problems. They account for 75% of the world population and their primary resource bases differ widely. Nevertheless, they are most vulnerable to the adverse consequences of climate change because of limited access to the necessary information, infrastructure, and human and financial resources.

Main findings

1) Climate change is a global issue; effective responses would require a global effort which may have a considerable impact on humankind and individual societies.

2) Industrialized countries and developing countries have a common responsibility in dealing with problems arising from climate change.

3) Industrialized countries have specific responsibilities on two levels:

   a) major part of emissions affecting the atmosphere at present originates in industrialized countries where the scope for change is greatest. Industrialized countries should adopt domestic measures to limit climate change by adapting their own economies in line with future agreements to limit emissions;

   b) to co-operate with developing countries in international action, without standing in the way of the latter's development, by contributing additional financial resources, by appropriate transfer of technology, by engaging in close co-operation concerning scientific observation, by analysis and research, and finally by means of technical co-operation geared to forestalling and managing environmental problems.

4) Emissions from developing countries are growing and may need to grow in order to meet their development requirements and thus, over time, are likely to represent an increasingly significant percentage of global emissions. Developing countries have the responsibility, within the limits feasible, to take measures to suitably adapt their economies.

5) Sustainable development requires the proper concern for environmental protection as the necessary basis for continuing economic growth. Continuing economic development will increasingly have to take into account the issue of climate change. It is imperative that the right balance between economic and environmental objectives be struck.

6) Limitation and adaptation strategies must be considered as an integrated package and should complement each other to minimize net costs. Strategies that limit greenhouse gases emissions also make it easier to adapt to climate change.

7) The potentially serious consequences of climate change on the global environment give sufficient reasons to begin by adopting response strategies that can be justified immediately even in the face of significant uncertainties.

8) A well-informed population is essential to promote awareness of the issues and provide guidance on positive practices. The social, economic and cultural diversity of nations will require tailored approaches.

A flexible and progressive approach

Greenhouse gas emissions from most sources are likely to increase significantly in the future if no response measures are taken.

Although some controls have been put in place under the Montreal Protocol for CFCs and halons, emissions of CO_2, CH_4, N_2O and other gases such as several CFC-substitutes will grow. Under these scenarios, it is estimated that CO_2 emissions will increase from approximately 7 billion (or 1000 million) tonnes carbon (BtC)in 1985 to between 11-15 BtC by 2025. Similarly, man-made methane emissions are estimated to increase from about 300 teragrams (Tg) to over 500 Tg by the year 2025. Based on these projections, Working Group I estimated that global warming of 0.3°C/decade could occur.

The climate scenario studies of Working Group I further suggest that control policies on emissions can indeed slow global warming, perhaps from 0.3°C/decade to 0.1°C/decade. The social, economic and environmental costs and benefits of these control policies have not been fully assessed. It must be emphasized that implementation of measures to reduce global emissions are very difficult as energy use, forestry, and land use patterns are primary factors in the global economy. To take maximum advantage of our increasing understanding of scientific and socio-economic aspects of the issue, a flexible and progressive approach is required. Subject to their particular circumstances, individual nations may wish to consider taking steps now to attempt to limit, stabilize or reduce the emission of greenhouse gases resulting from human activities and prevent the destruction and improve the effectiveness of sinks. One option that governments may wish to consider is the setting of targets for CO_2 and other greenhouse gases.

Because large, projected increase in world population will be a major factor in causing the projected increase in global greenhouse gases, it is essential that global climate change strategies include strategies and measures to deal with the rate of growth of the world population.

<u>Shorter-term</u>

The Working Group has identified measures at the national, regional and international levels as applicable which, while helping to tackle climate change, can yield other benefits.

Limitation

- Improved energy efficiency reduces emissions of carbon dioxide, the most significant greenhouse gas, while improving overall economic performance and reducing other pollutant emissions and increasing energy security.

- Use of cleaner energy sources and technologies reduces carbon dioxide emissions, while reducing other pollutant emissions that give rise to acid rain and other damaging effects.

- Improved forest management and, where feasible, expansion of forest areas as possible reservoirs of carbon.

- Phasing out of CFCs under the Montreal Protocol, thus removing some of the most powerful and long-lived greenhouse gases, while also protecting the stratospheric ozone layer.

- Agriculture, forestry and other human activities are also responsible for substantial quantities of greenhouse gas emissions. In the short term, reductions can be achieved through improved livestock waste management, altered use and formulation of fertilizers, and other changes to agricultural land use, without affecting food security, as well as through improved management in landfill and wastewater treatment.

Adaptation

- Developing emergency and disaster preparedness policies and programmes.

- Assessing areas at risk from sea-level rise and developing comprehensive management plans to reduce future vulnerability of populations and coastal developments and ecosystems as part of coastal zone management plans.

- Improving the efficiency of natural resource use, research on control measures for desertification and enhancing adaptability of crops to saline regimes.

Longer-term

Governments should prepare for more intensive action which is detailed in the report. To do so, they should undertake now:

- Accelerated and coordinated research programmes to reduce scientific and socio-economic uncertainties with a view towards improving the basis for response strategies and measures.

- Development of new technologies in the fields of energy, industry and agriculture.

- Review planning in the fields of energy, industry, transportation, urban areas, coastal zones and resource use and management.

- Encourage beneficial behavioral and structural (e.g., tranportation and housing infrastructure) changes.

- Expand the global ocean observing and monitoring systems.

It should be noted that no detailed assessments have been made as of yet of the economic costs and benefits, technological feasibility or market potential of the underlying policy assumptions.

International cooperation

The measures noted above require a high degree of international cooperation with due respect for national sovereignty of states. The international negotiation on a framework convention should start as quickly as possible after the completion of the IPCC First Assessment Report. This, together with any additional protocols that might be agreed upon, would provide a firm basis for effective cooperation to act on greenhouse gas emissions and adapt to any adverse effects of climate change. The convention should, at a minimum, contain general principles and obligations. It should be framed in such a way as to gain the adherence of the largest possible number and most suitably balanced range of countries while permitting timely action to be taken.

Key issues for negotiation will include the criteria, timing, legal form and incidence of any obligations to control the net emissions of greenhouse gases, how to address equitably the consequences for all, any institutional mechanisms that may be required, the need for research and monitoring, and in particular, the request of the developing countries for additional financial resources and for the transfer of technology on a preferential basis.

Further consideration

The issues, options and strategies presented in this document are intended to assist policymakers and future negotiators in their respective tasks. Further consideration of the summary and the underlying reports of Working Group III should be given by every government as they cut across different sectors in all countries. It should be noted that the scientific and technical information contained in the policymakers summary and the underlying reports of Working Group III do not necessarily represent the official views of all governments, particularly those that could not participate fully in all Working Groups.

FORMULATION OF RESPONSE STRATEGIES

by Working Group III

1. SOURCES OF ANTHROPOGENIC GREENHOUSE GASES

A wide range of human activities result in the release of greenhouse gases, particularly CO_2, CH_4, CFCs and N_2O, into the atmosphere. Anthropogenic emissions can be categorized as arising from energy production and use, non-energy industrial activities (primarily the production and use of CFCs), agricultural systems, and changes in land-use patterns (including deforestation and biomass burning). The relative contributions of these activities to radiative forcing during the 1980s are discussed in the text and shown below in Figure 2 (see Working Group I report for further explanation of the radiative forcing of the various greenhouse gases; see also the Chairman's introduction regarding these activities for the quantitative estimates of their contributions to radiative forcing).

IPCC Working Group I calculated that the observed increases in the atmospheric concentrations of CO_2, CH_4, CFCs and N_2O during the 1980s, which resulted from human activities, contributed to the enhanced radiative forcing by 56%, 15%, 24% and 5%, respectively.

Energy

The single largest anthropogenic source of radiative forcing is energy production and use. The consumption of energy from fossil fuels (coal, petroleum and natural gas excluding fuel wood) for industrial commercial, residential, transportation and other purposes results in large emissions of CO_2 accompanied by much smaller emissions of CH_4 from coal mining and the venting of natural gas; the energy sector accounts for an estimated 46% (with an uncertainty range of 38-54%) of the enhanced radiative forcing resulting from human activities.

Natural fluxes of CO_2 into the atmosphere are large (200 Bt/yr[1]), but inputs of man made sources are large enough to significantly disturb the atmospheric balance.

Industry

The production and use of CFCs and other halocarbons in various industrial processes comprise about 24% of the enhanced radiative forcing.

Forestry

Deforestation, biomass burning including fuel wood, and other changes in land-use practices, release CO_2, CH_4, and N_2O into the atmosphere and together comprise about 18% (with an uncertainty range of 9-26%) of the enhanced radiative forcing.

Agriculture

Methane releases from rice cultivation and from livestock systems, and nitrous oxide released during the use of nitrogenous fertilizers together comprise about 9% (with an uncertainty range of 4-13%) of the enhanced radiative forcing.

Other sources

Carbon dioxide from cement manufacturing and methane from

1. *Billion (or 1000 million) tonnes per year.*

ESTIMATED CONTRIBUTION OF DIFFERENT HUMAN ACTIVITIES TO THE CHANGE IN RADIATIVE FORCING DURING THE DECADE FROM 1980 TO 1990*

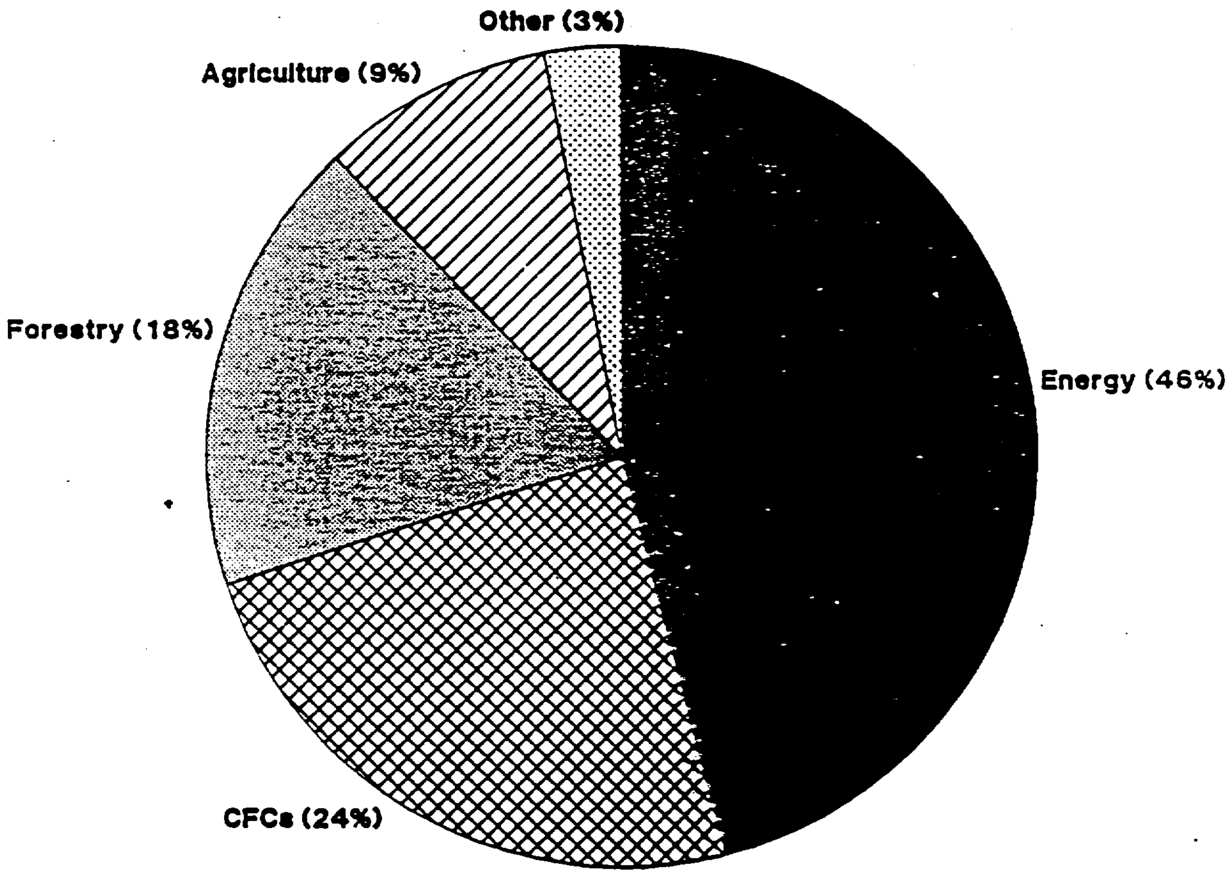

Figure 2.

* Percentages derived from estimated greenhouse gas concentrations in the atmosphere and the Global Warming Potentials of these greenhouse gases given in the Policymakers Summary of Working Group I on Pages 11 and 12.

land-fills together comprise about 3% (with an uncertainty range of 1-4%) of the enhanced radiative forcing.

Estimates of current greenhouse gas emissions are not precise because of uncertainties regarding both total emissions and emissions from individual sources. Global emissions from certain sources are particularly difficult to determine, e.g., CO_2 emission from deforestation, CH_4 emission from rice cultivation, livestock systems, biomass burning, coal mining and venting of natural gas, and N_2O emissions from all sources. The range of such estimates can be quite large, typically, a factor of 1.5 for methane from livestock, a factor of 4 for CO_2 from deforestation, and upto a factor of 7 for rice.

2. FUTURE EMISSIONS OF GREENHOUSE GASES

Greenhouse gas emissions from most sources are likely to increase significantly in the future if no policy measures are taken. As economic and population growth continue, in particular in the developing countries, there is expected to be an increase in energy use, industrial and agricultural activity, deforestation, and other activities which result in a net increase of greenhouse gas emissions. Although some controls have been put in place under the Montreal Protocol for certain CFCs and halons, emissions of CO_2, methane, nitrous oxide, and other greenhouse gases are likely to increase under current patterns of economic activity and growth.

However, because of the inherent limitations in our ability to estimate future rates of population and economic growth, etc, there is some uncertainty in the projections of greenhouse gas emissions, individual behaviour, technological innovation, and other factors which are crucial for determining emission rates over the course of the next century. This lends uncertainty to projections of greenhouse gas emissions over several decades or longer. Reflecting these inherent difficulties, the RSWG's work on emissions scenarios are the best estimates at this time covering emissions over the next century but further work needs to be done.

The RSWG used two methods to develop scenarios of future emissions as discussed in Sections 3.1. and 3.2. One method used global models to develop four scenarios which were subsequently used by Working Group I to develop estimates of future warming. The second method used studies of the energy and agriculture sectors submitted by over 21 countries and international organizations to estimate emissions. These latter studies were aggregated into a reference scenario. Both approaches show that emissions of CO_2 and CH_4 will increase in the future. Both approaches indicate that CO_2 emissions will grow from approximately 7 BtC to between 11-15 BtC by the year 2025.

2.1 Emissions scenarios

One of the RSWG's first tasks was to prepare some initial scenarios of possible future greenhouse gas emissions for the use of the three IPCC Working Groups. An experts' group was formed which looked at four hypothetical future patterns of greenhouse gas emissions and their effect on the atmosphere. The cumulative effect of these emissions was calculated using the concept of equivalent CO_2 concentrations (e.g. the contributions of all greenhouse gases to radiative forcing are converted into their equivalent in terms of CO_2 concentrations). Global economic growth rates were taken from World Bank projections and population estimates were taken from UN studies and assumed equal for all scenarios.

The first of the scenarios, called the Business-as-Usual or the 2030 High Emissions Scenario, assumes that few or no steps are taken to limit greenhouse gas emissions. Energy use and clearing of tropical forests continue and fossil fuels, in particular coal, remain the world's primary energy source. The Montreal Protocol comes into effect but without strengthening and with less than 100 percent compliance. Under this scenario, the equivalent of a doubling of pre-industrial CO_2 levels occurs, according to Working Group I, by around 2025.

The predicted anthropogenic contributions to greenhouse gas emissions in 2025 are shown in Table 1. The RSWG attempted to synthesize and compare the results of the AFOS/EIS Reference Scenario and the Task A "Business-as-Usual" (or "2030 High Emissions") Scenario (see Figure 3). The figure shows the equivalent CO_2 concentrations for the Task A "Business-as-Usual" Scenario and the AFOS/EIS Reference Scenario with its higher CO_2 emissions and the CFC phaseout agreed to by the Parties to the Montreal Protocol. The results indicate that the CO_2 equivalent concentrations and thus the effect on the global climate are similar for both scenarios.

The second of the scenarios, the 2060 Low Emissions Scenario, assumes that a number of environmental and economic concerns result in steps to reduce the growth of greenhouse gas emissions. Energy efficiency measures, which might only be possible with government intervention, are implemented, emissions controls are adopted globally, and the share of the world's primary energy provided by natural gas increases. Full compliance with the Montreal Protocol is achieved and tropical deforestation is halted and reversed. Under this scenario, the cumulative effect of such measures is a CO_2 equivalent doubling around 2060.

The remaining two scenarios reflect futures where steps in addition to those in the 2060 Low Emissions Scenario are taken to reduce greenhouse gas emissions. These steps include rapid utilization of renewable energy sources, strengthening of the Montreal Protocol, and adoption of agricultural policies to reduce emissions from livestock systems, rice paddies, and fertilizers.

All of the above scenarios provide a conceptual basis for considering possible future patterns of emissions and the broad responses that might affect those patterns. However, they represent assumptions rather than cases derived from specific studies. In addition, no full assessment was made as yet of the total economic costs and benefits, technological feasibility, or market potential of the underlying policy assumptions.

2.2 Reference scenario

Table 2 shows the results of the EIS Reference Scenario (for CO_2 emissions from the energy sector only) divided by region. The table is incomplete and does not include CO_2 emissions from non-energy sources nor other greenhouse gases and sinks. While it is not directly a measure of a region's climate forcing contribution, this table does portray a future where, in the absence of specific policy measures, global emissions of one major gas, CO_2, grow from 5.15 BtC in 1985, to 7.30 BtC in 2000 and 12.43 BtC in 2025. Primary energy demand more than doubles between

TABLE 1: Anthropogenic Greenhouse Gas Emissions From Working Group III Scenarios

	AFOS/EIS Reference Scenario modified to include CFC phaseout[2]		Task A "Business as Usual" Scenario	
	1985	2025	1985	2025
CO_2 Emissions (BtC)				
Energy	5.1	12.4	5.1	9.9
Deforestation	1.7[3]	2.6	0.7[4]	1.4
Cement	0.1	0.2	0.1	0.2
Total	6.9	15.2	5.9	11.5
CH_4 Emission ($TgCH_4$)[5]				
Coal Mining	44	126	35	85
Natural Gas	22	59	45	74
Rice	110	149	110	149
Enteric Ferm.	75	125	74	125
Animal Wastes	37	59	-	-
Landfills	30	60	40	71
Biomass Burning	53	73	53	73
Total	371	651	357	577
N_2O (TgN)[5]	4.6	8.7	4.4	8.3
CO (TgC)[5]	473	820	443	682
NO_x (TgN)[5]	38	69	29	47
CFCs (Gg)				
CFC-11	278	11	278	245
CFC-12	362	10	362	303
HCFC-22	97	1572	97	1340
CFC-113	151	0	151	122
CFC-114	15	0	15	9
CFC-115	5	0	5	5
CCl_4	87	110	87	300
CH_3CCl_3	814	664	814	1841
Halon 1301	2.1	1.8	2.1	7.4

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[2] The estimates for emissions of CFCs in 1985 and 2025 reflect the decisions taken at the meeting of the Parties to the Montreal Protocol in London in June 1990. At that meeting, the parties agreed to accelerate the phase out of the production and consumption of CFCs, halons, carbon tetrachloride and methyl chloroform.

[3] Midrange estimates for deforestation and biomass consistent with preferred value from Working Group I.

[4] Assuming low biomass per hectare and deforestation rates.

[5] Differences in the 1985 emissions figures are due to differences in definitions and qualifying the emissions from these particular sources.

EIS/AFOS Reference Scenario--Task A: Business as Usual

CO2 Equivalent Concentrations

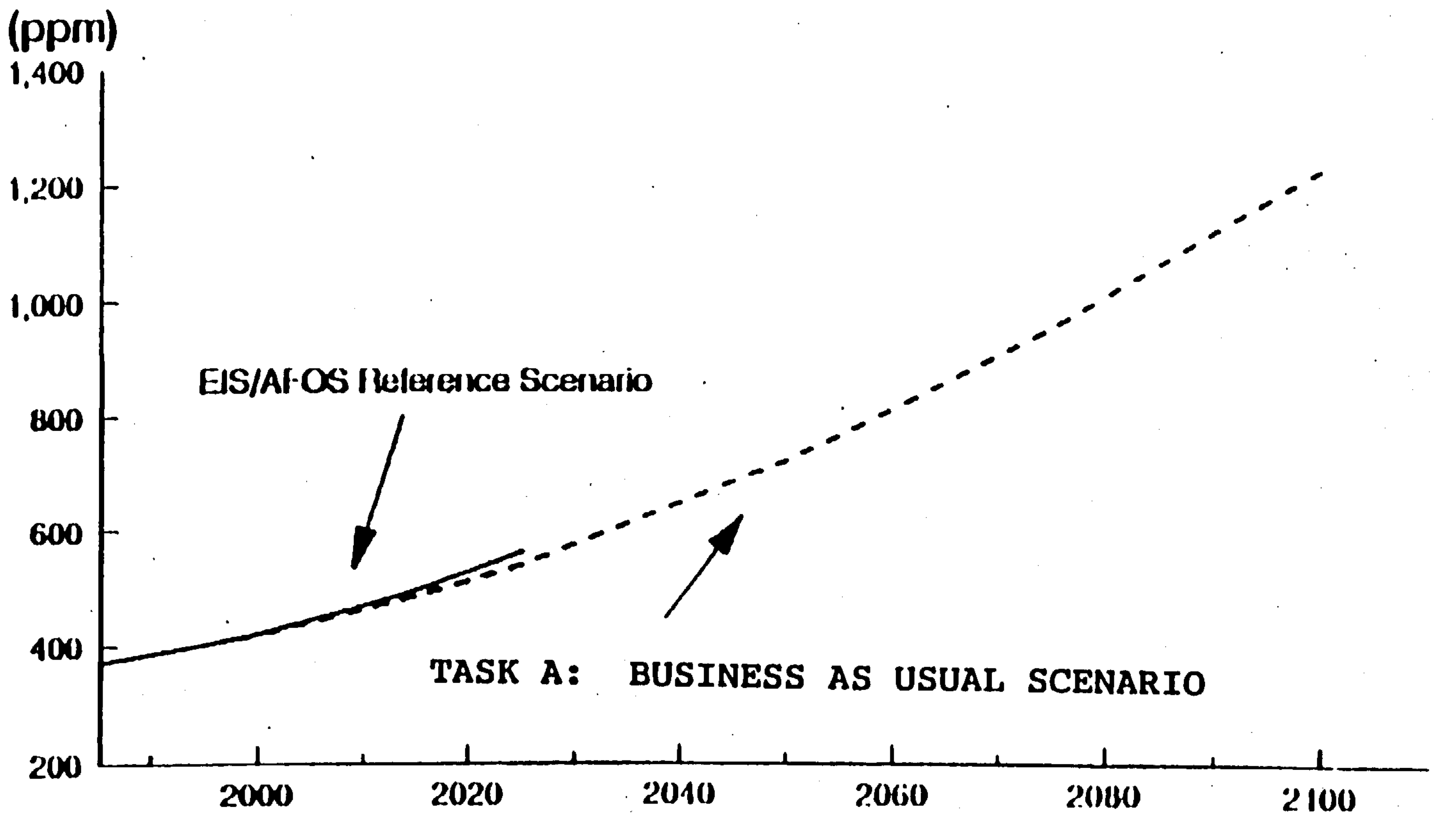

Figure 3.

1985 and 2025, an average annual growth rate of 2.1%.

The annual rate of growth in CO_2 emissions varies between 0.7% in Western Europe, 1.3% in North America and the Pacific OECD Countries, and 3.6% in developing countries. The share of emissions between regions varies over time.

Under this scenario, the per capita emissions in the industrialized countries increase from 3.1 tonnes carbon (TC) per capita in 1985 to 4.7 TC per capita in 2025. For the developing countries, the per capita emissions rise from 0.4 TC per capita in 1985 to 0.8 TC per capita in 2025.

The Reference Scenario sets out an example of the scope of the reductions in total global emissions which might be necessary to stabilize or reduce CO_2 emissions. The stabilization of global emissions at 1985 levels would require reductions of 29% by 2000 and 59% by 2025. A reduction of global emissions to 20% below 1985 levels would require reductions of 44% in 2000 and 67% by 2025.

The carbon intensity figures show, for each region, the amount of carbon emitted per unit of energy consumed. The contribution of energy consumption in a region to global warming is largely a function of its carbon intensity, total fuel use, and of the efficiency with which it consumes fossil fuels. Carbon intensity for industrialized countries changes from 16.3 tonnes carbon per gigajoule (TC-GJ) in 1985 to 15.5 in 2025. In the developing world the change is from 14.2 TC-GJ to 15.6.

3. RESPONSE STRATEGIES FOR ADDRESSING GLOBAL CLIMATE CHANGE

Because climate change could potentially result in significant impacts on the global environment and human activities, it is important to begin considering now what measures might be taken in response. Working Group 1 found that under a "Business-as-Usual" scenario global average temperature could rise by 0.3 degrees centigrade per decade; it also found that under the Accelerated Control Policies Scenario (scenario D) with extremely stringent emissions reductions the temperature rise could perhaps be reduced to 0.1 degree centigrade per decade. The RSWG identified a wide range of options for the international community to consider. These include measures both to limit net greenhouse gas emissions and to increase the ability of society and managed ecosystems to adapt to a changing climate.

Strategies which focus only on one group of emission sources, one type of abatement option or one particular greenhouse gas will not achieve this. Policy responses should, therefore, be balanced against alternative abatement options among the energy, industry, forestry and agricultural sectors, and adaptation options and other policy goals where applicable at both national and international levels. Ways should be sought to account for other countries, and intergenerational issues, when making policy decisions.

The consideration of climate change response strategies, however, presents formidable difficulties for policymakers. On the one hand, the information available to make sound policy analyses is inadequate because of: (a) remaining scientific uncertainties regarding the magnitude, timing, rate, and regional consequences of potential climate change; (b) uncertainty with respect to how effective specific response options or groups

TABLE 2

GROSS CO_2 EMISSIONS FROM THE ENERGY SECTOR*
(From the Reference Scenario)

CO_2 Emissions in the Reference Scenario (billion tonnes carbon/year)

	1985	%	2000	%	2025	%
Global Totals	5.15	(100)	7.30	(100)	12.43	(100)
Industrialized	3.83	(74)	4.95	(68)	6.95	(56)
North America	1.34	(26)	1.71	(23)	2.37	(19)
Western Europe	0.85	(16)	0.98	(13)	1.19	(10)
OECD Pacific	0.31	(6)	0.48	(7)	0.62	(5)
Centrally Planned Europe	1.33	(26)	1.78	(24)	2.77	(22)
Developing	1.33	(26)	2.35	(32)	5.48	(44)
Africa	0.17	(3)	0.28	(4)	0.80	(6)
Centrally Planned Asia	0.54	(10)	0.88	(12)	1.80	(14)
Latin America	0.22	(4)	0.31	(4)	0.65	(5)
Middle East	0.13	(3)	0.31	(4)	0.67	(5)
South and East Asia	0.27	(5)	0.56	(8)	1.55	(12)

	1985		2000		2025	
	PC**	CI***	PC	CI	PC	CI
Global Totals	1.06	15.7	1.22	15.8	1.56	16.0
Industrialized	3.12	16.3	3.65	16.1	4.65	16.0
North America	5.08	15.7	5.75	15.8	7.12	16.6
Western Europe	2.14	15.6	2.29	15.1	2.69	14.6
OECD Pacific	2.14	16.1	3.01	16.1	3.68	14.8
Non OECD Europe	3.19	17.5	3.78	16.9	5.02	16.4
Developing	0.36	14.2	0.51	15.2	0.84	16.0
Africa	0.29	12.3	0.32	13.2	0.54	15.2
Centrally Planned Asia	0.47	17.3	0.68	18.8	1.15	19.6
Latin America	0.55	11.5	0.61	11.4	0.91	11.8
Middle East	1.20	16.7	1.79	16.1	2.41	15.5
South and East Asia	0.19	12.3	0.32	14.3	0.64	15.6

* This table presents regional CO_2 emissions and does not include CFCs, CH_4, O_3, N_2O, or sinks. Climate change critically depends on all GHG from all economic sectors. This table should be interpreted with care.

** PC - Per capita carbon emissions in tonnes carbon per person.

*** CI - Carbon Intensity in kilograms carbon per gigajoule.

of options would be in actually averting potential climate change; and (c) uncertainty with respect to the costs, effects on economic growth, and other economic and social implications of specific response options or groupsof options. The potentially serious consequences of climate change on the global environment, however, give sufficient reasons to begin by adopting response strategies that can be justified immediately even in the face of such significant uncertainties.

Recognizing these factors, a large number of options were preliminarily assessed. It appears that some of these options may be economically and socially feasible for implementation in the near-term while others, because they are not yet technically or economically viable, may be more appropriate for implementation in the longer-term. In general, the RSWG found that the most effective response strategies, especially in the short-term, are those which are:

- beneficial for reasons other than climate change and justifiable in their own right, for example increased energy efficiency and lower greenhouse gas emission technologies, better management of forests and other natural resources, and reductions in emissions of CFCs and other ozone depleting substances that are also radiatively important gases;

- economically efficient and cost effective, in particular those that use market-based mechanisms;

- able to serve multiple social, economic, and environmental purposes;

- flexible and phased, so that they can be easily modified to respond to increased understanding of scientific, technological and economic aspects of climate change;

- economic growth and the concept of sustainable development;
- administratively practical and effective in terms of application, monitoring, and enforcement; and

- reflecting obligations of both industrialized and developing countries in addressing this issue, while recognizing the special needs of developing countries, in particular in the areas of financing and technology.

The degree to which options are viable will also vary considerably depending on the region or country involved. For each country, the implications of specific options will depend on its social, environmental, and economic context. Only through careful analysis of all available options will it be possible to determine which are best suited to the circumstances of a particular country or region. Initially, the highest priority should be to review existing policies with a view to minimizing conflicts with the goals of climate change strategies. New policies will be required.

4. OPTIONS FOR LIMITING GREENHOUSE GAS EMISSIONS

The RSWG reviewed potential measures for mitigating climate change by limiting net emissions of greenhouse gases from the energy, industry, transportation, housing and building, forestry, agriculture, and other sectors. These measures include those which limit emissions from greenhouse gas sources (such as energy production and use), those which increase the use of natural sinks (such as immature forests and other biomass) for sequestering greenhouse gases, as well as those measures aimed at protecting reservoirs such as existing forests. While RSWG was not mandated to consider the role of the oceans, Working Group I noted that oceans also play an equally important role as sinks and reservoirs for carbon dioxide. A discussion of both short and long-term options for each major emissions sector is provided below.

It also should be recognized that the large, projected increase in the world population, to as much as ten billion people during the next century, will be a major factor in causing the projected increase in global greenhouse gases. This is because larger populations will be accompanied by increased consumption of energy and of food, more land clearing, and other activities, all of which will cause an increase in net greenhouse gas emission. It is essential, therefore, that policies designed to deal effectively with the issue of potential global climate change include strategies and measures to reduce the rate of growth of the world population.

4.1 Limitation of net emissions from the energy sector

The energy sector plays a vitally important role in economic well-being and development for all nations. At the same time, because energy production and use accounts for approximately one half of the radiative forcing from human activities, energy policies need to ensure that continued economic growth occurs in a manner that, globally, conserves the environment for future generations. However, there is no single, quick-fix technological option for limiting greenhouse gas emissions from energy sources. A comprehensive strategy is necessary which deals with improving efficiency on both the demand and supply sides as a priority and emphasizes technological research, development, and deployment.

The RSWG recognizes the particular difficulties which will be faced by countries, particularly developing countries, whose economy is heavily dependent on the production and/or export of fossil fuels, as a consequence of actions taken by other countries to limit or reduce energy related greenhouse gas emissions. These difficulties should be taken into account when elaborating international strategies.

Various potential options have been identified for reducing greenhouse gas emissions from energy systems. The most relevant categories of options appear to be:

- efficiency improvements and conservation in energy supply, conversion, and end use;
- fuel substitution by energy sources which have lower or no greenhouse gas emissions;
- reduction of greenhouse gas emissions by removal, recirculation or fixation;
- management and behavioral changes (e.g. increased work in homes through information technology) and structural changes (e.g. modal shift in transport).

From an analysis of the technologies in these categories, it appears that some technologies are available now or in the short-term while others need further development to lower costs or to improve their environmental characteristics.

Tables 3 and 4 provide various examples of technological options within each of the broad categories defined above, and their possible application in the short, medium, and longer-term. This distinction

TABLE 3

Examples of Short-Term Options

I. IMPROVE EFFICIENCY IN THE PRODUCTION, CONVERSION AND USE OF ENERGY

Electricity Generation	Industry Sector	Transport Sector	Building Sector
. Improved efficiency in electricity generation - Repowering of existing facilities with high efficiency systems; - Introduction of integrated gasification combined cycle systems; - Introduction of atmospheric fluidised bed combustion; - Introduction of pressurised fluidised bed combustion with combined cycle power systems; - Improvement of boiler efficiency. . Improved system for co-generation of electricity and steam. . Improved operation and maintenance. . Introduction of photovoltaics, especially for local electricity generation. . Introduction of fuel cells.	. Promotion of further efficiency improvements in production process; . Materials recycling (particularly energy-intensive materials); . Substitution with lower energy intensity materials; . Improved electromechanical drives and motors; . Thermal process optimisation, including energy cascading and co-generation. . Improved operation and maintenance.	. Improved fuel efficiency of road vehicles; - Electronic engine management and transmission control systems; - advanced vehicle design; reduced size and weight, with use of lightweight composite materials and structural ceramics; improved aerodynamics, combustion chamber components, better lubricants and tyre design, etc.). - regular vehicle maintenance; - higher capacity trucks; - improved efficiency in transport facilities; - regenerating units; . Technology development in public transportation; - Intra-city modal shift (e.g. car to bus or metro); - advanced train control system to increase traffic density on urban rail lines; - High-speed inter-city trains; - Better intermodal integration. . Driver behaviour, traffic management, and vehicle maintenance.	. Improved heating and cooling equipment and systems; - Improvement of energy efficiency of air conditioning; - Promotion of introduction of area heating and cooling including use of heat pumps; - Improved burner efficiency; - Use of heat pumps in buildings; - Use of advanced electronic energy management control systems. . Improved space conditioning efficiency in house/building; - Improved heat efficiency through highly efficient insulating materials; - Better building design (orientation, window, building, envelope, etc.); - Improved air-to-air heat exchangers. . Improved lighting efficiency. . Improved appliance efficiency. . Improved operation and maintenance. . Improved efficiency of cook stoves (in developing countries).

TABLE 3 (CONTINUED)

II. NON FOSSIL AND LOW EMISSION ENERGY SOURCES

Electricity Generation	Other Sectors

- Construction of small-scale and large-scale hydro projects;
- Expansion of conventional nuclear power plants;
- Construction of gas-fired power plants;
- Standardised design of nuclear power plants to improve economics and safety;
- Development of geothermal energy projects;
- Introduction of wind turbines;
- Expansion of sustainable biomass combustion.
- Replacement of scrubbers and other energy consuming control technology with more energy efficient emission control.
	. Substitution of natural gas and biomass for heating oil and coal;
	. Solar heating.
	. Technologies for producing and utilising alternative fuels;
	    - Improved storage and combustion systems for natural gas;
	    - introduction of flexible-fuel and alcohol fuel vehicles.

III. REMOVAL, RECIRCULATION OR FIXATION

Energy/Industry	Landfills
. Recovery and use of leaked or released CH_4 from fossil fuel storage, coal mining; . Improved maintenance of oil and natural gas and oil production and distribution systems to reduce CH_4 leakage; . Improved emission control of CO, SO_x, NO_x and VOCs to protect sinks of greenhouse gases.	. Recycle and incineration of waste materials to reduce CH_4 emissions; . Use or flaring of CH_4 emissions; . Improved maintenance of landfill to decrease CH_4 emissions

TABLE 4

Examples of Medium-/Long-Term Options

I. IMPROVE EFFICIENCY IN THE PRODUCTION, CONVERSION AND THE USE OF ENERGY

Electricity Generation	Industry Sector	Transport Sector	Building Sector
· Advanced technologies for storage of intermittent energy; · Advanced batteries; · Compressed air energy storage; · Superconducting energy storage;	· Increased use of less energy-intensive materials; · Advanced process technologies; · Use of biological phenomena in processes; · Localised process energy conversion; · Use of fuel cells for co-generation.	· Improved fuel efficiency of road vehicles; · Improvements in aircraft and ship design: - Advanced propulsion concepts; - Ultra high-bypass aircraft engines; - Contra-rotating ship propulsion.	· Improved energy storage systems; - Use of information technology to anticipate and satisfy energy needs; - Use of hydrogen to store energy for use in buildings. · Improved building systems; - New Building materials for better insulation at reduced cost; - Windows which adjust opacity to maximise solar gain. · New food storage systems which eliminate refrigeration requirements.

TABLE 4 (CONTINUED)

III. NON FOSSIL AND LOW EMISSION ENERGY SOURCES

Electricity Generation	Other Sectors
. Nuclear power plants: - Passive safety features to improve reliability and acceptability. . Solar power technologies: - Solar thermal; - Solar photovoltaic (especially for local electricity generation). . Advanced fuel cell technologies.	. Other technologies for producing and utilising alternative fuels; - Improved storage and combustion systems for hydrogen; - Control of gases boiled off from cryogenic fuels; - Improvements in performance of metal hydrides; - High-yield processes to convert lingo-cellulosic biomass into alcohol fuels; - Introduction of electric and hybrid vehicles; - Reduced re-charging time for advanced batteries.

III. REMOVAL, RECIRCULATION OR FIXATION

. Improved combustion conditions to reduce N_2O emissions.

. Treatment of exhaust gas to reduce N_2O emissions.

. CO_2 separation and geological and marine disposal.

among time frames is used in order to reflect the remaining technological needs in each category and to assist in formulating technological strategies. Short-term technologies are those which apparently are orwill be both technically and economically ready for introduction and/or demonstration up to the year 2005 and beyond. Mid-term technologies are those which, while technically available now, are not yet economic and thus may not be implemented until the period from 2005 to 2030. Longer-term technologies are not yet available but may emerge after 2030 as a result of research and development. Such time frames could be influenced by such factors as the pace of the technological changes and economic conditions.

The technical, economic, and market potential of technological options will vary depending upon the sector in which they are to be applied. The technical potential of an energy technology is its capacity to reduce potential emissions, irrespective of the costs involved, and is largely a function of technical feasibility and resource availability. Economic potential refers to whether the application of the options is economically efficient and cost-effective - it may be significantly less than technical potential where there are positive resource costs. Market potential refers to whether the consumer or user is likely to adopt the option - it might be even less than economic potential due to market imperfections, attitudes to risk, and the presence of non-monetary costs.

There is, in general, extensive information available on the technical potential of the many technological options listed. For example:

- in the Transportation sector, vehicle efficiency improvements have very high technical potential (e.g. 50 percent improvement from the average vehicle on the road in some countries);

- in the Electricity Generation sector, efficiency improvements of 15 to 20 percent could be achieved for retrofits of coal plants and up to 65 percent for new generation versus average existing coal plants; fuel substitution could achieve 30 percent (for oil to natural gas) to 40 percent (for coal to natural gas) reduction in emissions of CO_2;

- in the Buildings sector, new homes could be roughly twice as energy efficient and new commercial buildings up to 75 percent as energy efficient as existing buildings; retrofitting existing homes could average 25 percent improvement and existing commercial buildings around fifty percent;

- in the Industry sector, the technical potential for efficiency improvements ranges from around 15 percent in some sub-sectors to over 40 percent in others (i.e. the best available technology versus the stock average).

The constraints to achieving the technical potential in these sectors can be generally categorized as:

- capital costs of more efficient technologies vis-à-vis the cost of energy;

- relative prices of fuels (for fuel substitution);

- lack of infrastructure;

- remaining performance drawbacks of alternative technologies;

- replacement rates;

- reaching the large number of individual decision-makers involved.

Each of these constraints may be more or less significant depending on the sector in question. While not a constraint, behavioral changes (e.g., improved driver behaviour, better vehicle maintenance and turning off unused lights) can make significant contributions to emissions reduction in all sectors. Achieving such changes requires the engagement of both the energy supplier and the consumer. Likewise, improvements in operational practices on the part of industry and government (e.g. better traffic management or boiler operation) offer significant potential but require increased attention. Transport and housing policies (e.g. promotion of public transport, home insulation) could also reduce greenhouse gas emissions. A more comprehensive assessment of the measures to overcome these constraints is contained in section 8 of this report.

Factors external to the energy sector also significantly constrain potential. These include the difficulty of:

- making basic changes in the structure of economies (e.g. development of new transportation and housing infrastructure);

- making fundamental changes in attitudinal and social factors (e.g. preferences for smaller and higher efficiency vehicles).

The challenge to policymakers is to enhance the market uptake of technological options and behavioral and operational changes as well as to address the broader issues outside the energy sector in order to capture more of the potential that exists.

Options and strategies

Tables 3 and 4 summarize the technological, regulatory, and institutional approaches which could form elements of strategies to control greenhouse gases.

A list of options recommended by EIS as measures for addressing greenhouse gas emissions is given below. Countries are encouraged to evaluate the social, economic and environmental consequences of these options.

- taking steps now[6] to attempt to limit, stabilize or reduce the emission of energy related greenhouse gases and prevent the destruction and improve the effectiveness of sinks. One option that governments may wish to consider is the setting of targets for CO_2 and other greenhouse gases;

- adopting a flexible progressive approach, based on the best available scientific, economic and technological knowledge, to action needed to respond to climate change;

- drawing up specific policies and implementing wide-ranging comprehensive programmes which cover all energy-related greenhouse gases;

6. *There was significant concern expressed at the RSWG meeting about the immediacy implied by the word now in option one, when implementation could only be considered at a rate consistent with countries' level of knowledge and particular circumstances.*

- starting with implementing strategies which have multiple social, economic and environmental benefits, are cost effective, are compatible with sustainable development and make use of market forces in the best way possible;

- intensifying international, multilateral and bilateral co-operation in developing new energy strategies to cope with climate change. In this context, industrialized countries are encouraged to promote the development and the transfer of energy efficient and clean technologies to other countries;

- increasing public awareness of the need for external environmental costs to be reflected in energy prices, markets and policy decisions to the extent that they can be determined;

- increasing public awareness of energy efficiency technologies and products and alternatives, through public education and information (e.g. labelling);

- strengthening research and development and international collaboration in energy technologies, and economic and energy policy analysis, which are relevant for climate change;

- encouraging the participation of industry, the general public, and NGOs in the development and implementation of strategies to limit greenhouse gas emissions.

Short-term strategy options

Short-term strategies for all individual nations include:

- improving diffusion of energy efficient and alternate energy technologies which are technically and commercially proven;

- improving energy efficiency of mass produced goods including motor vehicles and electrical appliances and equipment and buildings (e.g., through improved standards);

- developing, diffusing and transferring technologies to limit energy related greenhouse gas emissions;

- reviewing energy-related price and tariff systems and policy decisions on energy planning to better reflect environmental costs.

Long-term strategy options

Over the longer term, sustainable development will remain a central theme of policies and strategies. Specific approaches within a sustainable development policy framework will evolve as our understanding of climate change and its implications improves.

Long-term strategies for all individual nations include:

- accelerating work to improve the long-term potential of efficiency in the production and use of energy; encouraging a relatively greater reliance on no or lower greenhouse gas emissions energy sources and technologies; and enhancing natural and man-made means to sequester greenhouse gases;

- further reviewing, developing and deploying policy instruments, which may include public information, standards, taxes and incentives, tradeable permits, and environmental impact assessments, which will induce sustainable energy choices by producers and consumers without jeopardizing energy security and economic growth;

- developing methodologies to evaluate the trade off between limitation and adaptation strategies and establishing changes in infrastructure (e.g. pipelines, electrical grids, dams) needed to limit or adapt to climate change.

4.2 Limitation of net emissions from the industry sector

The most significant source of greenhouse gases associated with industrial activity not related to energy use is the production and use of CFCs and other halocarbons. CFCs represent a very important source of greenhouse gas emissions and account for about 24% of the total contributions to the enhanced radiative forcing for the period of the 1980s. While the RSWG did not consider control strategies for these gases since the issue is already addressed under the Montreal Protocol on Substances that Deplete the Ozone Layer, it noted that the review of the Montreal Protocol now underway should take into account the global warming potential of potential CFC substitutes.

The RSWG did develop future emission scenarios for CFCs and HCFC-22 (HCFC-22 was used as a surrogate for a potential mix of HCFCs and HFCs substitutes). The potential impact of such substitutes on radiative forcing was assessed by Working Group I. For a given emission rate, HCFCs and HFCs are less effective greenhouse gases than the CFCs because of their shorter lifetimes. The growth rates assumed in the IPCC scenarios will result in the atmospheric concentrations of HFCs and HCFCs becoming comparable to the CFCs during the next several decades assuming that the CFCs had continued to be used at current rates. Assuming the IPCC scenarios for HFCs and HCFCs, Working Group I calculated that these gases would contribute up to 10% of the total additional radiative forcing for the period 2000-2050.

4.3 Limitation of net emissions from the agriculture sector

About 9 percent of anthropogenic greenhouse gas emissions can be attributed to the agricultural sector, in particular livestock systems, rice cultivation, and the use of nitrogenous fertilizers. Limitation of emissions from this sector presents a challenge because the processes by which greenhouse gases, in particular methane and nitrous oxide, are released in agricultural activities are not well understood. In addition, response options in the agricultural sector must be designed to ensure maintenance of food supply. There appear, however, to be a number of short-term response options, some economically beneficial in their own right, which could contribute to a limitation of net emissions from agricultural sources. Where appropriate the removal of subsidies, incentives and regulatory barriers that encourage greenhouse gas emissions from the agricultural sector would be both environmentally and economically beneficial. In addition, there are a number of promising technologies and practices which, in the longer term, could significantly reduce greenhouse gas emissions.

Short-term options:

Livestock systems: Methane emissions could be reduced through improved management of livestock wastes, expansion of supplemental feeding practices, and increased use of production and growth enhancing agents with safeguards for human health.

Fertilizer use: Nitrous oxide emissions may be reduced by using existing improved fertilizer formulations, judicious use of animal manures and compost, and improved application technology and practices.

Marginal lands: Areas marginally suitable for annual cropping systems may be shifted to perennial cover crops for fodder, pastoral land uses or forests if soils are suitable. Such actions would increase carbon uptake, both in the vegetation and soil, and would yield other benefits.

Sustainable agricultural practices: Where possible, minimum or no-till systems should be introduced for those countries currently using tillage as part of the annual cropping sequence, thus maintaining and increasing soil organic matter.

Longer-term options:

Rice cultivation: A comprehensive approach, including management of water regimes, improvement of cultivars, efficient use of fertilizers, and other management practices, could lead to a 10 to 30 percent reduction in methane emissions from flooded rice cultivation although substantial research is necessary to develop and demonstrate these practices. It is estimated that at least 20 years would be needed to introduce such practices. Adaptable alternative crops research is needed to provide a more diverse crop base for rice growing regions.

Livestock: Through a number of technologies it appears that methane emissions may be reduced from livestock systems by up to 25 - 75 percent per unit of product in dairy and meat production, although many uncertainties exist.

Fertilizers: Fertilizer-derived emissions of nitrous oxide potentially can be reduced (although to what extent is uncertain) through changes in practices such as using fertilizers with controlled nitrogen conversion rates, improving fertilizer-use efficiency, and adopting alternative agricultural systems where possible.

Desertification: Enhanced research on control measures.

4.4 Limitation of net emissions from forestry and other activities

Forestry and related aspects of land use cannot be considered in isolation, and solutions must be based on an integrated approach which links forestry to other policies, such as those concerned with poverty and land resources, which should be supported by strong institutions in order to enhance overall forest management. The forest crisis is rooted in the agricultural sector and in people's needs for employment and income. Deforestation will be stopped only when the natural forest is economically more valuable for the people who live in and around the forests than alternative uses for the same land.

Forestry practices and other human activities associated with land use, such as biomass burning and landfills, account for about 18 percent of anthropogenic greenhouse gas emissions. A number of short and long-term response options for limiting net emissions from these sectors have been identified.

Short-term options:

1. Improvement of forest-management and reduction of deforestation and forest degradation which should be supported by:

- reduction of air pollution which contributes to forest degradation;
- elimination of inappropriate economic incentives and subsidies that contribute to forest loss, where appropriate;
- integration of forest conservation requirements and sustainable development in all relevant sectors of national development planning and policy taking account of the interests of local communities;
- co-ordinated remote sensing, data collection and analyses to provide the required data;
- a meeting of interested countries from the developing and the industrialized worlds and of appropriate international agencies to identify possible key elements of a world forest conservation protocol in the context of a climate convention process that also addresses energy supply and use, and practical means of implementing it. Such a meeting should also develop a framework and methodology for analysing the feasibility of the Noordwijk remit including alternative targets, as well as the full range of costs and benefits;
- strengthening Tropical Forestry Action Plan (TFAP) and in the light of the independent review which is being undertaken, the International Tropical Timber Organization (ITTO), and other international organizations whose objective is to help developing countries in achieving conservation, and sustainable development and management of forests;
- an assessment of incentives and disincentives for sustainable forest management, for example, the feasibility of labelling;
- introduction of sustainable forest harvesting and management;
- development of enhanced regeneration methods;
- development and implementation of (large-scale) national afforestation and forest conservation plans, where feasible.

2. Where appropriate expand forest areas, especially by afforestation, agroforestry and regreening of available surplus agricultural, urban and marginal lands.

3. Where appropriate strengthen and improve the use of forest products and wood through measures such as substituting a portion of fossil energy sources by wood or other sustainable managed biomass; partial replacement of high energy input materials by wood; further recycling of forest products; and, improved efficiency of use of fuel wood.

4. Development of methane recovery systems for landfill and waste water treatment facilities and their use, in particular, in industrialized countries.

Longer-term options:

1. Maintain the health and the continuance of existing forests as major natural carbon reservoirs,

especially through the development and implementation of

- silvicultural adjustment and stress management strategies;
- special forest protection strategies (developed under climate change scenarios);
- environmentally sound treatment practices for peatlands;
- standardisation of methods of forest inventory and bio-monitoring to facilitate global forest management.

2. Expand forest biomass, especially of intensively managed temperate forests, by silviculture measures and genetically improved trees.

3. With regard to waste management, use of gas collection and flaring to reduce methane emissions from landfills and development of biogas plants to reduce methane emissions from wastewater treatment. Demonstration, training and technology transfer are necessary to realise these potentials, which may range from 30 to 90 percent for landfills and up to 100 percent for wastewater treatment.

5. FURTHER WORK ON GREENHOUSE GAS EMISSION LIMITATION GOALS

There has been considerable international discussion of targets for specific greenhouse gas emissions, in particular, CO_2, which is the most abundant of the greenhouse gases. The final declaration at the November 1989 Noordwijk Conference on Atmospheric Pollution and Climate Change encouraged the IPCC to include in its First Assessment Report an analysis of quantitative targets to limit or reduce CO_2 emissions, and urged all industrialized countries to investigate the feasibility of achieving such targets, including, for example, a 20 percent reduction of CO_2 emissions by the year 2005. The Conference also called for assessing the feasibility of increasing net global forest growth by 12 million hectares per year. During its Third Plenary, the IPCC accepted the mandate.

Although the feasibility of quantitative targets on greenhouse gas emissions fell within the RSWG's original mandate through its Energy and Industry Subgroup (EIS), it was agreed that these new, specific tasks would require more time, data and analyses in order to be dealt with properly. It was decided, therefore, that the results of the deliberations of the EIS on these remits could not be fully included in its report, but only treated in an incomplete and preliminary way. A progress report is to be presented to the Fourth IPCC Plenary following an international workshop to be hosted by the United Kingdom in June 1990. As for the Noordwijk remit on global forest growth, the RSWG through its Agriculture, Forestry and Other Human Activities Subgroup (AFOS) noted that a framework and methodology for analyzing its feasibility should be developed.

While the technical potential of a number of options has been demonstrated, there is very little information available on the actual economic and social feasibility associated with implementation of such options. An adequate understanding of the benefits, in terms of changes in climate variables that are avoided, is also seriously lacking. It is imperative that further work on the cost and benefit implications of response strategies be undertaken. These issues have been identified as one of the most important areas for future research by the RSWG, concerned international organizations, and individual countries.

The material available to the EIS demonstrates the important role emissions of industrialized countries play in total global emissions in the near term. The material also indicates that the technical potential for reduction is large, and differs greatly between regions and countries. Therefore, in the near term, no significant progress in limiting global emissions will occur without actions by the industrialized countries. Some countries have already decided to stabilize or reduce their emissions.

6. MEASURES FOR ADAPTING TO GLOBAL CLIMATE CHANGE

In addition to the limitation options discussed above, the RSWG reviewed measures for adapting to potential climate change. The consideration of adaptation options is critical for a number of reasons. First, because it is believed that there is likely to be a lag time between emissions and subsequent climate change, the climate may already be committed to a certain degree of change. Implementation of adaptation measures may thus be necessary regardless of any limitation actions which may be taken. Secondly, natural climatic variability itself necessitates adaptation.

Furthermore, should significant adverse climate change occur, it would be necessary to consider limitation and adaptation strategies as part of an integrated package in which policies adopted in the two areas complement each other so as to minimize costs. Limitation and adaptation options should be developed and analyzed recognizing the relationship between the timing and costs of limitation and adaptation. For example, the more net emissions are reduced and the rate of climate change potentially slowed, the easier it would be to adapt. A truly comprehensive approach should recognize that controlling the different gases might have different effects on the adaptive capacity of natural resources.

The RSWG explored two broad categories of adaptation options:

- <u>Coastal zone management</u>, or options which maximize the ability of coastal regions to adapt to the projected sea level rise and to reduce vulnerability to storms; and

- <u>Resource use and management</u>, or options which address the potential impacts of global climate change on food security, water availability, natural and managed ecosystems, land, and biodiversity.

6.1 <u>Coastal zone management</u>

Under the 2030 high emissions scenario, global climate change is predicted to raise global mean sea level 65 cm (with an uncertainty range of 30 to 100 cm) by the year 2100. If sea level rises by 1 metre, hundreds of thousands of square kilometres of coastal wetlands and other lowlands could be inundated, while ocean beaches could erode as much as a few hundred metres over the next century. Flooding would threaten lives, agriculture, livestock, and structures, while saltwater would advance inland into aquifers, estuaries, and soils, thus threatening water supplies and agriculture in some areas. Loss of coastal ecosystems would threaten fishery resources.

Some nations would be particularly vulnerable to such changes. Eight to ten million people live within one metre of high tide in each of the unprotected river deltas of Bangladesh, Egypt, and Vietnam. Half a million people live in coral atoll nations that lie almost entirely within three metres of sea level, such as the Maldives, the Marshall Islands, Tuvalu, Kiribati, and Tokelau. Other states with coastal areas, archipelagos and island nations in the Pacific and Indian Oceans and the Caribbean could lose much of their beaches and arable lands, which would cause severe economic and social disruption.

Available responses to sea level rise fall broadly into three categories:

- o <u>Retreat</u>: Under this option no actions would be taken to protect the land from the sea - the focus would instead be on providing for people and ecosystems to shift landward in an optimal fashion. This choice could be motivated by either excessive costs of protection or by a desire to maintain ecosystems.

- o <u>Accommodation</u>: Under this strategy, while no attempt would be made to protect the land at risk, measures would be taken to allow for continued habitation of the area. Specific responses under this options would include erecting flood shelters, elevating buildings on pilings, converting agriculture to fish farming, or growing flood- or salt-tolerant species.

- o <u>Protection</u>: A protection strategy uses site-specific features such as sea walls, dikes, dunes, and vegetation to protect the land from the sea so that existing land uses can be retained.

There are various environmental, economic, social, cultural, legal, institutional and technological implications for each of these options. Retreat could lead to a loss of property, potentially costly resettlement of populations, and, in some notable cases, refugee problems. Accommodation could result in declining property values, and costs for modifying infrastructure. Protecting existing development from a one metre sea level rise would require about 360,000 kilometres of coastal defences at a total cost of US$ 500 billion, over the next 100 years. The annual cost of protection represents, on average, 0.04 percent of total gross national product (GNP), and ranges from zero to 20 percent for individual countries. The estimate is not discounted and does not reflect present coastal defence needs or impacts of salt water intrusion or flooding of unprotected lands. Further, the protection could have negative impacts on fisheries, wildlife and recreation. The loss of traditional environments could potentially disrupt family life and create social instability.

<u>Actions to prepare for possible sea level rise</u>

A number of response options are available which not only enhance the ability of coastal nations to adapt to sea level rise, but are also beneficial in their own right. Implementation of such options would be most effective if undertaken in the short-term, not because there is an impending catastrophe, but because there are opportunities to avoid adverse impacts by acting now - opportunities which may not be as effective if the process is delayed. These options include:

<u>National coastal planning</u>:

- o <u>Development and implementation in the short term of comprehensive</u>

national coastal zone management plans which (a) deal with both sea level rise and other impacts of global climate change and (b) ensure that risks to populations are minimized while recognizing the need to protect and maintain important coastal ecosystems.

- Identification of coastal areas at risk. National efforts are needed to (a) identify functions and resources at risk from a one metre rise in sea level and (b) assess the implications of adaptive response measures on them.

- Provisions to ensure that coastal development does not increase vulnerability to sea level rise. Actions in particular need of review include river levees and dams, conversions of mangroves and other wetlands for agriculture and human habitation, harvesting of coral and increased settlement in low-lying areas. In addition, while structural measures to prepare for sea level rise are not yet warranted, the design and location of coastal infrastructure and coastal defenses should include consideration of sea level rise and other coastal impacts of climate change. It is sometimes less expensive to design a structure today, incorporating these factors, than to rebuild it later.

- Review and strengthening of emergency preparedness and coastal zone response mechanisms. Efforts are needed to develop emergency preparedness plans for reducing vulnerability to coastal storms through better evacuation planning and the development of coastal defense mechanisms that recognize the impact of sea level rise.

International cooperation:

- Maintenance of a continuing international focus on the impacts of sea level rise. Existing international organizations should be augmented with new mechanisms to focus attention and awareness on sea level change and to encourage the nations of the world to develop appropriate responses.

- Provision of technical assistance and co-operation to developing nations. Institutions offering financial support should take into account the need for technical assistance and co-operation in developing coastal management plans, assessing coastal resources at risk, and increasing a nation's ability - through education, training, and technology transfer - to address sea level rise.

- Support by international organizations for national efforts to limit population growth in coastal areas. In the final analysis, rapid population growth is the underlying problem with the greatest impact on both the efficacy of coastal zone management and the success of adaptive response options.

Research, data, and information:

- Strengthening of research on the impacts of global climate change on sea level rise. International and national climate research programmes need to be directed at understanding and predicting changes in sea level, extreme events, precipitation, and other impacts of global climate change on coastal areas.

- Development and implementation of a global ocean observing network, for example through the efforts of the IOC, WMO, and UNEP to establish a coordinated international ocean observing network that will allow for accurate assessment and continuous monitoring of changes in the world's oceans and coastal areas, particularly sea level change and coastal erosion.

o Dissemination of data and information on sea level change and adaptive options. An international mechanism could be identified with the participation of the parties concerned for collecting and exchanging data and information on climate change and its impact on sea level and the coastal zone and on various adaptive options. Sharing this information with developing countries is critically important for preparation of coastal management plans.

A programme could begin now to enable developing countries to implement coastal zone management plans by the year 2000. The programme would provide for training of country experts, data collection and technical assistance and co-operation. Estimated funding to provide the necessary support over the next 5 years is US$ 10,000,000. It is suggested that international organizations such as UNEP and WMO consider co-ordinating this programme in consultation with interested nations.

6.2 Resource use and management

The reports of Working Groups I and II indicate significant and unavoidable impacts, both positive and negative, upon the very resources that humans and other species rely on to live. These resources include water, agriculture, livestock, fisheries, land, forests, and wildlife. The RSWG addressed these resource issues in the context of considering options for ensuring food security; conserving biological diversity; maintaining water supplies; and using land rationally for managed and unmanaged ecosystems.

The potential impacts of climate change on natural resources and human activities are poorly understood. First, credible regional estimates of changes in critical climatic factors, such as temperature, soil moisture, annual and seasonal variability, and frequencies of droughts, floods and storms, are simply not available. For many of these critical climatic factors even the direction of change is uncertain. Secondly, methods for translating these changes into effects on the quantity and quality of resources are generally lacking. While it is clear that some of the impacts of climate change on resources could be negative and others positive, a more specific quantification of those impacts is not possible at this time. Nevertheless, these uncertainties do not preclude taking appropriate actions, especially if they are worthwhile for other non-climate related reasons. However, it can be said that: (a) those resources which are managed by humans (e.g. agriculture, forestry) are more suited to successful adaptation than unmanaged ecosystems; and (b) the faster the rate of change, the greater the impact. In that regard, it is very important to realize that some species will not be able to survive rapid climate changes.

Through the ages societies and living things have developed the capability to adapt to the climate's natural variability and to extreme events. Several climatic zones span the globe, and resource use and management is an ongoing challenge in each of these zones. Therefore, society could borrow from this existing large reservoir of experience and knowledge in developing policies to adapt to possible climate change. In addition, expected future economic and technological progress would provide the financial and technical resources required to better adapt to a changing climate. Nevertheless, significant costs, and legal, institutional and cultural adjustments may be necessary to implement adaptation measures.

In recognition of the uncertainties regarding the impacts of climate change on resource use and management, the following sections provide general, rather than specific, options in three categories. The appropriateness of these options for individual countries may vary depending on the specific social, environmental and economic context.

Short-term research related options

There are a number of actions which would augment our knowledge base for making reasoned judgments about response strategies. These include:

- Developing inventories, data bases, monitoring systems, and catalogues of the current state of resources and resource use and management practices.

- Improving our scientific understanding of and predictive tools for critical climatic factors, their impacts on natural resources, and their socio-economic consequences.

- Undertaking studies and assessments to gauge the resilience and adaptability of resources and their vulnerability to climate change.

- Encouraging research and development by both public and private enterprises directed toward more efficient resource use and biotechnological innovation (with adequate safeguards for health, safety, and the environment), including allowing innovators to benefit from their work.

- Continuing existing research and development of methods to cope with the potentially worst consequences of climate change, such as developing more drought- or salinity-resistant cultivars or using classical and modern breeding techniques to help keep farming and forestry options open, and research on agrometeorology or agroclimatology.

- Increasing research on the preservation of biological resources _in situ_ and _ex situ_, including investigations into the size and location of protected natural areas and conservation corridors.

Short-term policy options

Some response strategies are available which are probably economically justified under present-day conditions and which could be undertaken for sound resource management reasons, even in the absence of climate change. In general, these relate to improving the efficiency of natural resource use, fuller utilization of the "harvested" component of resources, and waste reduction. Measures that could be implemented in the short-term include:

- Increased emphasis on the development and adoption of technologies which may increase the productivity or efficiency (per unit of land or water) of crops, forests, livestock, fisheries, and human settlements, consistent with the principles of sustainable development. Such efficiencies reduce the demand for land for human activities and could also help reduce emissions of greenhouse gases. Examples of specific options include more efficient milk and meat production; improved food storage and distribution; and better water management practices.

- o Increased promotion and strengthening of resource conservation and sustainable resource use - especially in highly vulnerable areas. Various initiatives could be explored for conserving the most sensitive and valuable resources, including strengthening conservation measures, managing development of highly vulnerable resources, and promoting reforestation and afforestation.

- o Acceleration of economic development efforts in developing countries. Because these countries often have largely resource-based economies, efforts at improving agriculture and natural resource use would be particularly beneficial. Such efforts would also promote capital formation, which would generally make adaptation to climate change and sustainable development more feasible.

- o Developing methods whereby local populations and resource users gain a stake in conservation and sustainable resource use, for example by investing resource users with clear property rights and long-term tenure, and allowing voluntary water transfer or other market mechanisms.

- o Decentralizing, as practicable, decision-making on resource use and management.

<u>Longer-term options</u>

There are also a number of other possible responses which are costly or otherwise appear to be more appropriate for consideration in the longer term, once uncertainties regarding climate change impacts are reduced. Options in this category include:

- o Building large capital structures (such as dams) to provide for enhanced availability of water and other resources.

- o Strengthening and enlarging protected natural areas and examining the feasibility of establishing conservation corridors to enhance the adaptation prospects for unmanaged ecosystems.
- o As appropriate, reviewing and eliminating direct and indirect subsidies and incentives for inefficient resource use, and other institutional barriers to efficient resource use.

7. MECHANISMS FOR IMPLEMENTING RESPONSE STRATEGIES

The RSWG also considered several priority areas which must be addressed in order to adequately implement limitation or adaptation responses. These "implementation mechanisms" represent the primary vehicles through which national, regional and international responses to climate can be brought into force. The specific implementation mechanisms considered were:

- o Public information and education;

- o Technology development and transfer;

- o Economic (market) mechanisms;
- o Financial mechanisms;
- o Legal and institutional mechanisms, including possible elements of a framework convention on climate change.

The results of the RSWG's deliberations on these issues are provided below.

7.1 Public information and education

A well informed global population is essential for addressing and coping with an issue as complex as climate change. Because climate change would affect, either directly or indirectly, almost every sector of society, broad global understanding of the issue will facilitate the adoption and implementation of such response options as deemed necessary and appropriate. The dissemination of information also represents a powerful economic instrument for ensuring that markets accurately take into account potential consequences and/or opportunities of climate change.

The core aims of public education and information programmes are to:

- o Promote awareness and knowledge of climate change issues;
- o Provide guidance for positive practices to limit and/or adapt to climate change;
- o Encourage wide participation of all sectors of the population of all countries, both developed and developing, in addressing climate change issues and developing appropriate responses; and
- o Especially emphasize key target groups, such as children and youth, as well as individuals at household levels, policymakers and leaders, media, educational institutions, scientists, business and agricultural sectors.

Given the importance of a well-informed population, the RSWG developed suggestions and approaches for improving international awareness of the potential causes and impacts of climate change. In this process it was recognized that, while broad-based understanding is essential, no single mechanism can work for every group or in every culture or country. The social, economic, and cultural diversity of nations will likely require educational approaches and information tailored to the specific requirements and resources of particular locales, countries, or regions. The importance of education and information for developing countries cannot be overemphasized.

A number of national and international actions should be taken to disseminate broadly information on climate change. These include the:

- o Establishment of national committees or clearing houses to collect, develop, and disseminate objective materials on climate change issues. This could help provide focal points for information on issues such as energy efficiency, energy savings, forestry, agriculture, etc.
- o Use by international organizations (UNESCO, UNEP, WMO, etc.) and non-governmental organizations of IPCC and other relevant reports in developing and providing to all countries an adequate understanding for future actions.

- o Use of an existing international institution, or development of a new institution, if necessary, to serve as a clearinghouse for informational and educational materials.

- o Upon completion of the IPCC reports, or earlier, arrange a series of short seminars targeted to inform high priority decision makers, world leaders and others of causes and effects of climate change.

7.2 Technology development and transfer

The development and transfer of technologies is vital to any effort to address global climate change. The development of new technologies may provide the means by which societies can meet their energy, food, and other needs in the face of changes in global climate, while at the same time minimizing emissions of greenhouse gases. Prompt transfer of technologies, especially to developing countries, is likewise an important aspect of any effort to limit or adapt to climate change.

Technology research and development

Technological development, including improvement and reassessment of existing technologies, is needed to limit or reduce anthropogenic greenhouse gas emissions; absorb such gases by protecting and increasing sinks; adapt human activities and resource use and management to the impacts of climate change; and detect, monitor and predict climate change and its impacts. Technological development could be pursued in a wide range of activities such as energy, industry, agriculture, transport, water supply, coastal protection, management of natural resources, and housing and building construction.

Adequate and trained human resources are a prerequisite for development and transfer of technologies, and technological actions, founded on a sound scientific basis, must be consistent with the concept of sustainable development.

Criteria for selecting technologies include such factors as the existence of economic and social benefits in addition to environmental benefits, economic efficiency taking into account all the external costs, suitability to local needs, ease of administration, information needs, acceptability to the public.

Appropriate pricing policies where applicable, information exchange on the state of development of technologies, and the support of governments are important measures that can promote technology development. Also of importance are international collaborative efforts, especially between the industrialized and the developing countries in the bilateral and multilateral context.

Technology transfer

There is a need for the rapid transfer to the developing countries, on a preferential basis, of technologies for addressing climate change. Developing countries are of the view that transfer of technologies on a non-commercial basis is necessary and that specific bilateral and multilateral arrangements should be established to promote this. Some other countries where technologies are not owned by the government believe that transfer of technologies would be a function of commercial negotiations. The issue of intellectual property rights also presents a case where international opinion is mixed.

A number of impediments also

exist which hinder the effective transfer of technologies to developing countries. These include lack of financial resources, necessary institutions, and trained human resources. Existing institutions could be strengthened, or new mechanisms established, where appropriate, to finance technology transfers, train human resources, and evaluate, introduce and operate existing or new technologies. Legal barriers and restrictive trade practices are also impeding factors.

It has not been possible to bridge the difference on views on some of the questions mentioned above. It is extremely important to reach early international agreement on these issues in order to promote effective flow of technologies to monitor, limit or adapt to climate change. One area where international agreement may be possible is the promotion of CFC substitutes and provision of assistance and cooperation to the developing countries in the acquisition and manufacture of such substitutes.

Several countries have suggested that the issue of technology transfer to Eastern European countries be addressed.

7.3 Economic mechanisms

It is important that any potential measures to limit or adapt to global climate change be as economically efficient and cost-effective as possible, while taking into account important social implications. In general, environmental objectives can be achieved either through regulations requiring the use of a specific technology or attainment of specified goals, or economic instruments such as emissions fees, subsidies, tradeable permits, or sanctions.

Economic instruments, through their encouragement of flexible selection of abatement measures, frequently offer the possibility of achieving environmental improvements at lower cost than regulatory mechanisms. Unlike many regulations, they tend to encourage innovation and the development of improved technologies and practices for reducing emissions. Economic mechanisms also have the potential to provide the signals necessary for more environmentally sensitive operation of markets. It is unlikely, however, that economic instruments will be applicable to all circumstances.

Three factors are considered as potential barriers to the operation of markets and/or the achievement of environmental objectives through market mechanisms. These are: information problems, which can often cause markets to produce less effective or unfavourable environmental outcomes; existing measures and institutions, which can encourage individuals to behave in environmentally damaging ways; and balancing competing objectives (social, environmental, and economic). An initial response strategy may therefore be to address information problems directly and to review existing measures which may be barriers. For example, prior to possible adoption of a system of emission charges, countries should examine existing subsidies and tax incentives on energy and other relevant greenhouse gas producing sectors.

A general advantage of market based economic instruments is that they encourage limitations or reductions in emissions by those who can achieve them at least cost. They also provide an ongoing incentive for industry and individual consumers to apply the most efficient limitation/reduction measures through, for example, more efficient and cleaner technologies. Such incentives may be lacking in the case of regulations.

Regulations, are the customary means of controlling pollution in both market and centrally planned economies. An advantage of regulations is that, in certain circumstances, they create more certainty as to desired outcomes, whereas major disadvantages are that they may discourage innovation, introduce in-flexibilities in meeting objectives, can discourage resource use efficiency, and offer few or no incentives to reduce emissions below specified levels.

It is evident that the question of adoption of any form of economic instrument, whether domestically or internationally, raises many complex and difficult issues. Careful and substantive analysis of all implications of such instruments is needed. Possible specific economic instruments which have been identified for consideration include:

- A system of tradeable emissions permits: An emission permit system is based on the concept that the economic costs of attaining a given environmental goal can be minimized by allowing for the trading of emissions rights. Once an overall limit on emissions has been set, emissions entitlements amounting to that limit could be provided to emitting sources and free trading of such entitlements allowed. This would reduce the costs of meeting a given emission target because: (a) as in trade, comparative advantages between trading entities would be maximized; and (b) economic incentives would be created for the development of improved greenhouse gas limitation technologies, sink enhancement, and resource use efficiency (energy conservation). Concerns with this approach include the limited experience with this instrument, the potential scope and size of trading markets and the need for the development of an administrative structure not currently in place.

- A system of emission charges: Emission charges are levied on specified emissions depending on their level of contribution to climate change. Such charges may provide a means of encouraging emitters to limit or reduce emissions and provide an incentive for diverse parties to implement efficient means of limiting or reducing emissions. Another advantage of charges is that they generate revenue which could provide a funding base for further pollution abatement, research, and administration, or allow other taxes to be lowered. Concerns with this approach include the difficulty of deciding on the basis and size of the tax, and the lack of certainty that the tax will achieve the agreed emission reduction target.

- Subsidies: Subsidies are aimed at encouraging environmentally sound actions by lowering their costs. Subsidies could be used, inter alia, to encourage the use of energy-efficient equipment and non-fossil energy sources, and the development and greater use of environmentally sound technologies. Concerns with subsidies include the possible size of the required financial commitment of governments, the need for careful design, the need for review, and the international trade aspects of such measures.

- Sanctions: A final type of economic instrument is the use of economic sanctions for the enforcement of international agreements. This would require an international convention to establish a system of agreed trade or financial sanctions to be imposed on countries not adhering to agreed regimes. Many contributors expressed considerable reservations about applying this approach to greenhouse gas emissions because of the complexity of the situation. The concerns include a belief that sanctions could appear to be arbitrary, could create confusion and resentment and could be used as a pretext to impose new non-tariff trade barriers.

It has also been suggested that the environmental protection could be advanced and economic costs of meeting greenhouse gas limitation targets , if any, minimized by addressing, to the extent feasible, all greenhouse gas sources and sinks comprehensively. This approach could employ an "index" relating net emissions of various greenhouse gases by further development of the index formulated by Working Group I.

Each of the approaches outlined above, however, poses potentially significant challenges in terms of implementation and acceptability. There is an incomplete understanding of the economic and social consequences of these various approaches. It is evident that further work is required in all countries, and in ongoing IPCC work, to fully evaluate the practicality of such measures and costs and benefits associated with different mechanisms, especially with their use internationally. It has, however, been pointed out that an international system of tradeable permits, or, alternatively, an international system of emissions charges, could offer the potential of serving as a cost-efficient main instrument for achieving a defined target for the reduction of greenhouse gas emissions.

Finally, it was stressed that in order to share equitably the economic burdens, implementation of any of the international economic instruments discussed above should take into account the circumstances that most emissions affecting the atmosphere at present originated in the industrialised countries where the scope for change is the greatest, and that, under present conditions, emissions from developing countries are growing and may need to grow in order to meet their development requirements and thus, over time, are likely to represent an increasingly significant percentage of global emissions. It is appreciated that each instrument assessed has a role in meeting greenhouse gas emission objectives, but the suitability of particular instruments is dependent on the particular circumstances and at this stage no measure can be considered universally superior to any other available mechanisms.

7.4 Financial mechanisms

Industrialized and developing countries consider it important that assurances of financial mechanisms are needed for undertaking adequate measures to limit and/or adapt to climate change.

GUIDING PRINCIPLES

The following principles should guide the financial approach:

a) Industrialized countries and developing countries have a common responsibility in dealing with problems arising from climate change, and effective responses require a global effort.

b) Industrialized countries should take the lead and have specific responsibilities on two levels:

i) Major part of emissions affecting the atmosphere at present originates in industrialized countries where the scope for change is greatest. Industrialized countries should adopt domestic measures to limit climate change by adapting their own economies in line with future agreements to limit emissions;

ii) To cooperate with developing countries in international action, without standing in the way of the latter's development, by contributing additional financial resources, by appropriate transfer of technology, by engaging in close cooperation concerning scientific observation, by analysis and research, and finally by means of technical co-operation geared to forestalling and managing environmental problems;

c) Emissions from developing countries are growing and may need to grow in order to meet their development requirements and thus, over time, are likely to represent an increasingly significant percentage of global emissions. Developing countries should, within the limits feasible, take measures to suitably adapt their economies.

Financial resources channelled to developing countries would be most effective if focused on those activities which contribute both to limiting greenhouse gas emissions and promoting economic development. Areas for cooperation and assistance could include:

- o Efficient use of energy resources and the increased use of fossil fuels with lower greenhouse gas emission rate or non-fossil sources;
- o Rational forest management practices and agricultural techniques which reduce greenhouse gas emissions;
- o Facilitating technology transfer and technology development;
- o Measures which enhance the capacity of developing countries to develop programmes to address climate change, including research and development activities and public awareness and education;
- o Participation by developing countries in international fora on global climate change, such as the IPCC.

It was also recognized that cooperation and assistance for adaptive measures would be required, noting that for some regions and countries, adaptation rather than limitation activities are potentially most important.

A number of possible sources for generating financial resources were considered. These include general taxation, specific taxation on greenhouse gas emissions, and emissions trading. For the significant complexities and implications of such taxes, reference is made to the economic measures paper (section 7.3). Creative suggestions include using undisbursed official resources, which might result from savings on government energy bills and lower levels of military expenditures, a fixed percentage tax on travel tickets, and levies on countries that have been unable to meet their obligations. The question has also been raised of whether such financial cooperation and assistance should only be given to those countries which abstain from activities producing greenhouse gases. A positive international economic environment, including further reduction of trade barriers, and implementation of more equitable trade practices would help to generate resources which can be applied towards pressing needs.

With respect to institutional mechanisms for providing financial cooperation and assistance to developing countries, a two track approach was considered:

i) one track built on work underway or planned in existing institutions. In this regard, the World Bank, a number of regional banks, other multilateral organizations, and bilateral agencies have initiated efforts to incorporate global climate change issues into their programmes. Bilateral donors could further integrate and reinforce the environmental components of their assistance programmes and develop cofinancing arrangements with multilateral institutions while ensuring that this does not impose inappropriate environmental conditions.

ii) parallel to this track the possibility of new mechanisms and facilities was considered. Some developing and industrialized countries suggested that new mechanism directly related to a future climate convention and protocols, such as a new international fund, were required. It was added that such new instruments could be located within the World Bank (with new rules) or elsewhere. It was also noted that the Global Environmental Facility proposed by the World Bank in collaboration with UNEP and UNDP was welcomed by industrialized and developing countries at the World Bank Development Committee meeting in May 1990.

It was noted that the issue of generating financial resources was distinct from that of allocating those resources.

Areas identified for future work include studies, with donor assistance, for developing countries on their current and projected net emissions levels and assistance and cooperation needs for limiting such emissions. Further consideration is also needed of the important role which the private sector might play, through technology transfer, foreign direct investment and other means to assist and cooperate with developing countries to respond to climate change.

7.5 Legal and institutional mechanisms

A number of institutions and international legal mechanisms exist which have a bearing on the climate change issue, in particular those dealing with the environment, science and technology, energy, natural resources, and financial assistance. One of these existing international legal mechanisms, the Vienna Convention on the Protection of the Ozone Layer and its associated Montreal Protocol on Substances that Deplete the Ozone Layer, deals specifically with reducing emissions of important greenhouse gases which also deplete the ozone layer. However, there is a general view that, while existing legal instruments and institutions related to climate change should be fully utilized and further strengthened, they are insufficient alone to meet the challenge.

A consensus emerged at the 44th session of the UN General Assembly on the need to prepare as a matter of urgency a framework convention on climate change, laying down, as a minimum, general principles and obligations. It should, in the view of RSWG, be framed in such a way as to gain the adherence of the largest possible number and most suitably balanced range of countries while permitting timely action to be taken. It may contain provision for separate annexes/protocol(s) to deal with specific obligations. As part of the commitment of the parties to action on greenhouse gas emissions and adverse effects of climate change, the convention should also address the particular financial and other needs of the developing countries (notably those most vulnerable to climate change agriculturally or otherwise), the question of access to and transfer of technology, the need for research and monitoring, and institutional requirements.

Decisions will have to be taken on a number of key issues. These include:

- the political imperative of striking the correct balances (a) between the arguments for a far-reaching, action-oriented convention and the need for urgent adoption of a convention so as to begin tackling the problem of climate change; and (b) among the risks of inaction, the costs of action and current levels of scientific uncertainty;
- the extent to which specific obligations, particularly on the control of emissions of greenhouse gases, should be included in the convention itself, possibly as annexes, or be the subject of a separate protocol(s);
- the timing of negotiation of protocol(s) in relation to the negotiations on the convention;
- the introduction as appropriate of sound scientific bases for establishing emission targets (such as total emission levels, per capita emissions, emissions per GNP, emissions per energy use, climatic conditions, past performance, geographic characteristics, fossil fuel resource base, carbon intensity per unit of energy, energy intensity per GNP, socio-economic costs and benefits or other equitable considerations);
- the extent to which specific goals with respect to global levels of emissions or atmospheric concentrations of greenhouse gases should be addressed;
- whether obligations should be equitably differentiated according to countries' respective responsibilities for causing and combatting climate change and their level of development;
- the need for additional resources for developing countries and the manner in which this should be addressed, particularly in terms of the nature, size and conditions of the funding, even if detailed arrangements form the subject of a separate protocol;
- the basis on which the promotion of the development and transfer of technology and provision of technical assistance and co-operation to developing countries should take place, taking into account considerations such as

terms of transfer (preferential or non-preferential, commercial or non-commercial), assured access, intellectual property rights, the environmental soundness of such technology, and the financial implications;

- o the nature of any new institutions to be created by the convention (such as a Conference of the Parties, an Executive Organ, as well as other bodies), together with their functions, composition and decision-making powers, e.g. whether or not they should exercise supervision and control over the obligations undertaken.

The international negotiation on a framework convention should start as quickly as possible after the completion of the IPCC interim report. The full and effective participation of developing countries in this process is essential. Many, essentially developing, countries stressed that the negotiation must be conducted in the forum, manner and with the timing to be decided by the UN General Assembly. This understanding also applies to anyassociated protocols. In the view of many countries and international and non-governmental organizations, the process should be conducted with a view of concluding it not later than the 1992 UN Conference on Environment and Development.

The foregoing does not necessarily constitute an exclusive list of issues which will arise inthe negotiations. However, a readiness to address these fundamental problems will be a prerequisite for ensuring the success of the negotiations and the support of a sufficiently wide and representative spread of nations.

The legal measures topic paper developed by the Working Group is given in Annex I.

ANNEX I

LEGAL MEASURES: REPORT OF TOPIC CO-ORDINATORS (Canada, Malta and the UK)

Executive Summary

1. The co-ordinators' report has as its primary objective the compilation of elements that might be included in a future framework Convention on Climate Change, and a discussion of the issues that are likely to arise in the context of developing those elements.

2. There is a general view that while existing legal instruments and institutions with a bearing on climate should be fully utilized and further strengthened, they are insufficient alone to meet the challenge. A very broad international consensus has therefore emerged in the IPCC, confirmed notably at the 44th United Nations General Assembly, on the need for a framework Convention on Climate Change. Such a Convention should generally follow the format of the Vienna Convention for the Protection of the Ozone Layer, in laying down, as a minimum, general principles and obligations. It should further be framed in such a way as to gain the adherence of the largest possible number and most suitably balanced spread of countries while permitting timely action to be taken; it should contain provision for separate annexes/protocols to deal with specific obligations. As part of the commitment of the parties to action on greenhouse gas emissions and the adverse effects of global warming, the Convention would also address the particular financial needs of the developing countries, the question of the access to and transfer of technology, and institutional requirements.

3. The paper points out a number of issues to be decided in the negotiation of a Convention. In general these are:

- the political imperative of striking the correct balances: on the one hand, between the arguments for a far-reaching, action-oriented Convention and the need for urgent adoption of such a Convention so as to begin tackling the problem of climate change; and, on the other hand, between the cost of inaction and the lack of scientific certainty;
- the extent to which specific obligations, particularly on the control of emissions of carbon dioxide and other greenhouse gases, should be included in the Convention itself or be the subject of separate protocol(s):
- the timing of negotiation of such protocol(s) in relation to the negotiations on the Convention.

4. In particular, within the Convention the following specific issues will need to be addressed:

a) <u>Financial needs of developing countries</u>: The need for additional resources for developing countries and the manner in which this should be addressed, particularly in terms of the nature, size and conditions of the funding, even if detailed arrangements form the subject of a separate

protocol, will have to be considered by the negotiating parties.

b) <u>Development and transfer of technology</u>: The basis on which the promotion of the development and transfer of technology and provision of technical assistance to developing countries should take place will need to be elaborated, taking into account considerations such as terms of transfer, assured access, intellectual property rights and the environmental soundness of such technology.

c) <u>Institutions</u>: Views differ substantially on the role and powers of the institutions to be created by the Convention, particularly in exercising supervision and control over the obligations undertaken.

5. The inclusion of any particular element in the paper does not imply consensus with respect to that element, or the agreement of any particular government to include that element in a Convention.

6. The co-ordinators have not sought to make a value judgement in listing and summarising in the attached paper the elements proposed for inclusion in a framework Convention: their text seeks merely to assist the future negotiators in their task. They note however that a readiness to address the foregoing fundamental problems in a realistic manner will be a prerequisite for ensuring the success of the negotiations and the support of a sufficiently wide and representative spread of nations.

POSSIBLE ELEMENTS FOR INCLUSION IN A FRAMEWORK CONVENTION ON CLIMATE CHANGE

PREAMBLE

In keeping with common treaty practice including the format of the Vienna Convention, the Climate Change Convention would contain a preamble which might seek to address some or all of the following items:

- a description of the problem and reasons for action (need for timely and effective response without awaiting absolute scientific certainty);
- reference to relevant international legal instruments (such as the Vienna Convention and Montreal Protocol) and declarations (such as UNGA Resolution 43/53 and Principle 21 of the Stockholm Declaration);
- recognition that climate change is a common concern of mankind, affects humanity as a whole and should be approached within a global framework, without prejudice to the sovereignty of states over the airspace superadjacent to their territory as recognized under international law;
- recognition of the need for an environment of a quality that permits a life of dignity and well-being for present and future generations;
- reference to the balance between the sovereign right of states to exploit natural resources and the concomitant duty to protect and conserve climate for the benefit of mankind, in a manner not to diminish either;
- endorsement and elaboration of the concept of sustainable development;
- recognition of the need to improve scientific knowledge (e.g. through systematic observation) and to study the social and economic impacts of climate change, respecting national sovereignty;
- recognition of the importance of the development and transfer of technology and of the circumstances and needs, particularly financial, of developing countries; need for regulatory, supportive and adjustment measures to take into account different levels of development and thus differing needs of countries;
- recognition of the responsibility of all countries to make efforts at the national, regional and global levels to limit or reduce greenhouse gas emissions and prevent activities which could adversely affect climate, while bearing in mind that:
  - o most emissions affecting the atmosphere at present originate in industrialized countries where the scope for change is greatest;
  - o implementation may take place in different time frames for different categories of countries and may be qualified by the means at the disposal of individual countries and their scientific and technical capabilities;
  - o emissions from developing countries are growing and may need to grow in order to meet their development

requirements and thus, over time, are likely to represent an increasingly significant percentage of global emissions;

- recognition of the need to develop strategies to absorb greenhouse gases, i.e. protect and increase greenhouse gas sinks; to limit or reduce anthropogenic greenhouse gas emissions; and to adapt human activities to the impacts of climate change.

Other key issues which will have to be addressed during the development of the preambular language include:

- should mankind's interest in a viable environment be characterized as a fundamental right?

- is there an entitlement not to be subjected, directly or indirectly, to the adverse effects of climate change?

- should there be a reference to the precautionary principle?

- in view of the inter-relationship among all greenhouse gases, their sources and sinks, should they be treated collectively?

- should countries be permitted to meet their aggregate global climate objectives through joint arrangements?

- should reference be made to weather modification agreements such as the ENMOD treaty as relevant legal instruments?

- is there a common interest of mankind in the development and application of technologies to protect and preserve climate?

- does the concept of sustainable development exclude or include the imposition of new conditionality in the provision of financial assistance to developing countries, and does it imply a link between the protection and preservation of the environment, including climate change, and economic development so that both are to be secured in a coherent and consistent manner?

- should the preamble address the particular problems of countries with an agricultural system vulnerable to climate change and with limited access to capital and technologies, recognizing the link with sustainable development?

- is there a minimum standard of living which is a prerequisite to adopting response strategies to address climate change?

DEFINITIONS

As is the practice, definitions will need to be elaborated in a specific article on definitions. The terms which will need to be defined will depend on the purpose of the Convention and thus the language used by the negotiating parties.

GENERAL OBLIGATIONS

Following the format of such treaties as the Vienna Convention, an article would set out the general obligations agreed to by the parties to the Convention. Such obligations may relate to, for example:

- the adoption of appropriate measures to protect against the adverse effects of climate change, to limit, reduce, adapt to and, as far as possible, prevent climate change in accordance with the means at the disposal of individual countries and their scientific and technical capabilities; and to avoid creating other environmental problems in taking such measures;

- the protection, stabilization and improvement of the composition of the atmosphere in order to conserve climate for the benefit of present and future generations;

- taking steps having the effect of limiting climate change but which are already justified on other grounds;

- the use of climate for peaceful purposes only, in a spirit of good neighbourliness;

- co-operation by means of research, systematic observation and information exchange in order to understand better and assess the effects of human activities on the climate and the potential adverse environmental and socio-economic impacts that could result from climate change, respecting national sovereignty;

- the encouragement of the development and transfer of relevant technologies, as well as the provision of technical and financial assistance, taking into account the particular needs of developing countries to enable them to fulfil their obligations;

- co-operation in the formulation and harmonization of policies and strategies directed at limiting, reducing, adapting to and, as far as possible, preventing climate change;

- co-operation in the adoption of appropriate legal or administrative measures to address climate change;

- provision for bilateral, multilateral and regional agreements or arrangements not incompatible with the Convention and any annex/protocol, including opportunities for groups of countries to fulfil the requirements on a regional or sub-regional basis;

- co-operation with competent international organisations effectively to meet the objectives of the Convention;

- the encouragement of and co-operation in the promotion of public education and awareness of the environmental and socio-economic impacts of greenhouse gas emissions and of climate change;

- the strengthening or modification if necessary of existing legal and institutional instruments and arrangements relating to climate change;

- a provision on funding mechanisms.

Other key issues which will have to be addressed in the process of elaborating this article include the following:

- should there be a provision setting any specific goals with respect to levels of emissions (global or national) or atmospheric concentrations of greenhouse gases while ensuring stable development of the world economy, particularly stabilization by industrialized countries, as a first step, and later reduction of CO_2 emissions and emissions of other greenhouse gases not controlled by the Montreal Protocol?

Such provision would not exclude the application of more stringent national or regional emission goals than those which may be provided for in the Convention and/or any annex/protocol.

- in light of the preambular language, should there be a provision recognizing that implementation of obligations may take place in different time frames for different categories of country and/or may be qualified by the means at the disposal of individual countries and their scientific and technical capabilities?

- should there be a commitment to formulate appropriate measures such as annexes, protocols or other legal instruments and, if so, should such formulation be on a sound scientific basis or on the basis of the best available scientific knowledge?

- in addressing the transfer of technology particularly to developing countries, what should be the terms of such transfers (i.e. commercial vs. non-commercial, preferential vs. non-preferential, the relationship between transfers and the protection of intellectual property rights)?

- should funding mechanisms be limited to making full use of existing mechanisms or also entail new and additional resources and mechanisms?

- should provision be made for environmental impact assessments of planned activities that are likely to cause significant climate change as well as for prior notice of such activities?

- what should be the basis of emission goals e.g., total emission levels, per capita emissions, emissions per GNP, emissions per energy use, climatic conditions, past performance, geographic characteristics, fossil fuel resource base, carbon intensity per unit of energy, energy intensity per GNP, socio-economic costs and benefits, or other equitable considerations?

- should the particular problem of sea-level rise be specifically addressed?

- is there a link between nuclear stockpiles and climate change?

INSTITUTIONS

It has been the general practice under international environmental agreements to establish various institutional mechanisms. The parties to a Climate Change Convention might, therefore, wish to make provision for a Conference of the Parties, an Executive Organ and a Secretariat.

The Conference of the Parties may, among other things: keep under continuous review the implementation of the Convention and take appropriate decisions to this end; review current scientific information; and promote harmonization of policies and strategies directed at limiting, reducing, adapting to and, as far as possible, preventing climate change.

Questions that will arise in developing provisions for appropriate institutional mechanisms include:

- should any of the Convention's institutions (e.g. the Conference of the Parties and/or the Executive Organ) have the ability to take decisions inter alia on response strategies or functions in respect of surveillance, verification and compliance that would be binding on all the parties and, if so, should such an institution represent all of the parties or be composed of a limited number of parties e.g. based on equitable geographic representation?

- what should be the role of the Secretariat?

- what should be the decision-making procedures, including voting requirements (e.g. consensus, majority)?

- if a trust fund or other financial mechanism were established under the Convention, how should it be administered?

- should scientific and/or other bodies be established on a permanent or ad hoc basis, to provide advice and make recommendations to the Conference of the Parties concerning research activities and measures to deal with climate change?

- should the composition of the above bodies reflect equitable climatic or geographic representation?

- should there be a provision for working groups, e.g. on scientific matters as well as on socio-economic impacts and response strategies?

- is there a need for innovative approaches to institutional mechanisms in the light of the nature of the climate change issue?

- what should be the role of non-governmental organizations?

RESEARCH, SYSTEMATIC OBSERVATIONS AND ANALYSIS

It would appear to follow general practice to include provision for co-operation in research and systematic monitoring. In terms of research, each party might be called upon to undertake, initiate, and/or co-operate in, directly or through international bodies, the conduct of research on and analysis of:

- physical and chemical processes that may affect climate;
- substances, practices, processes and activities that could modify the climate;
- techniques for monitoring and measuring greenhouse gas emission rates and their uptake by sinks;
- improved climate models, particularly for regional climates;
- environmental, social and economic effects that could result from modifications of climate;
- alternative substances, technologies and practices;
- environmental, social and economic effects of response strategies;
- human activities affecting climate;
- coastal areas with particular reference to sea-level rise;
- water resources; and
- energy efficiency.

The parties might also be called upon to co-operate in establishing and improving, directly or through competent international bodies, and taking fully into account national legislation and relevant on-going activities at the national, regional and international levels, joint or complementary programmes for systematic monitoring and analysis of climate, including a possible worldwide system; and co-operate in ensuring the collection, validation and transmission of research, observational data and analysis through appropriate data centres.

Other issues that will arise in developing this provision include:

- should consideration be given to the establishment of panels of experts or of an independent scientific board responsible for the co-ordination of data collection from the above areas of research and analysis and for periodic assessment of the data?

- should provision be made for on-site inspection?

- should there be provision for open and non-discriminatory access to meteorological data developed by all countries?

- should a specific research fund be established?

INFORMATION EXCHANGE AND REPORTING

Precedents would suggest the inclusion of a provision for the transmission of information through the Secretariat to the Conference of the Parties on measures adopted by them in implementation of the Convention and of protocols to which they are party. In an annex to the Vienna Convention, the types of information exchanged are specified and include scientific, technical, socio-economic, commercial and legal information.

For the purposes of elaborating this provision, issues having to be addressed by the negotiating parties include the following:

- is there a need for the elaboration of a comprehensive international research programme in order to facilitate co-operation in the exchange of scientific, technological and other information on climate change?

- should parties be obliged to report on measures they have adopted for the implementation of the Convention, with the possible inclusion of regular reporting on a comparable basis of their emissions of greenhouse gases?

- should each party additionally be called upon to develop a national inventory of emissions, strategies and available technologies for addressing climate change? If so, the Convention might also call for the exchange of information on such inventories, strategies and technologies.

DEVELOPMENT AND TRANSFER OF TECHNOLOGY

While the issue of technology has been addressed in the section on General Obligations, it might be considered desirable to include separate provisions on technology transfer and technical co-operation. Such provisions could call upon the parties to promote the development and transfer of technology and technical co-operation, taking into account particularly the needs of developing countries, to enable them to take measures to protect against the adverse effects of climate change, to limit, reduce and, as far as possible, prevent climate change, or to adapt to it.

Another issue which will arise is: should special terms be attached to climate-related transfers of technology (such as a preferential and/or non-commercial basis and assured access to, and transfer of, environmentally sound technologies on favourable terms to developing countries), taking into consideration the protection of intellectual property rights?

SETTLEMENT OF DISPUTES

It would be usual international practice to include a provision on the settlement of disputes that may arise concerning the interpretation or application of the Convention and/or any annex/protocol. Provisions similar to those in the Vienna Convention for the Protection of the Ozone Layer might be employed, i.e. voluntary resort to arbitration or the International Court of Justice (with a binding award) or, if neither of those options is elected, mandatory resort to conciliation (with a recommendatory award).

OTHER PROVISIONS

It would be the usual international practice to include clauses on the following topics:

- amendment of the Convention;
- status, adoption and amendment of annexes;
- adoption and entry into force of, and amendments to, protocols;
- signature;
- ratification;
- accession;
- right to vote;
- relationship between the Convention and any protocol(s);
- entry into force;
- reservations;
- withdrawal;
- depositary;
- authentic texts.

ANNEXES AND PROTOCOLS

The negotiating parties may wish the Convention to provide for the possibility of annexes and/or protocols. Annexes might be concluded as integral parts of the Convention, while protocols might be concluded subsequently (as in the case of the Montreal Protocol to the Vienna Convention on Protection of the Ozone Layer). While it is recognized that the Convention is to be all-encompassing, the negotiating parties will have to decide whether greenhouse gases, their sources and sinks, are to be dealt with: individually, in groups or comprehensively; in annexes or protocols to the Convention. The following, among others, might also be considered as possible subjects for annexes or protocols to the Convention:

- agricultural practices;
- forest management;
- funding mechanisms;
- research and systematic observations;
- energy conservation and alternative sources of energy;
- liability and compensation;
- international emissions trading;
- international taxation system;
- development and transfer of climate change-related technologies.

Issues that will arise in connection with the development of annexes and protocols include:

- timing, i.e. negotiating parties advocating a more action-oriented Convention may seek to include specific obligations in annexes as opposed to subsequent protocols and/or negotiate one or more protocols in parallel with the Convention negotiations;

- sequence, i.e. if there is to be a series of protocols, in what order should they be taken up?

LIST OF ACRONYMS AND CHEMICAL SYMBOLS

AFOS	Agriculture, Forestry and Other Human Activities Subgroup of IPCC Working Group III
BaU	Business as Usual Scenario. Same as Scenario A of Working Group III
Bt	Billion (1000 million) tonnes
BTC	Billion (or 1000 millions) tonnes Carbon
CFCs	Chlorofluorocarbons
CH_4	Methane
CI	Carbon Intensity in kilogram carbon per gigajoule
CO	Carbon monoxide
CO_2	Carbon dioxide
EIS	Energy and Industry Subgroup of Working Group III
Gg	Gigagram (10^9 grams)
GHG	Greenhouse Gas
GDP	Gross Domestic Product
GNP	Gross National Product
GtC	Gigatonnes (10^9 tonnes) carbon
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
IOC	Intergovernmental Oceanographic Commission of UNESCO
IPCC	Intergovernmental Panel on Climate Change
ICSU	International Council of Scientific Unions
ITTO	International Tropical Timber Organization
Mt	Megatonnes (10^6 tonnes)
N_2O	Nitrous oxide
NGOs	Non-Governmental Organizations
NOx	Nitrogen oxides
O_3	Ozone
OECD	Organization for Economic Cooperation and Development
pa	per annum
PC	per capita carbon emissions in tonne carbon
ppm	part per million
RSWG	Respone Strategies Working Group of IPCC Working Group III
SOx	Sulphur oxides
TC	Tonne Carbon
TC-GJ	Tonne Carbon per GigaJoule
TFAP	Tropical Forstry Action Plan
Tg	Teragrams (10^{12} grams)
TgC	Teragram Carbon
TgCH4	Teragram Methane
TgN	Teragram Nitrogen
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VOCs	Volatile Organic Compounds
WMO	World Meteorological Organization

WMO

UNEP

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

POLICYMAKERS SUMMARY

OF THE IPCC SPECIAL COMMITTEE ON THE PARTICIPATION OF DEVELOPING COUNTRIES

AUGUST 1990

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POLICYMAKERS SUMMARY OF THE IPCC SPECIAL COMMITTEE ON THE PARTICIPATION OF DEVELOPING COUNTRIES

EXECUTIVE SUMMARY

1. The Special Committee on the Participation of Developing Countries was established by the Intergovernmental Panel on Climate Change (IPCC) to promote, as rapidly as possible, full participation of the developing countries in IPCC activities. Action was taken, funds were raised and attendance of the developing countries increased.

2. Full participation includes the development of national competence to address all issues of concern such as the appreciation of the scientific basis of climate change, the potential impacts on society of such change and evaluations of practical response strategies for national/regional applications.

3. There is a close link between issues addressed by the IPCC Working Groups such as access to technology and financial resources and the participation of the developing countries in IPCC. The work of the Special Committee was carried out in parallel, necessitated by the tight timetable and limited resources, with work on such issues carried out in Working Group III. The Committee will need to meet periodically to co-ordinate the integration of its conclusions and other concerns of the developing countries in the work of the Working Groups, particularly Working Group III, and the implementation of its recommendations.

4. The industrialized world today emits about 75% of the world total greenhouse gas emissions, and although the emissions are increasing in the developing countries, where 75% of the world population lives, they emit the balance. The legitimate concerns on the part of the developing countries that, although their impact on global climate change is minimal, its impact on them can be grave, need to be taken into account.

5. Any significant climate change would affect every sector of individual and social activity. Thus a single nation or even a group of nations cannot hope to manage the issue adequately by itself. It would take the concerted action of all nations to achieve that end, taking into account not only the past and present responsibility of the industrialized world in the accumulation of the greenhouse gases, but also the present economic and financial capacities of the developing countries.

6. While the global environment has assumed today greater significance for the industrialized countries, the priority for the alleviation of poverty continues to be the overriding concern of the developing countries; they rather conserve their financial and technical resources for tackling their immediate economic problems than make investments to avert a global problem which may manifest itself after two generations, particularly when their contribution to it is significantly less than that of the industrialized countries.

7. The Committee noted that developing countries consider the lack of sufficient assurance so far on the provision and requisite, adequate, new and additional funding particularly for the identification, transfer, adaptation and implementation

of alternative safer technologies on a preferential, non-commercial and grant basis added substantially to the inhibition of the developing countries in taking active part in IPCC activities. It further noted that these countries consider that the formulation of guidelines for funding mechanisms for transfer, adaptation and implementation of clean technologies as against legal and economic measures would create healthier conditions for the participation of the developing countries.

8. These considerations have led the Special Committee to focus on the following five factors that inhibit the full participation of the developing countries in the IPCC process:

* insufficient information;
* insufficient communication;
* limited human resources;
* institutional difficulties;
* limited financial resources.

(i) Insufficient information: Many developing countries do not have sufficient information on the issue of potential climate change to appreciate the concern it evokes elsewhere in the world. Information is often insufficient with respect to the scientific basis for concern, on the potential physical and socio-economic impacts of climate change as well as on response options. This applies not only to scientific milieux but also to policymakers and public opinion.

(ii) Insufficient communication: Even if the situation with respect to information were to improve, there is the problem of insufficient internal and external communication mechanisms for the proper dissemination of the information on matters related to climate change.

(iii)Limited human resources: Lack of adequate number of trained personnel in almost all areas ranging from academic, scientific efforts to applications of knowledge to food and energy production, to water management, to human settlements problems, to trade and economic growth, and to a host of other related endeavours is common to many developing nations. Most of them, if not all, can command only limited pool of experts and responsible and knowledgeable officials, and even that only in a few of these areas.

(iv) Institutional difficulties: The multi-disciplinary and cross-cutting nature of the issues involved demands relatively high degree of co-ordination among the various departments/ ministries of governments.

(v) Limited financial resources: Survival needs come first. After that, the limited financial, and consequent general lack of technological, resources dictate the priorities. Means of meeting the incremental costs of ensuring a viable environment frequently cannot be found. Also, local immediate, environmental concerns generally receive political priority over impersonal, global concerns.

9. The Committee did not consider in detail topics such as financial assistance, economic incentives/disincentives, formulation of legal instruments, and development of, and access to, environmentally-benign and energy-efficient technologies. These were dealt with by Working Group III and are likely to form the substance of future negotiations among governments. However, the Committee expressed the view that actions to promote the full participation of the developing countries in climate change issues should not await the outcome of such negotiations.

10. Also, there are actions that will arise as a result of negotiations and agreements, and machinery will have to be put in place to implement

these. But there are others that need to be taken now, that can be done through existing arrangements; most in this category should be planned and carried out for several years.

11. The impacts of climate change will vary from region to region and nation to nation. Although response strategies for developing countries have to take into account the need for adequate funding and safer technologies, country-specific and/or region-specific approaches will be necessary. For example, response measures that small island states require could be very different from those for large industrializing countries within the developing world. Success in the implementation of many of the recommended actions depend not only on national initiatives but also on stronger regional or sub-regional co-operation.

RECOMMENDED ACTIONS

12. Uninterrupted travel assistance to the developing countries for attendance at the meetings of IPCC and follow-up activities should be ensured. The Committee wishes to call the attention of the Panel to the importance of continuing this effort and of the donor nations continuing and increasing contributions to the effort, with no cessation after the fourth plenary of IPCC.

13. Serious consideration should be given to supporting more than one expert from each participating developing country to those climate change-related meetings that deal with several aspects of the problem. The developing countries on their part should facilitate action in this regard as much as possible.

14. Governments and organizations from the industrialized nations are encouraged to continue and increase their efforts in organizing seminars. Developing countries could organize, under the sponsorship of international organizations or otherwise, regional seminars and workshops in order to exchange scientific and technical information. For this purpose, necessary programmes and lists of experts should be developed. As part of the continuing process of information exchange, the Committee recommends that IPCC circulate this policymakers summary to all concerned including those attending the Second World Climate Conference. The developing countries on their part could where appropriate designate focal points, as soon as possible, for transmittal of reports, documentation, data and information on seminars. Such focal points should be briefed on forwarding the material to appropriate recipients within the nation for response, review etc.

15. The establishment of mechanisms for national co-ordination of all their activities related to climate change could be considered by the developing countries. The mechanisms could aid such areas as information dissemination, development and implementation of plans for research and monitoring, and formulation of policy options. The industrialized countries could consider assisting the developing countries in these areas with easy access to needed technologies.

16. The Committee recommends that acquisition, analyses and interpretation of information on climatic and related data would enable developing countries to take more effective account of climate change considerations in formulating national policies. Such actions are necessary also at regional levels to undertake and refine impact studies. The current unevenness in the acquisition and use of such data which is evident between the hemispheres should be

eliminated. The Committee further recommends that the developing countries take immediate action to identify their specific needs to determine the financial implications of such action. It would be necessary to mobilize appropriate funding in order to mount a sustained programme and create regional centres to organize information networks on climate change.

17. In many developing countries the meteorological/ hydrological service is the main and often the only institution collecting and recording data with relevance to climate. If associated weather patterns are modified, as some predict they would as a result of climate change, then the capabilities of such services need to be reinforced to enhance their contributions to sustainable development.

18. The Committee recommends that considerations of climate change should be integrated in development policies. National environmental studies should also take into account predicted climate change in order to determine sustainable development strategies. To reach these objectives, the developing countries and many industrialized countries consider it essential that additional funding be available to enable developing countries to meet the incremental costs resulting from their efforts to combat climate change.

19. The Committee further recommends that its findings be duly taken into account in all relevant areas of the work of IPCC. Programmes of action should be developed and implemented (and the concepts which would lead to such programmes of action developed where needed) without delay, with a view to ensure, provided the necessary means are made available, the full participation of developing countries in the future work and activities on climate change. UNEP and WMO should take the lead in this regard and initiate the necessary consultations. Other multilateral or bilateral organizations should also be contacted for elaborating and implementing these programmes of action.

20. The Committee also recommends that serious consideration be given by IPCC to the provision of simultaneous interpretation and documentation in the customary UN languages for the meetings of the Special Committee, given the complex nature of the subject matter covered and the particular difficulties encountered by the developing countries.

21. The Special Committee is ready to assist in monitoring and reviewing the preparation and the implementation of the above mentioned and other relevant programmes of action.

POLICYMAKERS SUMMARY OF THE IPCC SPECIAL COMMITTEE ON THE PARTICIPATION OF DEVELOPING COUNTRIES

1. INTRODUCTION

1.1 Establishment of the Special Committee

1.1.1 When the Intergovernmental Panel on Climate Change (IPCC) began its work in November 1988, only a few developing countries attended. The reason was not that they were indifferent to the issue of climate change. They were lacking in neither interest nor concern. Climate change had appeared only a short while earlier on the international agenda. By its nature, it is a complex and multi-sectoral issue. Few developing countries have adequate data bases and research facilities to address the problem directly. For most of them, national spending priorities for rapid economic growth precluded expenditure of scarce resources on travel to attend IPCC meetings.

1.1.2 The Special Committee on the Participation of Developing Countries was established by IPCC (in June 1989) to promote, as rapidly as possible, active participation of the developing countries in IPCC activities. This action followed the report of an Ad Hoc Subgroup which was established by the IPCC Bureau in February 1989 to promote ways and means of increasing such participation. The Subgroup was under the chairmanship of Dr. A. Al-Gain, who is also the Vice-Chairman of IPCC. The members of the Ad Hoc Subgroup were Brazil, Saudi Arabia, Senegal and Zimbabwe.

1.1.3 The Special Committee's deliberations owe much to the report of the Ad Hoc Subgroup. The Committee consists of the following members: France (Chair), Algeria, Brazil, India, Indonesia, Japan, Kenya, Norway, USA and USSR. Dr. Al-Gain is a co-opted member of the Committee. (The Committee met as an open-ended group during its plenary session held in Geneva on 31 May and 1 June 1990 following a decision made at the third plenary session of IPCC in Washington D.C., on 5 to 7 February 1990.) The Committee's terms of reference are given in Annex I to this policymakers summary.

1.1.4 There is a close link between issues addressed by the Working Groups of IPCC such as access to technology and financial resources and the participation of the developing countries in IPCC. The work of the Committee was carried out in parallel with work on such issues carried out within the subgroups, and the topics groups on implementation measures, of Working Group III. This parallel work was necessitated by the tight timetable and limited resources available to the Committee. The Special Committee stresses the importance of taking into account, to the extent feasible, the conclusions of this policymakers summary in the report of Working Group III. Further, the Committee will need to meet periodically to co-ordinate the integration of the concerns of the developing countries in the work of Working Group III and the implementation of its recommendations.

1.2 Joint partnership of the industrialized and developing countries

1.2.1 Global warming of current concern results from emissions of the so-called greenhouse gases into the atmosphere.

While many of these gases occur in the natural atmosphere, recently observed increases in them come about because of activities that have contributed in a very big way to human survival and welfare such as industrialization, food production and general economic development.

1.2.2 The industrialized world today emits about 75% of the world total greenhouse gas emissions, and although the emissions are increasing in the developing countries, where 75% of the world population lives, they emit the balance. The source of the emissions can be any nation but any warming will not be confined to that nation alone; it will go beyond, encompassing the entire globe. Any significant climate change would affect every sector of individual and social activity. Thus a single nation or even a group of nations cannot hope to manage the issue adequately by itself. It would take the concerted action of all nations to achieve that end. That is, both the industrialized and the developing worlds have to join hands in the action, taking into account not only the past and present responsibility of the industrialized world in the accumulation of greenhouse gases, but also the present economic and financial capacities of the developing countries. This is imperative.

1.2.3 While the management of climate change has to be based on globally agreed-upon action, the deciding factors in arriving at such agreements will be dictated by national and regional consideratio-ns. The impact of the predicted warming will be uneven, ranging from beneficial to harmful in various sectors of the economy, and differing from nation to nation and from region to region. Thus, nations and groups of nations will need a sound knowledge base to embark on the agreement process. This need is especially dire in the case of the developing countries. Their access to scientific and other information, and resources will have to be attended to, if they are to share in, and contribute to, the solution. In the process, legitimate concerns on the part of the developing countries that, although their impact on global climate change is minimal, its impact on them could be grave, need to be taken account. Their differing stages of development, and hence their country-specific needs to adjust to climate change, will have to be taken into account also.

1.2.4 The developing world faces special problems. Greater investments for rapid economic development and better satisfaction of basic needs such as food, shelter and income assume paramount importance. At the same time the habitability of the planet cannot be compromised. The developing countries, thus, have to participate fully, willingly and knowingly in the planetary decision-making and the follow-up actions on climate change.

1.2.5 Full participation includes the development of national capacity to address the issues of concern such as the appreciation of the scientific basis for climate change, the potential impacts of such change and evaluations of practical response strategies for national applications. It is intertwined with the general process of sustainable and steady development.

1.3 Structure of the policymakers summary

1.3.1 After introduction, the policymakers summary discusses factors inhibiting full participation by the developing countries (section 2), areas of possible action (section 3) and the Committee's conclusions and recommendations (section 4).

2. FULL PARTICIPATION OF THE DEVELOPING COUNTRIES

2.1 Objectives

2.1.1 The Committee recognized that achieving full participation of the developing countries in the IPCC process is a necessary but difficult goal: it embraces a number of related objectives. These objectives are both quantitative and qualitative. With respect to quantitative objectives, the Committee acknowledged the need to:

(i) increase the number of developing countries taking part in IPCC meetings and actions arising therefrom; these include seminars, meetings of the Working Groups and their subgroups etc.;

(ii) expand the travel support so as to enable a number of experts from each developing country to attend meetings on climate change and related issues to provide for meaningful participation particularly when meetings consider different but related issues simultaneously;

(iii)expand the opportunities for developing countries to increase their knowledge of the science on climate change and policy-making (e.g., energy policy), impacts, and response options appropriate to them, with respect to climate change;

(iv) expand the opportunities for developing countries to train and enhance the skills of experts in climate-related and climate change-related research.

2.1.2 With respect to qualitative objectives, the Committee acknowledged the need to:

(i) provide for continuity of participation from developing countries in the IPCC process to further their involvement;

(ii) encourage dissemination within the developing countries of information and data on climate issues to increase awareness and knowledge;

(iii)encourage that climate issues are rationally considered in developing national policies with respect to science, economics and the environment to achieve sustainable development;

(iv) promote effective co-operation within developing countries among those responsible for the different aspects of climate issues to foster informed decision-making.

2.2 Factors inhibiting full participation

2.2.1 The factors identified by the Special Committee which inhibit the active participation of the developing countries in IPCC activities can be grouped into the following categories:

(i) insufficient information;
(ii) insufficient communication;
(iii) limited human resources;
(iv) institutional difficulties;
(v) limited financial resources.

2.2.2 The above factors have been elaborated at length in the paragraphs below. Without prejudice to their generality, the Committee also took note of the fact that most of the developing countries faced the dilemma of deciding allocation of priorities between environmental issues and economic development. While the global environment has assumed today greater significance for the industrialized countries, the priority for the alleviation of poverty continues to be the overriding concern of the developing countries; they rather conserve their financial and technical resources for tackling their immediate economic problems than make investments to avert a global problem which may manifest itself after two generations, particularly when their contribution to it is significantly less than that of the industrialized countries.

2.2.3 The Committee acknowledged that the above dilemma of priorities poses a serious obstacle to enhancing the participation by developing countries in the IPCC process. The Committee further acknowledged that, even as the process of effective economic development in the course of time would increase the understanding that developmental goals and environmental concerns need not be mutually exclusive, it was necessary to enable the developing countries to perceive the problem in its correct perspective by deepening their understanding of the science of global climate change, its potential physical and socio-economic impacts and response options.

2.2.4 The Committee noted that developing countries consider the lack of sufficient assurance so far on the provision and requisite, adequate, new and additional funding particularly for the identification, transfer, adaptation and implementation of alternative safer technologies on a preferential, non-commercial and grant basis added substantially to the inhibition of the developing countries in taking active part in IPCC activities. It further noted that these countries consider that the formulation of guidelines for funding mechanisms for transfer, adaptation and implementation of clean technologies as against legal and economic measures would create healthier conditions for the participation of the developing countries.

2.3 Insufficient information

2.3.1 The Committee noted that many developing countries do not have sufficient information on the issue of potential climate change to appreciate the concern it evokes elsewhere in the world. Information is often insufficient with respect to the scientific basis for concern, on the potential physical and socio-economic impacts of climate change as well as on response options (see also para 2.2.4). This applies not only to scientific milieux but also to policymakers and public opinion.

2.3.2 Access to scientific data is limited in the developing countries. Many are unable to participate in regional monitoring programmes, where these exist, or to monitor weather and climate continuously within their national boundaries and in accordance with international requirements.

2.3.3 As stated above, information available in developing countries on the likely impacts of climate change within their national boundaries is limited. While Working Group I of IPCC has noted the inability of current scientific models to anticipate specific regional distributions of climate change, the problem in developing countries is more basic. Many do not have the ability, for example, to project how various increases in sea level rise would affect them, and hence what steps might be necessary to adapt to it. Similarly, many developing countries do not have sufficient information to judge how best to achieve energy efficiency, or to gauge its costs, security and trade implications. Another area where there is lack of information is that of environmentally less harmful technologies and products. Gaps in information about proper technologies in moisture conservation, afforestation and soil protection were noted as glaring examples in this regard.

2.3.4 With adequate information, developing countries would be able to take more effective account of climate change considerations in formulating national policies. They would also then be in a better position to appreciate that the deliberations on climate change had far-reaching implications on their economic and developmental strategies, and to identify their specific needs to determine which may be met from existing resources and which may require additional resources.

2.4 Insufficient communication

2.4.1 The Committee noted that even if information on climate change and related activities were to be provided, there was a need to improve internal and external communication to ensure the flow of information to appropriate recipients including economists, scientists and policy-level officials in the developing countries. Internal communication is important for informed considerations of national policy issues while improved external communication facilitates the flow of information to and from the outside world.

2.4.2 The Committee also noted that within the developing countries there was need to strengthen and streamline mechanisms to co-ordinate, receive, store and disseminate relevant information either originating from within the country and/or flowing from outside. Lack of such mechanisms often resulted in insufficient appreciation of the need to participate in the international discussions on climate change.

2.4.3 In a similar manner, the Committee noted that existing international arrangements, to transmit information on climate change and related activities among the developing countries were not yet effective enough.

2.5 Limited human resources

2.5.1 The Committee noted that to receive, communicate and disseminate information on climate change and related activities, there was not sufficient informed manpower available within the developing countries. Full participation by developing countries has sometimes been hampered by the limited pool of expertise available in each country. Those few experts as are available shoulder heavy responsibilities and are extremely hard pressed to take time away from important national tasks.

2.5.2 Developing countries seek to alleviate the problem in some instances by having their embassy representatives take part in those IPCC activities that are scheduled in various capitals. Even this measure is difficult for smaller developing countries with sparse representation. Another approach, albeit less used at present, is to designate regional experts to represent a group of countries. There are drawbacks inherent in both approaches. Embassy officials may lack the background information in the issues to take effective part in meetings, particularly those calling for specific expertise in science, impacts, policy and legal analyses, problems of human settlements in coastal and low-lying areas, behavioral sciences, and cost and economic analyses. In addition, because IPCC meetings take place in many areas of the globe, it is difficult to provide for continuity of representation through the use of embassy officials. On the other hand, designating regional experts to represent a group of countries invariably requires a high degree of co-operation among such countries and a relatively long preparatory process, unless experts are designated to serve on a long term basis.

2.6 Institutional difficulties

2.6.1 The Committee noted that in many developing countries the manpower engaged in co-ordinating receiving, transmitting, disseminating and effectively using information on climate change and related activities was not sufficiently supported by institutional infrastructure.

2.6.2 While this requirement for national infrastructure has been met successfully in some of the developing nations, such is not the general case. It is often not clear which ministry or agency is responsible or should have responsibility for a particular climate issue or decision. In addition, co-ordination mechanisms among ministries and agencies in many developing countries are not as well established or effective as climate issues may demand.

2.7 Limited financial resources

2.7.1 For the reasons stated elsewhere in the policymakers summary, the Committee did not consider in detail topics such as financial assistance, economic incentives/disincentives, formulation of legal instruments, and development of, and access to, environmentally-benign and energy-efficient technologies. These are being dealt with by Working Group III and are likely to form the substance of future negotiations among governments. However, the Committee expressed the view that actions to promote the full participation of the developing countries in climate change issues should not await the outcome of such negotiations. Some of them could be taken now.

2.7.2 Limited financial resources are intimately tied to a general lack of access to new and better technologies. In addition, survival needs have to be satisfied first. Means of meeting the incremental costs of ensuring a viable environment frequently cannot be found. Also, local, immediate environmental concerns generally receive political priority over impersonal, invisible, somewhat remote, global concerns.

2.7.3 While the root causes of the problem of lack of financial resources may lie in the past patterns of economic development, there are simpler but nonetheless indispensable needs such as travel funds, so that a nation can keep itself informed of activities elsewhere in climate change and related fields.

2.7.4 Developing countries require support for the attendance of their experts at IPCC meetings. Travel needs compete with other national priorities for funds. Without travel support, many developing countries simply would not be able to attend even a single meeting; for others, adequate and effective representation would not be possible. Here, as elsewhere, the issue is not so much an absolute lack of financial resources as the absolute necessity of establishing spending priorities amid a large and growing number of international environmental and other meetings and conferences. This is particularly problematic for the least developed countries as well as for smaller developing countries, particularly those in the Southern Hemisphere since the majority of these meetings are held in the Northern Hemisphere.

2.7.5 The Committee noted that the attendance of the developing countries in IPCC meetings has shown a steady improvement (see sub-section 2.8 below). Ironically, as the IPCC succeeds in increasing the participation of developing countries, the problem becomes more complex unless funding assistance for participation increases commensurately. To date, IPCC has not established specific criteria or priorities by which requests from developing countries for travel assistance should be considered.

2.7.6 In addition, while pledges to the IPCC Trust Fund for the travel support of invited experts from the developing countries have been generous and increasing, the process has been ad hoc and the remittances have not been timely to prevent periodic acute shortfalls.

2.8 Progress in IPCC

2.8.1 In spite of the factors discussed in the previous sections which inhibit full participation by the developing countries, it is clear that IPCC has accomplished much in its brief existence.

2.8.2 For example, the number of developing countries attending the first plenary of the Panel in November 1988 was 11; this number rose to 17 at the second plenary (June 1989) and to 33 at the third (February 1990). The number of developing countries at the third plenary surpassed that of the industrialized countries (27).

2.8.3 In addition, the Panel had initially allocated SF 222,510 for travel support for the developing countries in its 1989 budget estimate. The actual amount spent was approximately SF 383,904 (see Annex II for a listing of contributions). This amount paid for 85 trips by 80 experts to attend the meetings of the Panel, the Bureau, the Working Groups and their subgroups, and the Special Committee in 1989. The budget for 1990 for similar support is SF 794,000, which is one half of the IPCC 1990 budget. This has already been exceeded at the time of the writing of this policymakers summary and is in addition to that channelled through bilateral arrangements.

2.8.4 Moreover, several governments (from the industrialized and developing parts of the world) and regional intergovernmental organizations are holding information exchange and other seminars, for the developing countries, in 1990 and 1991 on the specific issue of climate change. These are designed to build awareness and assist the understanding of the complex interrelationship of the various aspects of the subject.

2.8.5 The IPCC process itself has served to increase awareness and knowledge of the industrialized and the developing countries with respect to climate change issues. In this sense, while more remains to be done to increase the participation of developing countries, IPCC has succeeded partially in an essential function. The improving situation cannot yet be termed satisfactory by any means, as the full participation by the developing countries is a prerequisite for any successful action such as the adoption of a climate convention.

2.8.6 As a result of the combined efforts and initiative of a few governments, major financial institutions have undertaken to raise fresh funds to be allocated to the problems associated with climate change. Specifically, the World Bank has targeted climate change as one of the four issues of global importance eligible for additional funding at concessional rates.

3. AREAS OF ACTION

The impacts of climate change will vary from region to region and nation to nation, as already stated elsewhere in the policymakers summary. Although response strategies for developing countries have to take into account the needs for adequate funding and safer technologies, country-specific and/or region-specific approaches will be necessary. For example, response measures that small island states require could be very different from those for large industrializing countries within the developing world. Nevertheless, the discussion in this section is relevant in general to all developing nations (and, indeed, to all nations) and the Special Committee will need to devote more attention to specific requirements in its future work.

Success in the implementation of many of the recommended actions (see section 4) depend not only on national initiatives but also on stronger regional or sub-regional co-operation. Co-operation between countries of the same region, between countries and regional or sub-regional institutions, and between institutions themselves will achieve cost savings and efficiency. This is particularly indispensable for the smaller countries, including island nations.

Advantages of regional co-operation are obvious for research activities but they are there also for many other sectors. For example, with regards to energy savings, countries could benefit from the know-how of regional "technical centres" which encourage research. Together they could develop technologies adapted to their particular situation by sharing their equipment and existing infrastructures. The creation or strengthening, for example, of regional "departments" of energy and environment would assist the mobilisation of support and the co-ordination of research and approaches common to many countries.

Also, there are actions that will arise as a result of negotiations and agreements, and machinery will have to be put in place to implement these. But there are others that need to be taken now, that can be done through existing arrangements; most in this category should be planned and carried out for several years.

The Committee compiled a list of areas of possible action. This list is not to be viewed as all-inclusive. It is a beginning and is expected to be reviewed periodically and modified and added to as needed. The recommendations of the Committee on specific action items are given in section 4.

3.1 <u>Development of information</u>

3.1.1 While insufficient information is not unique to the developing countries, rectification of the associated problems is likely to take longer in their case.

3.1.2 The kind of information that is insufficient includes:

* reliable scientific data, predictions and interpretation;
* techniques of designing numerical (computer) models;
* analytical tools for performing impact analyses;
* cost and other implications of addressing climate change;
* state-of-the-art methods of energy production;
* availability and the nature of possible policy options.

3.1.3 Such insufficiency can be partially redressed, inter alia, through:

* information exchange seminars;
* skill enhancement seminars;

* development of information centres.

3.1.4 Information exchange seminars should be undertaken on global, regional and national levels. A few governments and international organizations have already planned some. The seminars should be periodic or cyclical to maximize retention and wider dissemination of information. They should be aimed at senior officials, the media and the public. Opportunities such as World Meteorological Day, World Health Day, the Earth Day and World Environment Day could be taken advantage of. The seminars could include novel initiatives such as conferences of planners. In this respect, for example, a seminar organized by the UNEP in Paris has as its objective raising the awareness of policy and opinion makers on the issue of climate change and of organizing, at the same time, training activities on the actions to be taken.

3.1.5 Skill enhancement seminars are similar to training sessions. These are best achieved in a regional setting. A number of bilateral, multilateral and international organizations have such programmes. These may require co-ordination to increase their effectiveness.

3.1.6 As stressed in the relevant part of the report of Working Group III, an important component of this effort is the introduction at all stages of education and on a continuing basis, curricula to inform future citizens and decision-makers. Wider public information programmes are also important to strengthen the mandate of governments to act.

3.2 Development of communication

3.2.1 Networking of scientific and other experts on climate change and related matters at national, regional and international levels is a valuable mechanism for rapid flow of information. National, regional and international conferences planned and held in the developing countries would provide good opportunities for such flow. Existing plans of international organizations such as UNEP and WMO could play a critical catalytic role in this regard.

3.2.2 One of the difficulties for the timely transmittal of documents, letters and requests for information and action between, for example, the IPCC Secretariat and governments is that only a few countries have designated focal/contact points for the purpose. A related problem is that often the focal/ contact point is not instructed as to where, for example, a given document should be sent for review etc. Governments are urged to improve appropriate national communication mechanisms to ensure timely dissemination of documents to relevant officials and authorities. The establishment of national climate committees composed of all relevant expertise would be one way to approach this issue (see also section 2 and sub-section 3.5).

3.2.3 In the past, national embassies have been used by governments to promote this communication. This practice could be helpful in selected cases. Embassy staff, where available, can also be designated to represent governments at IPCC meetings. This can especially be helpful when designated experts, for one reason or another, are unable to attend.

3.3 Development of human resources

3.3.1 Development of informed manpower is crucial if a developing country is to contribute fully and effectively to managing climate change. Any programme in this area should address simultaneously the related issues of education, training and technical assistance (i.e., ready access to analytical tools, techniques and methodologies, etc.).

3.3.2 Programmes for the training of experts in the specific field which is relatively new, namely, climate change, are needed. Specialization must be achieved in such areas as the construction and use of numerical models (e.g., climate prediction models, biospheric models, econometric models), observations and surveys (e.g., atmospheric observations for climate and related data, socio-economic surveys), laboratory and engineering techniques, human settlements in coastal and other low-lying regions, and data analyses and interpretation for policy applications. Programmes specifically tailored to regional questions would be helpful in addressing common concerns such as policy considerations.

3.3.3 Exchange of visits of experts on climate change and related issues between the industrialized and the developing worlds should be instituted on a continuing, long-term basis. Academic staff from the industrialized countries could be encouraged to spend their sabbaticals in the developing countries with fellowships dedicated for the purpose. Exchange between academic institutions could be encouraged. Account should be taken of the particular difficulties that will be encountered in those developing countries with poorly developed educational infrastructures where the capacity to respond to new educational demands is limited.

3.3.4 Involvement of local expertise should be sought and encouraged when studies in given geographical areas are undertaken, and advantage taken of opportunities for training which arise as a result.

3.3.5 Programmes to provide ready access to state-of-the-art technology and investigative and implementation tools and methodologies (e.g., computers of adequate power that could be shared on a regional basis, mass communication methods) should be instituted.

3.3.6 In this context, the Committee is of the view that assistance be provided at the regional level by the United Nations Development Programme and specialized agencies such as WMO and UNEP. Their assistance should cover, inter alia, the development of expertise in such areas as climate modeling, formulation of scenarios for decision makers, human settlements programmes, and for transfer of adaptive and updated technology. Existing regional centres of relevance in this regard should also be strengthened.

3.4 Functioning of institutions

3.4.1 Difficulties in national co-ordination are evident to most of the developing countries. In the case of IPCC activities, for example, only a few countries have designated national focal points (see also sub-section 3.3). This not only hampers the flow of information and the continuing participation of the developing countries, but also the follow-up actions needed to be taken at the national level.

3.4.2 Efforts to promote national co-ordination of activities on all aspects of climate change should be redoubled. This is imperative for information flow, planning and implementation of data collection and analyses programmes, studies on cost, international treaty and trade implications, and policy options, and to establish and maintain national review and implementation machineries. Achieving co-operation among the many national agencies engaged in climate change in one way or another is a long process requiring many steps. Any delay in initiating this effort will make it that much more difficult to respond to climate change and maintain sustainable development. Information on effective institutional arrangements and their establishment should be exchanged between countries.

3.4.3 National centres would provide natural foci for timely and effective flow of internal and external information. This is important in view of the possibility of concerted regional and international actions in addition to purely national ones. The centres would facilitate communication among experts in different discipline areas; the necessity for such communication cannot be overemphasized in the context of climate change, which is inherently multi-disciplinary.

3.4.4 There are many international organizations that are involved in climate change studies and issues such as ICSU, UNEP, WMO, WHO, FAO and the World Bank. While their work is necessarily mission-specific as mandated by their respective governing bodies, the efforts are quite complementary to each other and can profit from more cross-referencing. In this regard, it would be very helpful if the same briefs are provided on the climate change issue to all delegations from a nation to the different meetings of the various international organizations. The respective governing bodies would then be kept fully in the picture and can make decisions in a wider context. This would avoid unintended duplication of work and at the same time help identify questions that are likely to be missed because of novel inter-disciplinary and multi-disciplinary characteristics. All this can, in turn, only strengthen national co-ordination. The offices of the UNDP resident representatives and resident co-ordinators could assist recipient governments in their efforts of co-ordination at country level in this regard.

3.5 Development of financial resources

3.5.1 Plans and action strategies of developing countries for their economic development should be respected. Developmental assistance should in general be enlarged and accelerated.

3.5.2 The question of access to new technologies and methodologies for undertaking studies as well as putting into effect implementation measures is intertwined with that of general lack of financial resources. Bilateral and multilateral technical assistance is imperative for initiating and/or modernizing existing installations and practices to address climate change. (The problem of technology development and its transfer to the developing countries, and financial assistance, is dealt with by Working Group III, as already stated.)

3.5.3 The Committee, however, wants to stress that developing countries would require financial assistance to meet the incremental costs of incorporating climate change considerations in their current developmental planning. Such assistance should be extended. Wherever it is feasible for the developing countries to incorporate climate change considerations in their action strategies without incurring additional costs, such incorporation should be made. The modalities (the amount and method of funding, for example) form part of the consideration of Working Group III. The Committee noted the conclusions of the Working Group III financial measures paper on a future work programme, including the need to advance the concept of a new mechanism, in the context of a future climate convention or its protocols. It considered that this issue should be given a high priority.

3.5.4 Recognizing the need to incorporate measures for adjusting to climate change with developmental planning, all developing countries which are in a position to integrate activities such as climate monitoring, impact analyses and studies on adaptation options should be encouraged to promote them and carry out research with financial assistance that primarily aims at securing the following:

* data acquisition and exchange;
* data archival, retrieval and analyses;
* correlative studies (e.g., precipitation & vegetation, energy production & climate factors, health indicators & desertification, policy responses & cost implications);
* education and training including provision of scholarships and fellowships;
* specific technological development.

3.5.5 Continuity of travel assistance to experts from developing countries to attend IPCC meetings should be ensured. Such assistance should be extended for attendance at follow-up activities and other climate and climate change meetings (e.g., the Second World Climate Conference, Geneva, 29 October - 7 November 1990). As has already been stated, full participation implies more than physical presence at meetings.

4. CONCLUDING REMARKS AND RECOMMENDATIONS

4.1 Overview and need for action

4.1.1 The Special Committee on the Participation of Developing Countries was set up by IPCC to seek ways and means of promoting, as quickly as possible, effective participation by the developing countries in its activities. There is a clear need to continue the efforts of the Committee.

4.1.2 The Committee hopes that the views expressed here and its recommendations would be helpful in ongoing international efforts to draft and adopt a convention on climate change and protocols.

4.1.3 The Committee takes the opportunity to express its gratitude to the countries that have contributed generously to the IPCC Trust Fund so that support can be extended to experts from the developing countries to participate in the meetings of IPCC. It urges that contributions for such purpose continue and be increased in the future.

4.1.4 It is necessary to prepare specific programmes of action for the furtherance of the participation by the developing countries in the IPCC process and in the activities based on that process. Such programmes should include, as extensively as possible, action items, time schedules, identification of requisite resources and institutions, and implementation and review procedures. The Committee will give priority to the promotion of such programmes.

4.1.5 It should be noted that action on the Committee's recommendations should be initiated and developed as quickly as possible. Action on some has already begun and needs to be sustained. It is likely that IPCC will continue its work after its fourth plenary when it will complete its First Assessment Report. Thus the recommended actions should continue through the life of IPCC. Some of the actions are of such a nature that international organizations (e.g., WMO, UNDP, UNEP, ICSU, WHO) can implement them.

4.1.6 The Committee emphasizes that having regard to the global nature of climate change and the need for participation by all States if the objectives of the recommended activities are to be achieved, the total programme will stand or fall depending on the availability of adequate funding to those countries in need.

4.2 Specific recommendations

4.2.1 The Committee recognizes that there are several issues justifying actions in their own right and which will contribute to dealing with the longer term climate change issues. It is thus evident that no country should rely solely on the international processes leading to protection of the climate to deal with all the issues which have been identified.

4.2.2 Uninterrupted travel assistance to the developing countries for attendance at the meetings of IPCC should be ensured. The Committee wishes to call the attention of the Panel to the importance of continuing this effort and of the donor nations continuing and increasing contributions to the effort, with no cessation after the fourth plenary of IPCC.

4.2.3 Serious consideration should be given to supporting more than one expert from each participating developing country to those climate change-related meetings that deal with several aspects of the problem. The developing countries on their part:

* should compile a list of national experts and make it available for travel assistance;

* should agree to contribute to the effort through travel subsidies when their national air carriers fly to meeting places;

* should agree to designate jointly an expert or a single group of experts to attend meetings where their interests can be commonly represented.

4.2.4 Governments and organizations from the industrialized nations are encouraged to continue and increase their efforts in organizing seminars. Developing countries could organize, under the sponsorship of international organizations or otherwise, regional seminars and workshops in order to exchange scientific and technical information. For this purpose, necessary programmes and lists of experts should be developed. As part of the continuing process of information exchange, the Committee recommends that IPCC circulate this policymakers summary to all concerned including those attending the Second World Climate Conference. The developing countries on their part should designate focal points, as soon as possible, for transmittal of reports, documentation, data and information on seminars. Such focal points should be briefed on forwarding the material to appropriate recipients within the nation for response, review etc.

4.2.5 Developing countries should consider the establishment of mechanisms for national co-ordination of all their activities related to climate change. The mechanisms would aid such areas as information dissemination, development and implementation of plans for research and monitoring, and formulation of policy options. The industrialized countries should consider assisting the developing countries in these areas with easy access to needed technologies.

4.2.6 The Committee recommends that acquisition, analyses and interpretation of information on climatic and related data would enable developing countries to take more effective account of climate change considerations in formulating national policies. Such actions are necessary also at regional levels to undertake and refine impact studies. The current unevenness in the acquisition and use of such data which is evident between the hemispheres should be eliminated. The Committee further recommends that the developing countries take immediate action to identify their specific needs to determine the financial implications of such action. It would be necessary to mobilize appropriate funding in order to mount a sustained programme and create regional centres to organize information networks on climate change.

4.2.7 In many developing countries the meteorological/ hydrological service is the main and often the only institution collecting and recording data with relevance to climate. If associated weather patterns are modified, as some predict they would as a result of climate change, then the capabilities of such services need to be reinforced to enhance their contributions to sustainable development.

4.2.8 The Committee recommends that considerations of climate change should be integrated in development policies. These policies could favour projects which have as their objective the prevention of and adjustment to adverse effects of climate change, promotion of the awareness of, and education on, the problem and the development and deployment of appropriate techniques and methodologies. National environmental studies should also take into account predicted climate change in order to determine sustainable development strategies. To reach these objectives, the developing countries and many industrialized countries consider it essential that additional funding be available to enable developing countries to meet the incremental costs resulting from their efforts to combat climate change.

4.2.9 The Committee further recommends that its findings be duly taken into account in all relevant areas of the work of IPCC. Programmes of action should be developed and implemented (and the concepts which would lead to such programmes of action developed where needed) without delay, with a view to ensure, provided the necessary means are made available, the full participation of developing countries in the future work and activities on climate change. UNEP and WMO should take the lead in this regard and initiate the necessary consultations. Other multilateral or bilateral organizations should also be contacted for elaborating and implementing these programmes of action, such as:

(i) In the field of research and monitoring

* the United Nations and its Specialized Agencies

* regional intergovernmental organizations such as the European Community

* non-governmental organizations such as the International Council of Scientific Unions.

(ii) On seminars and workshops in such areas as public information, negotiations and legal aspects

* non-governmental organizations in addition to the UN and its Specialized Agencies and regional intergovernmental organizations.

(iii)On education and training and technical assistance

* UN and its Specialized Agencies

(iv) On financing or funding

* multilateral financing institutions such as the World Bank, the Regional Development Banks, the UN Development Programme etc.

The Committee also recommends that serious consideration be given by IPCC to the provision of simultaneous interpretation and documentation before, during and after a session in the customary UN languages for the meetings of the Special Committee, given the complex nature of the subject matter covered and the particular difficulties encountered by the developing countries.

The Special Committee should be mandated by IPCC to monitor and review the preparation and the implementation of the above mentioned and other relevant programmes of action.

4.2.10 To provide a basis for future programmes of action, the Committee requested the Chairman, within the financial resources available, to arrange for the extraction of the recommendations and action options arrived at by the Working Groups of IPCC; this document should be circulated, after review by the Special Committee, to donor and other countries, international organizations and regional groups.

ANNEX 1

TERMS OF REFERENCE OF THE IPCC SPECIAL COMMITTEE ON THE PARTICIPATION OF DEVELOPING COUNTRIES

1. The Committee will recommend to IPCC and its Bureau, specific measures to be undertaken for promoting the full participation of the developing countries in all IPCC activities.

2. It will include in such recommendation institutional arrangement(s) and implementation schedule(s) if and as needed.

3. It will develop action plans for the implementation of its recommendations.

4. It will identify the resource requirements and the means of meeting them to accomplish the task outlined in (1) above.

5. It will periodically review the progress of the implementation of its recommendations and make modifications thereof, as appropriate.

6. It will work closely with IPCC Working Groups.

7. It will continue its work until its dissolution by IPCC.

ANNEX 2

31 August 1990

Table 1

1989 Contributions to the joint WMO/UNEP IPCC Trust Fund

CONTRIBUTOR	AMOUNT SFR	CURRENCY RECEIVED	
Australia	24,963.05	$	15,175.00
Canada	14,519.50	C$	11,000.00
China	16,400.00	$	10,000.00
Denmark	7,550.00	$	5,000.00
Finland	7,950.00	$	5,000.00
France	25,303.00	FF	100,000.00
Federal Republic of Germany	43,750.00	Sfr	43,750.00
Japan	75,500.00	$	50,000.00
Netherlands	40,250.00	$	25,000.00
Norway	25,050.00	$	15,000.00
Saudi Arabia	16,500.00	$	10,000.00
Switzerland	55,000.00	SFr	55,000.00
UK	90,578.85	£	35,000.00
USA	199,500.00	$	120,000.00
UNEP	125,000.00	SFr	125,000.00
WMO	125,000.00	SFr	125,000.00
TOTAL	SFr 892,814.40		

a. The IPCC budget is in Swiss francs (SFr) since this is the currency of the WMO budget. The joint WMO/UNEP IPCC Trust Fund is administered by the Secretary-General of WMO in accordance with WMO Financial Regulations.

b. The amount contributed exclusively for travel support to developing countries in 1989 was SFr 182,000. Many contributors gave flexibility to the IPCC Secretariat on expenditures, while all affirmed their desire that at least part of their contributions should be spent on travel support to developing countries to attend IPCC meetings.

c. One-half of the 1989 expenditures in the IPCC Trust Fund was devoted to the travel support of the developing countries.

d. The 1989 account of the IPCC Trust Fund showed a surplus which was carried over to 1990. Nevertheless, the Fund was experiencing acute and continuing cash shortages throughout 1989.

e. The Government of Norway has given Nkr 700,000 to the IPCC Secretariat for organizing an information exchange seminar for the developing countries on climate change issues. This has not been shown in the table, since this contribution is through a special Memorandum of Understanding and not to the Trust Fund.

In this connection, it may be noted that several countries are planning regional seminars on the same and related topics. These countries are:

- France: Seminar on greenhouse warming in late 1990/early 1991 jointly with the Energy and Industry Office of UNEP;
- Japan: Seminar on the environment and fossil fuel consumption in the Pacific Region, mid-December 1990; information exchange seminar for the developing countries in Asia at the end of January 1991;
- Spain: Seminar for the Spanish-speaking developing countries in the third quarter of 1990;
- Australia: possible joint seminar with the Economic and Social Commission for Asia and the Pacific (ESCAP).

Table 2

Receipts, IPCC Trust Fund, for 1990

MEMBER		AMOUNT EQ.SFR	
Australia		83,490	*(4)
Canada		30,506	*(7)
Denmark		153,000	*(3)
Finland		15,743	
France		48,573	*(5)
Federal Republic of Germany		70,494	*(2)
Italy		83,500	
Japan		75,500	paid in 1989
Netherlands		151,384	
Norway		33,985	*(6)
Sweden		43,075	*(8)
Switzerland		30,000	
UK		86,224	*(10)
USA		298,970	*(1)
UNEP		329,000	
WMO		125,000	
Rockefeller Foundation		68,000	
TOTAL		1,726,444	
USSR	$	85,000	*(9)

*(1) Of the US contribution, $ 100,000 is earmarked for the travel support

to the developing countries.

*(2) The Federal Republic of Germany contribution is DM 160,000 for both IPCC and the Second World Climate Conference. The contribution to IPCC is one-half of this amount.

*(3) The Denmark contribution is specifically for travel and other assistance to the low income developing countries for 1989 and 1990 (see the following page for a listing).

*(4) Of the Australian contribution, AUD 20,000 was earmarked for the travel support of South Pacific delegates to the meeting of the Coastal Zone Management Subgroup of Working Group III (Perth, 19-23 February 1990).

*(5) In addition, France has contributed Ffr 200,000 to augment the staff of the IPCC Secretariat; the Secretary-General of WMO has assigned to the IPCC Secretariat a full-time Scientific Officer seconded to WMO by the Government of France.

*(6) In addition, Norway has given Nkr 700,000 for the purpose of holding an IPCC Information Exchange Seminar for the developing countries on climate change issues through a special Memorandum of Understanding.

*(7) The Canadian contribution is part of Can$ 100,000; the full Canadian contribution includes translation of the three IPCC Working Group reports into French.

*(8) This is in addition to the support provided by Sweden to the 4th Plenary of IPCC.

*(9) The equivalent in roubles was provided by the USSR to support travel of experts from developing countries to meetings of Working Group II.

*(10) In addition, UK may give £ 100,000 for a series of seminars for policymakers in developing countries, through a special Memorandum of Understanding, in a manner similar to the contribution of Norway reflected in (6) above.

LIST OF LOW INCOME DEVELOPING COUNTRIES

Afghanistan	...	Laos	...
Bangladesh	160	Lesotho	410
Benin	270	Malawi	160
Bhutan	160	Maldives	310
Botswana	840	Mali	170
Burkina Faso	150	Mauritania	420
Burma	200	Nepal	160
Burundi	240	Niger	260
Cape Verde	500	Rwanda	290
Central African Rep.	310	Sao Tome & Principe	340
Chad	...	Sierra Leone	310
Comoros	...	Somalia	280
Djibouti	...	Sudan	320
Equatorial Guinea	...	Tanzania	230
Ethiopia	130	Togo	250
Gambia	230	Tuvalu	...
Guinea	290	Uganda	...
Guinea-Bissau	170	Vanuatu	...
Haiti	330	Western Samoa	690
Kiribati	...	Yemen	550
Yemen Dem.	480		

OTHER LOW INCOME COUNTRIES:

Anguilla	...	Mozambique	...
Bolivia	540	Nicaragua	790
China	280	Pakistan	380
Côte d'Ivoire	720	Papua New Guinea	690
Dominican Republic	710	Senegal	420
Egypt	730	Solomon Islands	...
Ghana	390	Sri Lanka	400
Guyana	500	St. Helena	...
Honduras	740	Swaziland	610
India	270	Tonga	690
Indonesia	500	Turks & Caicos Islands	...
Kampuchea	...	Viet Nam	...
Kenya	310	Zaire	160
Liberia	450	Zambia	300
Madagasca	230	Zimbabwe	620
Mayotte			
Mongolia			