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CONFERENCE PROCEEDINGS

ACTES DE LA CONFÉRENCE

THE CHANGING ATMOSPHERE
Implications for Global Security

L'ATMOSPHÈRE EN ÉVOLUTION
Implications pour la sécurité du globe

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Secretariat of the World Meteorological Organization - Geneva - Switzerland
Secrétariat de l'Organisation météorologique mondiale - Genève - Suisse

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**The Changing Atmosphere:
Implications for Global Security
Toronto, Canada
27-30 June 1988**

**L'atmosphère en évolution:
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FOREWORD

In September 1987, the World Commission on Environment and Development (WCED) reported to the United Nations General Assembly that Earth's ability to support life is being seriously threatened by the influences of humanity. It indicated that the ecology and economics of human development "are becoming ever more inter-woven - locally, regionally and globally - into a seamless network of causes and effects". The Commission issued a call to "people of all countries and all walks of life" to move quickly in restructuring national and international policies and institutions in order to foster the sustainability of social and economic development. Nowhere is the problem more evident than in the Earth's atmosphere. Increases in concentrations of greenhouse gases and reductions in the protective high-altitude ozone layer are altering its unique life-support characteristics, while acid rain and long range transport of air pollutants are affecting fragile eco-systems over large regions of the globe. These changes are unprecedented in human history and appear to be escalating in magnitude.

During the WCED public hearings held in Ottawa in May, 1986, Canada's then Minister of the Environment, Tom McMillan, stated that Canada would be pleased to host an international conference to consider ways of improving the world capacity for forecasting environmental change. He suggested that climate change should be one of the first topics considered. With the encouragement of the Commission, Canada initiated the process that culminated in the World Conference on The Changing Atmosphere: Implications for Global Security, held in Toronto June 27 - 30, 1988.

In many respects the Toronto Conference was an event waiting to happen. Indeed the concerns expressed by the WCED to the United Nations General Assembly were a reflection of the growing conviction within the international scientific community that the fundamental characteristics of natural life support systems are changing at such a rate that the security of food, water and global energy supplies may be threatened within the next few decades. That conviction had already led to the formation of the World Climate Programme and the International Geosphere-Biosphere Programme, aimed at improving the scientific understanding of how the planetary systems work. Many conferences had already been convened and international agreements had been developed on specific atmospheric environmental issues such as acid rain and stratospheric ozone depletion. Meetings of atmospheric scientists in Villach, Austria in 1985 and 1987, followed by a gathering of scientists and policy advisors in Bellagio Italy, in November 1987 provided important conclusions and recommendations for dealing with future global warming.

Canada has been very much involved in all of these regional and global issues, scientifically and diplomatically. In organizing the Toronto Conference, we were intent on demonstrating our conviction that these major atmospheric pollution issues are not independent, but are inextricably linked, and that political action to deal with both causes and effects must be based on a more holistic approach to atmospheric change and the human and economic dimensions of such change. Furthermore, the projected magnitude and rate of atmospheric change, its apparent irreversibility on a decadal time scale, the related risk of major and possibly catastrophic consequences to our global ecosystems and human society and the long delay in international policy response often encountered when dealing with environmental change - all suggested that the time was ripe for a major world conference on The Changing Atmosphere. Its objectives would be:

1) To increase international awareness of, and ability to respond to, consequences of a changing atmosphere;

2) To develop strategies and actions to recognize and deal with human influences on the atmosphere that are socially and environmentally unacceptable;

3) To examine ways and means of developing an international agreement to stabilize and reduce the adverse human influences on the global atmosphere; and

4) To promote and increase global cooperation in programs that attempt to forecast change, reduce harmful emissions and adapt to or mitigate adverse effects.

It was recognized from the outset, however, that achieving these objectives would not be simple and would demand the participation of experts from all sectors of society and from all geopolitical regions of the world. The Conference would also need to build on, rather than duplicate, the efforts and results of the many related international meetings that had gone on before. The recommendations of the Conference would furthermore need to be based on an up-to-date scientific consensus and be of a practical nature, yet sufficiently quantitative and specific to instigate concrete responses within the policy-making bodies of national governments and industrial boardrooms. An international Conference Steering Committee, with members from major international institutions involved in related work, was established to seek advice on how the above objectives might be achieved. Within Canada, several Advisory Committees were established to ensure optimum collaboration among various Canadian government departments. A Conference Secretariat was established at the Atmospheric Environment Service headquarters in Toronto to undertake the arduous task of planning and organizing the Conference.

The Conference was organized into three segments, as indicated in the agenda provided in Appendix 1. During the first one and one half days, the background scenarios for subsequent working group discussions were provided through challenges presented by keynote speakers and expositions of the reasons for concern (including assessments of uncertainties and knowledge gaps) presented by spokespersons from the scientific community. During the second day, Conference participants gathered into thematic working groups to assess policy implications of the scenarios provided by the speakers. The final stage of the Conference was devoted to the drafting of a consensus Conference Statement and summary comments of an international panel of political leaders.

The considerable success of the Working Groups in achieving well balanced and practical conclusions and recommendations is in great measure attributable to the broad political and inter-disciplinary representation of the participants, as well as their unquestionable dedication to seeking answers. Among the 341 delegates present, there were: 20 politicians and ambassadors; 118 policy and legal advisors and senior government officials; 73 physical scientists; 50 industry representatives and energy specialists; 30 social scientists and 50 environmental activists. They came from 46 countries with the following geopolitical distribution: North America - 204; Western Europe - 46; Asia - 24; Africa - 16; South and Central America - 16; Eastern Europe - 6; Australia/New Zealand - 5; International organizations - 24, representing 15 agencies. Despite the diversity of backgrounds and opinions within the Working Groups, they dealt with the issues in practical terms, listened carefully to each other and through their reports provided major inputs to the Conference Statement. The delegates also participated in the final plenary session which developed consensus recommendations.

These Proceedings include the invited presentations to the Conference and the results of its deliberations. The document is organized into four sections. The first presents the special addresses provided by the keynote and luncheon speakers. That is followed by all the theme papers. The third part includes the various conference documents and reports which emerged, including the final statement, working group reports, a background document by J. Jaeger and a statement prepared by the non-governmental organizations. The final section consists of a series of appendices presenting other documents pertinent to the Conference, as well as a list of participants and of conference committees and their members.

The organization and success of the Conference, and the editing and preparation of these Proceedings, are the product of many hours of dedicated effort by many individuals over a period of more than two years. Appendix 6 provides an incomplete list of committees and individuals who assisted in the program development and provided advice on many aspects of the Conference that contributed to its success. Many others were also involved in organizing the Conference logistics and in identifying and inviting key participants.

The Conference could not have achieved its final results without the thoughtful challenges presented by the keynote and luncheon speakers and the excellent material and presentations provided by the theme speakers during the first day and a half. The Conference Steering Committee also worked almost round the clock to help hammer out drafts of the Statement which, with some minor amendments in the final plenary session, met with the acquiescence of the Conference participants. Individual members of the Conference Steering Committee took turns chairing the drafting sessions and must share the credit for excellent and successful teamwork.

The representatives from non-government organizations provided unique perspectives and insights during the discussions as well as their combined statement reproduced in these Proceedings. All the participants, through their concerted efforts in the working group sessions, contributed to the individual group reports included in these Proceedings and thus to the final Conference Statement.

Special acknowledgement must be made of the excellent support rendered to the Conference Director by the late Diane McKay and subsequently Gordon McKay and members of the Conference Secretariat, the assistance of External Affairs Canada in identifying and inviting key international participants, and the contribution of Jill Jaeger in preparing the Conference background documentation.

I am sure that Conference participants will also want to share with me votes of thanks to Canada's former Environment Minister, the Honourable Tom McMillan, for convening and guiding the organization of the Conference, and to former Ambassador Stephen Lewis for his dedication and skill as Conference Chairman.

I wish to express my sincere appreciation to both the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) for their enthusiastic endorsement of the Conference, their generous financial support and their important contributions during the planning of the Conference. WMO has also graciously agreed to assist in the publication and distribution of these Proceedings.

H.L. Ferguson
Conference Director

AVANT-PROPOS

En septembre 1987, la Commission mondiale sur l'environnement et le développement (CMED) a signalé à l'Assemblée générale des Nations Unies que la capacité de la Terre d'entretenir la vie était gravement compromise par les influences de l'humanité. Elle a précisé que l'écologie et l'économie du développement humain "forment de plus en plus des rapports d'interdépendance locaux, régionaux et mondiaux, en constituant un réseau monobloc de causes et d'effets". La Commission a lancé un appel aux "gens de tous les pays et de tous les milieux", en leur demandant de restructurer sans tarder les lignes de conduite et les institutions internationales pour favoriser la viabilité écologique du développement social et économique. Le problème se pose tout particulièrement pour l'atmosphère de la Terre. La hausse de la concentration des gaz à effet de serre et la réduction de la couche protectrice d'ozone à haute altitude en modifient les uniques propriétés d'entretien de la vie, tandis que les pluies acides et le transport à grande distance des polluants atmosphériques touchent de fragiles écosystèmes dans de vastes régions du globe. Ces changements sont sans précédent dans l'histoire de l'humanité et, apparemment, ils s'amplifient.

Au cours des audiences publiques que la CMED a tenues à Ottawa en mai 1986, le ministre de l'Environnement du Canada d'alors, M. Tom McMillan, a déclaré que notre pays se ferait un plaisir d'être l'hôte d'une conférence internationale qui étudierait les moyens d'améliorer la capacité mondiale de prévision du changement survenant dans l'environnement. Il a avancé que le changement climatique devrait figurer parmi les premiers sujets d'étude. Encouragé par la Commission, le Canada a entamé le processus qui a conduit à tenir, du 27 au 30 juin 1988 à Toronto, la Conférence mondiale sur l'atmosphère en évolution : implications pour la sécurité du globe.

A bien des égards, la conférence de Toronto était inévitable. En effet, les préoccupations que la CMED a exprimées à l'Assemblée générale des Nations Unies font ressortir le fait que les milieux scientifiques du monde entier sont de plus en plus convaincus que les caractéristiques fondamentales du système naturel d'entretien de la vie changent à un rythme qui risque de compromettre la sécurité des réserves d'aliments, d'eau et d'énergie au cours des prochaines décennies. Cette conviction a déjà conduit à la constitution du Programme climatologique mondial et du Programme international concernant la géosphère et la biosphère, qui visent à améliorer la compréhension scientifique du mécanisme des systèmes planétaires. On avait déjà tenu nombre de conférences et des accords internationaux portant sur des questions précises, notamment les pluies acides et l'épuisement de l'ozone stratosphérique, avaient été produits. Les réunions de scientifiques de l'atmosphère à Villach (Autriche) en 1985 et 1987, suivies par une rencontre de scientifiques et de conseillers en orientation à Bellagio (Italie) en novembre 1987, ont fourni d'importantes conclusions et recommandations qui traitent du futur réchauffement du globe.

Le Canada participe très activement, sur le plan scientifique et diplomatique, à l'étude de ces questions régionales et mondiales. En organisant la Conférence de Toronto, nous comptions bien montrer notre conviction que ces grandes questions de pollution atmosphérique n'étaient pas indépendantes, mais inextricablement liées, et que l'action politique qui traite tant des causes que des effets devait reposer sur une démarche plus holistique face au changement atmosphérique et aux dimensions humaines et économiques d'un tel changement. En outre, l'ampleur et la vitesse projetées du changement atmosphérique, son apparente irréversibilité à l'échelle des décennies, le risque associé de conséquences majeures ou éventuellement catastrophiques pour nos écosystèmes mondiaux et la société humaine, et le long retard qu'accusent souvent les mesures internationales de redressement vis-à-vis du changement environnemental donnaient à penser qu'il était grand temps de passer à l'action et de tenir une grande conférence mondiale sur l'atmosphère en évolution ayant les objectifs suivants :

1) Accroître, à l'échelon international, la sensibilisation aux conséquences du changement atmosphérique et l'aptitude à y réagir;

2) Concevoir des stratégies et des mesures pour détecter les influences de l'homme sur l'atmosphère inacceptables du point de vue social et environnemental et pour réagir à ces influences;

3) Examiner les moyens de concevoir une entente internationale pour stabiliser et réduire l'influence de l'homme sur l'atmosphère du globe;

4) Faciliter et accroître la coopération pour des programmes qui tentent de prévoir le changement, de réduire les émissions nocives, de s'adapter aux effets négatifs ou de les réduire.

On a toutefois établi d'emblée qu'il ne serait pas simple d'atteindre ces objectifs, qu'il faudrait pour cela la participation des experts de tous les secteurs de la société et de toutes les régions géopolitiques du monde. Cette Conférence devrait aussi exploiter, sans les reproduire, les efforts et les résultats de nombreuses réunions internationales connexes déjà tenues. En outre, les recommandations de la Conférence devraient reposer sur un consensus scientifique actualisé et présenter un caractère pratique, mais assez quantitatif et précis, pour inciter à prendre des mesures concrètes au sein des organismes d'orientation des gouvernements des nations et des conseils d'administration de l'industrie. Pour déterminer les moyens éventuels de réalisation des objectifs ci-dessus, on a créé le Comité directeur d'une conférence internationale réunissant des membres d'importants établissements internationaux qui effectuent un travail connexe. Au Canada, on a formé plusieurs comités consultatifs pour assurer une collaboration optimale parmi les divers ministères du Canada. A Toronto, à l'Administration centrale du Service de l'environnement atmosphérique, on a constitué un secrétariat qui s'est chargé de la laborieuse tâche de planifier et d'organiser la Conférence.

Comme l'indique le programme figurant à l'appendice 1, la Conférence comptait trois phases. Pendant la première période, d'une journée et demie, on a fourni les scénarios de base pour les débats ultérieurs des groupes de travail. Les premiers conférenciers ont lancé des défis et des porte-parole du monde scientifique ont présenté les raisons des préoccupations (y compris l'évaluation des incertitudes et des lacunes de connaissances). Pendant la deuxième journée, les participants se sont rassemblés en groupes d'étude thématique pour évaluer les implications des scénarios donnés par les porte-parole. La dernière étape fut consacrée à la rédaction d'une version de la Déclaration commune de la Conférence et aux observations sommaires des dirigeants politiques lors d'une tribune internationale.

Si les groupes de travail sont si bien parvenus à présenter des conclusions et des recommandations bien équilibrées et applicables, c'est en grande partie du fait de la large représentation géopolitique et interdisciplinaire des participants, ainsi que de leur dévouement incontestable dans la quête de réponses. Parmi les 341 délégués présents, on comptait : 20 personnalités politiques et ambassadeurs; 118 conseillers en matière juridique et politique et hauts fonctionnaires; 73 physiciens; 50 représentants de l'industrie et spécialistes en matière d'énergie; 30 scientifiques du domaine social et 50 écologistes. Ces participants venaient de 46 pays : 204 d'Amérique du Nord; 46 d'Europe de l'Ouest; 24 d'Asie; 16 d'Afrique; 16 d'Amérique du Sud et d'Amérique centrale; 6 d'Europe de l'Est; 5 d'Australie et de Nouvelle-Zélande; 24 autres personnes représentant 15 organismes internationaux. En dépit de la diversité des formations et des opinions, les groupes de travail ont étudié les questions sur le plan pratique. On écoutait attentivement ce que l'autre avait à dire. Les rapports de ces groupes ont fourni d'importants éléments à la Déclaration de la Conférence. Les délégués ont aussi participé à la dernière séance plénière où l'on a produit des recommandations acceptables à tous.

Les actes comprennent les exposés des conférenciers invités et les résultats des délibérations. Le document compte quatre parties. La première présente les allocutions particulières des premiers conférenciers et des personnalités ayant pris la parole aux déjeuners. Puis vient la partie qui renferme les communications sur un thème donné. La troisième contient les divers documents de la Conférence et les divers rapports établis, y compris la déclaration définitive, les rapports des groupes de travail, le document de base de J. Jaeger et la déclaration des organismes non gouvernementaux. La dernière consiste en une série d'appendices qui présentent d'autres documents pertinents, ainsi que la liste des participants, des comités et de leurs membres.

L'organisation et le succès de la conférence, ainsi que la révision et la préparation des actes, ont pris de nombreuses heures d'un travail acharné accompli pendant plus de deux ans. L'appendice 6 donne une liste incomplète des comités et des particuliers qui ont aidé à concevoir le programme et fourni des conseils sur de nombreux aspects qui ont contribué au succès de la conférence. Nombre d'autres personnes ont aussi participé à l'organisation de la logistique, à la sélection et à l'invitation des participants-clés.

Les délégués n'auraient pu obtenir de résultats aussi probants sans les sérieux défis lancés par les premiers conférenciers et les personnes ayant pris la parole aux déjeuners, et sans les excellents documents et exposés donnés par les conférenciers ayant abordé un thème pendant la première journée et demie. En outre, le Comité directeur a travaillé près de 24 heures sur 24 pour aider à élaborer des ébauches de la Déclaration qui, après quelques modifications mineures apportées lors de la séance plénière, a reçu l'assentiment des participants. Les divers membres du Comité directeur ont présidé à tour de rôle les séances de rédaction et doivent partager aussi l'honneur d'avoir accompli un excellent et fructueux travail d'équipe.

Les représentants des organismes non gouvernementaux ont contribué aux débats par des perspectives et des points de vue uniques en leur genre. Ils ont aussi communiqué leur déclaration mixte, reproduite dans les actes. Par les efforts concertés qu'ils ont déployés dans les séances des groupes de travail, tous les participants ont contribué aux divers rapports de groupe figurant dans les actes et, par là, à la Déclaration finale.

Nous nous devons de signaler l'excellente aide fournie au Directeur de la conférence par la regrettée Diane McKay et, par la suite, par Gordon McKay et les membres de la Conférence, l'aide offerte par Affaires extérieures Canada pour désigner et inviter les participants-clés du monde entier et l'assistance de Jill Jaeger pour la préparation des documents de base.

Je suis persuadé que les participants tiendront à remercier avec moi l'ex-ministre de l'Environnement du Canada, Tom McMillan, qui a convoqué la Conférence et en a guidé l'organisation, ainsi que l'ancien ambassadeur Stephen Lewis, qui a manifesté son dévouement et ses talents à titre de président de la Conférence.

Je tiens à exprimer ma sincère gratitude tant à l'Organisation météorologique mondiale (OMM) qu'au Programme des Nations Unies pour l'environnement (PNUE) pour leur enthousiaste appui de la Conférence, leur généreux soutien financier et leur importante participation au cours de la planification de la Conférence. En outre, l'OMM a aussi gracieusement convenu de contribuer à la publication et à la diffusion des actes.

Le directeur de la conférence
H.L. Ferguson

SPECIAL ADDRESSES

ALLOCUTIONS

OPENING ADDRESS

The Right Honourable Brian Mulroney
Prime Minister of Canada

It is with genuine pleasure that I welcome you to this historic conference - "The Changing Atmosphere: Implications for Global Security". Over 350 experts from over 40 countries, you are gathered here to address the global threat to the earth's atmosphere.

We are honoured today by the presence of Prime Minister Brundtland who chaired the United Nation's World Commission on Environment and Development. You have, Dr. Brundtland, provided vital leadership to the world community in approaching the interrelated issues of environment and development. The landmark report of the Brundtland Commission, "Our Common Future", underscored the urgent need for international action to address the threats of chemical changes to our atmosphere.

As you know, Prime Minister, your Commission's recommendations received strong support at last week's Economic Summit in this very building. As Summit leaders noted in the Toronto Communiqué: "We endorse the concept of sustainable development".

Among the serious problems facing industrial society, none is more acute than the deterioration of our environment. One of the most pressing responsibilities of modern governments is to recognize this problem and to work to restore the integrity of the environment. Our government has tackled this immense and urgent task on a priority basis. We have made encouraging progress in many areas related to the environment:

1. We have made it a matter of the utmost importance to immediately reduce and eventually eliminate the scourge of acid rain.

We have reached a series of agreements with the seven provinces east of Saskatchewan on reducing acid rain emissions by 50% by the year 1994. Yet clouds and winds cannot be contained by laws or borders. So until the United States enacts laws and regulations as strict as ours for combatting acid rain, our forests, lakes and rivers will never be adequately protected. I have taken this issue up at every meeting with President Reagan, and in my meetings with leaders of the U.S. Congress in April.

I can tell you this - we will stay with this issue until there is a satisfactory resolution. We shall persevere until our skies regain their purity and our rains recover the gentleness that gives life to our forests and streams. There will be a bilateral accord on acid rain between Canada and the U.S. Its components are simply a matter of logic, and its negotiation, a matter of time.

2. On emissions reductions, we launched a program in 1986 to eliminate lead in gasoline. By 1990, lead emissions will be reduced by 60% and by 1992, virtually eliminated.

3. Within the next few days, our House of Commons will pass the Canadian Environmental Protection Act, the most comprehensive Omnibus legislation of its kind ever adopted in Canada. This law will control toxics from production to disposal.

4. We have established mechanisms to ensure that economic decisions take environmental impact into account.

5. We have reached an agreement with the provinces and territories on developing a coordinated approach for controlling the processing, transport and use of PCBs.

6. We have developed a new federal water policy, and with the Toledo Accord, improved the Great Lakes Water Quality Agreement with the United States and signed an agreement to reduce pollution in the Niagara River. In the newly updated Great Lakes Agreement, we agreed not only on the nature of toxic wastes, but on a process for action to restore the lakes. The Great Lakes agreements prove what Canada and the U.S. can achieve together. The Great Lakes are coming back - one sure sign of this is the return in numbers of wildlife species once thought to be on the verge of extinction. And we are intensifying our efforts to restore our Inland waterways.

7. Just this month, we launched a major effort to clean up the St. Lawrence River, and to create a new marine park in the Saguenay region of Quebec.

Already, in less than four years, we have increased our commitment to national parklands by 40,000 square kilometres, with decisions to create four new National Parks, each with its own unique vocation - Ellesmere Island, South Moresby, Pacific Rim and Bruce Peninsula. As well, Gros Morne National Park in Newfoundland has recently been designated a world heritage site. South Moresby, in particular, meets our commitment to "sustainable development", with the province and the federal government specifically creating the park as a demonstrator project toward that goal. National Parks preserve our environment, enhance our sovereignty, and enrich our sense of country. We call this "l'Appartenance canadienne", a sense of belonging to the land, and it runs very deep with all Canadians. For Canadians, it is important to have a good standard of living; it is equally important to have a good standard of life.

In Canada, environmental concerns are in the mainstream of public opinion, and in the mainstream of public policy. We want our children and families to enjoy a clean and healthy environment - with green spaces, clear water and fresh air, both in our major metropolitan areas and in less populated regions of the nation. Living in a big city like Toronto should not mean functioning in a diminished environment. In many important ways, Toronto is a model city, a world class city, but one that has never forgotten its sense of scale and of neighbourhood. It's a city that works, a city where quality of life matters, where family life means recreation and clean streets, fresh air and open spaces.

This has something to do with the Canadian dream, and it has very much to do with lakes and forests, with field and stream. Canadians know that environmental issues cannot be considered in isolation any more than economic issues can. Indeed, there is a growing awareness in this country that the environment and the economy, as well as human health, are inextricably linked. It is impeccably logical that if acid rain kills forests, there will be fewer trees to cut; that if the earth's rain forests are stripped away, the global life-support system will be endangered; that if the ozone layer continues to deteriorate, mankind will be dangerously exposed to the sun. And when Beluga whales are washed ashore in the St. Lawrence, bloated with toxic chemicals, their remains declared dangerous waste sites, then surely nature is sending us an urgent message.

Last week, in this very Conference Centre, Canada hosted the Economic Summit of the leading industrialized democracies. We dealt with critical international economic problems - exchange rates, trade imbalances, the staggering Third World debt, agricultural subsidies, and the environment. Our discussion of the environment was vigorous and it figured prominently in our deliberations. I can tell you, for example, that it took up an entire dinner meeting among the Summit leaders last Monday at Hart House of the University of Toronto. In a special way, Chancellor Kohl of West Germany and Prime Minister De Mita of Italy provided leadership in this important area. The concerns expressed here were strong, and they were shared.

The Europeans have the same concerns as we do - on acid rain, which falls on German forests, on Italian monuments, on French museums, on British fishing streams. The Europeans, and the Japanese and the Americans share our concern about the ozone layer, about deforestation, about the greenhouse effect. The language of our communiqué was quite unambiguous: "Global climate change, air, sea and freshwater pollution, acid rain, hazardous substances, deforestation, and endangered species require priority attention." As well, the Summit leaders "very much welcomed" this conference on the atmosphere.

The world is coming to recognize what we believe to be self-evident - that economic development and environmental protection are mutually reinforcing, not mutually exclusive. Our economic activity must be increasingly compatible with today's environmental facts of life. We are faced with climate shifts, desertification, flooding, drought, ozone depletion and acidification - these are major global issues.

Consider the so-called "greenhouse effect". Carbon dioxide from fossil-fuel burning and methane from modern agricultural and industrial practices are accumulating in the atmosphere and trapping solar energy reflected from the earth. While research remains to be conducted on the impact of "greenhouse gases", scientists predict an average global warming of up to 4.5 degrees Celsius within the next 50 years. This is not a distant prospect. The year 1987 was the hottest, on average, in the last 150 years. The four hottest years in the last 130 years have occurred since 1980. A global change of 4.5 degrees Celsius over such a relatively short period of time is unprecedented in human history.

We are also attacking the stratospheric ozone - that thin blanket of gases around the earth that protects the human race and all other life forms from the most lethal of the sun's rays. Chemicals used in refrigerators, spray cans, fire extinguishers and industrial processes are being released into the atmosphere in such heavy volumes that they are endangering that protective shield. Between 1976 and 1983, the ozone layer over this city decreased between 2 and 3%. A 1% shrinkage is thought to cause an increase in the incidence of skin cancer in some people by 4% - not to mention increases in other human conditions such as cataracts and leukemia.

As we confront such problems as stratospheric ozone depletion and climate warming, we realize that there are global dimensions to what had been viewed as local or regional air quality issues. Clearly the threats to our environment cannot be met within the borders of any one country. As Prime Minister Brundtland has said, "The environment must become an ally, not a victim of development". Canada is committed to taking the necessary action.

We endorsed the Brundtland Report at the United Nations, and strongly support the proposal for a 1992 World Conference on sustainable development, under the auspices of the U.N.

I am pleased to announce today that Canada would be honoured to host, and the Government of Canada pleased to support the organization of the 1992 Conference.

Twenty years after the Stockholm Conference, five years after the Brundtland Report and the Montréal Protocol, the 1992 Conference will be a critical opportunity for the international community to take stock of our progress and assess our actions on world environmental issues. By the time of the 1992 Conference, we should be able to achieve an international law of the atmosphere accord, or at least the elements of an agreement. For in diplomacy, just as in politics, there is nothing like a deadline to concentrate the mind. We have worked with the international community to successfully conclude important planks that we hope can grow into an international law of the atmosphere. The first international accord was the Helsinki Protocol on acid rain. The second international accord was the Montréal Protocol to reduce ozone-depleting chemicals by 50%.

I am pleased to advise that our key legislative instrument required to implement all phases of the protocol, the new Canadian Environmental Protection Act, will soon receive royal assent. We will then ratify the Montréal Protocol, becoming the third of the signatories to do so. Heeding the warnings of science that an 85% reduction is necessary, we will advance regulations to ban all non-essential uses of CFCs and halons.

Another plank in our international atmospheric legal framework, a protocol for control of nitrogen oxides, will likely be signed by European and North American countries next fall. We need new international legal mechanisms to forge global cooperation to protect and restore our atmospheric life-support system. Your deliberations in such international legal regimes will be crucial. The outcome of your work will form the basis for a follow-up meeting, to be hosted by Canada early next year, of international legal and policy experts on the law of the atmosphere - with particular focus on climate change.

In Canada, as an immediate response to the Brundtland Commission, our Provincial and Federal Environment Ministers struck a multi-partite task force on the environment and economy. Leaders of our largest industries, as well as academics and environmentalists, worked with the Environment Ministers to develop consensus recommendations for action and their report was endorsed last November by Canada's First Ministers. One of their key recommendations was that governments improve the decision-making process.

Today, I wish to announce an action plan to improve our decisions through economic and environment integration:

- First, to improve decision-making at the national level, we intend to implement one of the central recommendations of that task force - the creation of a multi-sectoral national round table to develop strategies for the integration of economic and environmental decision-making in Canada.
- Second, within individual departments of the federal government, we are working toward sustainable development.

In no area is the link between our economic activity and environmental disruption more evident or more troubling than in the area of energy policy.

Canada is committed to applying the principles of sustainable development to our energy future.

- Third, the federal government wants to empower its citizens to make environmentally appropriate choices - in the home, in the workplace, and in the boardroom.

We have instituted the first-ever state of the environment reporting system, guided by a citizens' advisory panel, and secured by law.

We will also help consumers protect our environment by making it easier to identify those products that are environmentally friendly.

Products and processes that conserve energy, are recycled or recylable, biodegradable and free of ozone-depleting substances will be identified by a distinctive, made-in-Canada logo.

I want to say a word about the threat of global climate change and the need to develop an equitable resolution to Third World debt. It is not just altruism. It is in our self-interest. If the debtor nations of the tropics stopped stripping their rainforests to generate export earnings to service their debt, the industrialized countries would benefit. The slowing of carbon dioxide buildup would give the developed world much needed flexibility in adjusting our energy mix to reduce our reliance on fossil fuels.

Canada is committed to working with developing nations to find solutions to their staggering debt. Last year, we forgave $670 million in development assistance-related debt to the poorest nations of Africa. At last week's Toronto Summit, the other leading industrialized democracies took a clear step in this direction. Structural adjustment programmes should be considered, along with debt-rescheduling and/or concessional financing undertaken with the goal of sustainable development.

Canada is also supporting a feasibility study into a World Conservation Bank to work in concert with the World Bank. This innovative recommendation of the Brundtland Commission deserves serious consideration. We are heartened by the recent response of the World Bank to incorporate the ethic of sustainable development into their programmes and policies. CIDA is doing good work, in West Africa, for example, where in Senegal last year I visited an important reforestation project in which they are reclaiming land that had been lost to the advancing desert.

We believe that there are no limits to economic growth, other than those imposed by our imagination, but we do recognize that there are real limits to natural systems and resources. This is not just about the atmosphere, it is not just about the environment, it is about the future of the planet itself. And to address the environmental agenda, it is not enough to conduct research and put out information, we also need leadership and statesmanship in the international community. Prime Minister Brundtland has been a visionary in this challenging area. The founding father of my party and our country showed remarkable foresight and concern for the enviromment over 100 years ago.

Sir John A. Macdonald was the first Canadian politician who understood the importance of the environment. A little over a century ago, in 1885, he established Canada's first National Park at Banff. And in 1887, at Last Mountain Lake in Saskatchewan, he established North America's first wildlife sanctuary, which became an international nesting ground for migratory water fowl. In those days, Western Canada was a pioneer territory, a virgin land in need of people. There were no votes in the environment then, but Sir John A. brought the same sort of vision he brought to creating a country.

Well, as far as today's environmental issues are concerned, we all belong to one human family, and we are all in this together.

Thank you for your commitment and your work at this Conference, Rest assured that the Government of Canada, and the Prime Minister of Canada, are fully aware, and fully engaged on the environment. The Government of Canada, and indeed governments around the world, eagerly await your recommendations for action.

DISCOURS INAUGURAL

Premier Ministre du Canada
Le très Honorable Brian Mulroney

Je suis vraiment heureux de vous accueiller à cette conférence historique, tenue sous le thème "L'atmosphère en évolution : implications pour la sécurité du globe". Cette conférence réunit plus de 350 experts de 40 pays qui se sont rassemblés ici pour affronter résolument la menace qui pèse sur l'atmosphère terrestre.

Nous sommes honorés aujourd'hui par la présence du Premier ministre Brundtland, qui a présidé la Commission mondiale de l'ONU sur l'environnement et le développement. Grâce à vous, Madame Brundtland, la communauté mondiale est maintenant beaucoup mieux éclairée sur la façon d'aborder les questions intimement liées de l'environnement et du développement.

Dans son remarquable rapport intitulé "Notre avenir à tous", la Commission Brundtland soulignait l'urgente nécessité d'une action internationale visant à contrer les menaces auxquelles nous exposent les modifications chimiques que subit notre atmosphère. Comme vous le savez, Madame le Premier ministre, les recommandations de votre Commission ont reçu un vigoureux appui de la part des participants au Sommet économique qui a eu lieu la semaine dernière dans l'édifice même où nous nous trouvons présentement. Comme ils l'ont affirmé dans leur Déclaration de Toronto, les leaders du Sommet souscrivent au principe du "développement durable".

De tous les problèmes auxquels sont confrontées les sociétés industrialisées, aucun ne se pose avec autant d'acuité que la dégradation de notre milieu de vie. Et l'une des responsabilités les plus urgentes des gouvernements d'aujourd'hui est d'enrayer cette dégradation et de travailler à restaurer l'intégrité de l'environnement.

Notre gouvernement s'est attaqué en priorité à cette tâche immense et pressante. Nous avons accompli des progrès encourageants dans plusieurs domaines touchant l'environnement.

1. Nous avons accordé la plus haute importance à la réduction immédiate et à l'élimination éventuelle du fléau de pluies acides.

Nous avons conclu avec les sept provinces situées à l'est de la Saskatchewan une série d'ententes visant à réduire de moitié, d'ici à 1994, les émissions de pollutants acidogènes. Mais les nuages et les vents n'obéissent pas aux lois des pays et ne respectent pas les frontières. Alors, aussi longtemps que les États-Unis n'édicteront pas des lois et des règlements aussi sévères que les nôtres pour combattre les pluies acides, nos forêts, nos lacs et nos rivières ne seront jamais convenablement protégés. J'ai soulevé cette question à chacune de mes rencontres avec le Président Reagan, et lors des entretiens que j'ai eus avec les dirigeants du Congrès américain en avril. Je peux vous dire que nous reviendrons à la charge tant et aussi longtemps que nous ne serons pas parvenus à une solution satisfaisante. Nous lutterons jusqu'à ce que nos cieux retrouvent leur pureté et jusqu'à ce que nos pluies ne soient plus un poison pour nos forêts et nos cours d'eau. Il y aura assurément un accord bilatéral sur les pluies acides entre le Canada et les États-Unis. Ses éléments sont simplement une question de logique, et sa négociation une question de temps.

2. En ce qui concerne la réduction des émissions de substances polluantes, nous avons lancé en 1986 un programme visant à éliminer le plomb dans l'essence.

   Dès 1990, les émissions de plomb auront été réduites de 60 %, et deux ans plus tard, elles auront été pratiquement éliminées.

3. Dans les jours qui viennent, notre Parlement adoptera la Loi canadienne sur la protection de l'environnement, qui constituera la législation du genre la plus complète jamais adoptée au Canada.

   Cette loi nous permettra d'exercer un contrôle total sur les produits toxiques, depuis leur production jusqu'à leur élimination.

4. Nous avons établi des mécanismes qui imposeront l'examen des incidences environnementales dans les décisions d'ordre économique.

5. Nous nous sommes entendus avec les provinces et les territoires pour élaborer une approche concertée afin de contrôler le traitement, le transport et l'utilisation des BPC.

6. Nous avons défini une nouvelle politique fédérale de l'eau, conclu l'Accord de Toledo, qui améliore l'Entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs, et signé une entente pour réduire la pollution de la Niagara.

   Dans la nouvelle version de l'Entente sur les Grands Lacs, nous nous entendons non seulement sur la nature des déchets toxiques, mais aussi sur un plan d'action pour les recycler. La dépollution des Grands Lacs est une brillante illustration de ce que le Canada et les États-Unis peuvent réaliser ensemble. Les Grands Lacs sont en train de reprendre vie, comme en témoigne le retour en grands nombres d'espèces de poissons et d'oiseaux aquatiques qu'on a déjà cru en voie d'extinction. Et nous intensifions nos efforts pour restaurer nos cours d'eau intérieurs.

7. Au début du mois, nous avons lancé une initiative majeure axée sur l'assainissement du fleuve Saint-Laurent et la création d'un nouveau parc marin dans la région du Saguenay au Québec.

Déjà, en moins de quatre ans, nous avons accru de 40 000 km la superficie du territoire canadien réservée à des parc nationaux, en créant quatre nouveaux parcs ayant chacun sa propre vocation : le parc de l'île Ellesmere, le parc Moresby-Sud, le parc Pacific Rim et le parc de la péninsule de Bruce. Par ailleurs, le parc national du Gros-Morne, à Terre-Neuve, a récemment été désigné site du patrimoine mondial. Le parc de Moresby-Sud, en particulier, témoigne de l'importance que nous attachons au principe du "développement durable", les gouvernements provincial et fédéral l'ayant précisément créé à titre de projet pilote en ce sens. Nos parcs nationaux contribuent à la préservation de notre environnement, à l'affirmation de notre souveraineté et au renforcement de notre sentiment d'appartenance nationale, qui est profondément ancré dans le coeur de tous les Canadiens.

Pour les Canadiens, il importe d'avoir un bon niveau de vie, mais il importe tout autant de jouir d'une bonne qualité de vie. Au Canada, les gens attachent beaucoup d'importance à la qualité de leur environnement, et l'État intervient vigoureusement pour le protéger. Nous voulons continuer de vivre et de nous divertir dans un environnement sain, d'où notre souci de préserver nos espaces verts et de conserver la pureté de l'air et de l'eau ausi bien dans nos plus grands centres urbains que dans les régions moins populeuses du pays.

Vivre dans une grande ville comme Toronto ne devrait pas vouloir dire vivre dans un environnement de moins bonne qualité. Toronto est certes une très grande ville, et ce à bien des égards, mais elle a su garder une dimension humaine. C'est une ville dynamique, une ville où la qualité de vie importe, une ville où la possibilité de se recréer dans des espaces verts où l'air est pur et sain fait partie des plaisirs de la vie familiale. Cela fait partie du rêve canadien et c'est pour cela que nous tenons tant à protéger nos lacs et nos forêts et tout ce qui constitue notre environnement naturel.

Les Canadiens savent que les questions environnementales ne peuvent être traitées isolément, pas plus que nous ne pouvons dissocier les questions économiques d'autres importantes considérations. En fait, le peuple canadien prend de plus en plus conscience du fait que les questions d'environnement et d'économie, comme celle de la santé humaine, sont inextricablement liées. Il est tout à fait évident que si les pluies acides détruisent nos forêts, il n'y aura plus d'arbres à abattre; que si les forêts tropicales de la terre sont rasées, les systèmes qui entretiennent la vie sur cette terre seront gravement menacés; et que si la couche d'ozone continue de se détériorer, l'humanité sera dangereusement exposée aux radiations solaires. Et quand les bélugas viennent s'échouer sur les rives du Saint-Laurent, le corps tellement infesté de produits chimiques toxiques qu'il faut déconseiller aux gens de s'en approcher, il y a sûrement là un message urgent de la part de la nature.

La semaine dernière, le Canada a été l'hôte ici même, dans ce centre de conférences, du Sommet économique des principales démocraties industrielles. Nous nous sommes alors penchés sur des dossiers économiques internationaux de la plus haute importance, dont les problèmes des taux de change, des déséquilibres commerciaux, de la dette écrasante des pays du tiers monde et des subventions agricoles, ainsi que sur la question de l'environnement. Nous avons eu de vigoureuses discussions à ce sujet et cette question a occupé une place très importante dans nos délibérations. Je peux vous dire, par exemple, qu'elle a monopolisé les entretiens des leaders du Sommet pendant un diner complet, lundi dernier, à la maison Hart de l'Université de Toronto. Le chancelier Kohl d'Allemagne de l'Ouest et le Premier ministre De Mita d'Italie ont exercé un leadership particulièrement notable dans cet important domaine.

Les préoccupations exprimées ici la semaine dernière étaient vives, et tous y étaient profondément sensibles. Les Européens ont les mêmes inquiétudes que nous au sujet des précipitations acides qui s'abattent sur les forêts allemandes, les monuments italiens, les musées français et les cours d'eau poissonneux de Grande-Bretagne. Les Européens, de même que les Japonais et les Américains, s'inquiètent autant que nous de la dégradation de la couche d'ozone, du déboisement et de l'effet de serre. Les termes de notre déclaration commune sont particulièrement clairs : "La priorité doit être accordée aux changements climatiques mondiaux, à la pollution de l'air, de la mer et des étendues d'eau douce, aux pluies acides, aux substances dangereuses, au déboisement et aux espèces en voie d'extinction." Les leaders du Sommet se sont aussi vivement réjouis de la tenue de cette Conférence sur l'atmosphère.

Le monde est en train de reconnaître ce que nous jugeons évident, à savoir que, loin d'être inconciliables, le développement économique et la protection de l'environnement sont parfaitement compatibles. Notre activité économique doit devenir de plus en plus compatible avec les réalités environnementales d'aujourd'hui.

Les changements climatiques, la désertification, les inondations, les sécheresses, l'appauvrissement de la couche d'ozone et l'acidification sont des phénomènes inquiétants qui se rangent parmi les grands problèmes mondiaux. Songez au phénomène qu'on appelle "l'effet de serre". Le dioxyde de carbone provenant des combustibles fossiles et les émissions de méthane causées par les pratiques agricoles modernes s'accumulent dans l'atmosphère et emprisonnent l'énergie solaire reflétée par la planète. Bien qu'on ne connaisse pas encore très bien les effets des gaz responsables de l'effet de serre, les scientifiques prédisent un réchauffement moyen de la température du globe pouvant atteindre 4,5 degrés Celsius dans les 50 prochaines années. Ce n'est pas une perspective lointaine. La température moyenne enregistrée en 1987 a été la plus forte des 150 dernières années. Les quatre années les plus chaudes des 130 dernières années ont été enregistrées dans la présente décennie. Un réchauffement de 4,5 degrés Celsius pendant les 50 prochaines années, période relativement assez courte, est un fait sans précédent dans l'histoire de la planète.

Nous sommes aussi en train d'endommager la couche d'ozone de la stratosphère, cette mince nappe de gaz qui entoure la terre et qui protège l'espèce humaine et toutes les autres formes de vie des radiations les plus dangereuses du soleil. Les produits chimiques utilisés dans les réfrigérateurs, les bombes aérosol, les extincteurs et dans de nombreux procédés industriels sont relâchés dans l'atmosphère en quantités si importantes qu'ils menacent cet écran protecteur. Entre 1976 et 1983, la couche d'ozone au-dessus de cette ville a diminué de plus de 2 %. On estime qu'une diminution de 1 % de la couche d'ozone augmente de 4 % la fréquence des cas de cancer chez certaines gens, sans compter l'augmentation des cas de cataracte et de leucémie.

L'ampleur qu'ont prise des problèmes comme l'appauvrissement de la couche d'ozone et le réchauffement des températures nous fait prendre conscience que les préoccupations concernant la qualité de l'air, que nous considérions jusqu'ici comme des questions d'intérêt local ou régional, revêtent en fait une dimension globale. Il est évident qu'aucun pays ne peut contrer à l'intérieur de ses frontières les menaces qui pèsent sur notre environnement.

Comme l'a dit le Premier ministre Brundtlant : "L'environnement doit devenir un allié plutôt qu'une victime du développement". Le Canada est déterminé à prendres les mesures qui s'imposent à cet égard. Nous avons entériné le rapport Brundtland aux Nations Unies et nous sommes fortement en faveur de la tenue en 1992, sous les auspices de l'ONU, d'une conférence mondiale sur le développement durable. Je suis heureux d'annoncer aujourd'hui que le Canada serait honoré d'accueillir la conférence de 1992 et que le gouvernement canadien serait heureux de contribuer à son organisation.

Vingt ans après la Conférence de Stockholm, cinq ans après le rapport Brundtland et le Protocole de Montréal, la conférence de 1992 sera pour la communauté internationale une occasion cruciale de faire le bilan des progrès réalisés et l'analyse des efforts déployés à l'égard des problèmes environnementaux d'intérêt mondial. Au moment de la conférence de 1992, nous devrions être en mesure de conclure un accord international sur le droit de l'atmosphère, ou du moins de nous entendre sur les éléments d'un tel accord. Car, en diplomatie comme en politique, il n'y a rien de tel qu'une date limite pour forcer l'esprit à se concentrer.

Nous avons travaillé de concert avec la communauté internationale pour jeter les bases de ce qui deviendra peut-être un jour, espérons-le, un droit international de l'atmosphère. Le premier accord international a été le Protocole d'Helsinki sur les pluies acides. Le deuxième a été le Protocole de Montréal destiné à réduire de moitié les émissions de produits chimiques qui attaquent la couche d'ozone.

Je suis heureux de vous signaler que le principal instrument législatif dont le Canada a besoin pour mettre en oeuvre touts les phases de ce Protocole, la Loi canadienne sur la protection de l'environnement, recevra bientôt la sanction royale. Nous allons ensuite ratifier le Protocole de Montréal, devenant ainsi le cinquième signataire à le faire. Conscients des mises en garde de la science, qui signale la nécessité d'une réduction de 85 p. 100, nous favoriserons l'adoption des règlements qui interdiront tous les usages non essentiels de CFC et de halons.

L'automne prochain, les pays d'Europe et d'Amérique du Nord signeront sans doute un protocole d'entente pour la réduction des oxydes d'azote, autre élément du droit international qui s'élabore à l'égard de l'atmosphère. Nous avons besoin de nouveaux instruments juridiques de ce genre pour que la protection et la réhabilitation du système atmosphérique essentiel à la vie fassent l'objet d'une coopération mondiale. Vos délibérations sur de tels régimes internationaux seront cruciales. Les résultats de vos travaux constitueront le point de départ d'une réunion de suivi, qui se tiendra au Canada au début de l'an prochain, entre des juristes et des experts internationaux en droit de l'atmosphère qui se pencheront plus particulièrement sur la question du changement climatique.

Le Canada s'est empressé de réagir aux recommandations de la Commission Brundtland en mettant sur pied, par l'entremise de ses ministres fédéral et provinciaux de l'Environnement, un groupe de travail multipartite sur l'environnement et l'économie. Des dirigeants de nos plus grandes industries ainsi que des universitaires et des environnementalistes ont travaillé avec nos ministres de l'Environnement afin de dégager un consensus sur les mesures à prendre dans ce domaine, et leurs recommandations ont été approuvées par les onze premiers ministres du Canada en novembre dernier. L'une de leurs principales recommandations était que les gouvernements améliorent le processus de décision.

Je voudrais annoncer aujourd'hui un plan d'action qui nous aidera à prendre de meilleures décisions en intégrant les facteurs économiques et les facteurs environnementaux :

- Premièrement, pour améliorer les décisions à l'échelon national, nous avons l'intention d'appliquer une des recommandations centrales du groupe de travail, soit la création d'une table ronde nationale multisectorielle appelée à élaborer des stratégies d'intégration des décisions d'ordre économique et d'ordre environnemental dans notre pays.
- Deuxièment, le principe du développement durable deviendra une préoccupation majeure dans différents ministères du gouvernment fédéral.

Il existe indéniablement un rapport entre l'activité économique et la dégradation de l'environnement, mais c'est dans le secteur énergétique que ce rapport devient le plus évident et le plus inquiétant. Le Canada entend appliquer les principes du développement durable face aux besoins énergétiques de demain.

- Troisièmement, le gouvernement fédéral tient à ce que les citoyens canadiens puissent faire des choix qui respectent l'environnement, tant dans leurs foyers que dans leurs milieux de travail. C'est ainsi que nous avons mis sur pied le tout premier système qui rend compte de l'état de l'environnement, un système sur lequel veille un comité consultatif de citoyens et qui est protégé par la loi.

Nous allons aussi aider les consommateurs à identifier plus facilement les produits qui sont inoffensifs pour l'environnement. Les produits et les procédés qui conservent l'énergie, les produits qui sont recyclés ou recyclables, biodégradables et exempts de toute substance dangereuse pour la couche d'ozone seront identifiés par un logo canadien distinctif.

Je voudrais parler brièvement de la menace du changement climatique mondial et de la nécessité de trouver une solution équitable à l'endettement du Tiers-Monde. Ce n'est pas une simple questions d'altruisme. Il y va de notre propre intérêt. Si les nations endettées des tropiques cessaient de raser leurs forêts tropicales pour en tirer des recettes d'exportation destinées au service de leur dette, les pays industrialisés en profiteraient aussi. Si l'on ralentissait l'accumulation des dioxydes de carbone, les pays développés auraient la latitude dont ils ont grand besoin pour ajuster leurs choix énergétiques en fonction d'une moindre dépendance à l'égard des carburants fossiles.

Le Canada est déterminé à travailler avec les nations en développement pour trouver des solutions à leur énorme endettement. L'an dernier, nous avons fait grâce aux nations les plus pauvres d'Afrique de 670 millions $ de dettes liées à l'aide au développement. Au Sommet de Toronto la semaine dernière, les dirigeants des autres grandes démocraties industrialisées se sont aussi engagés dans cette voie. Il faut envisager à cet égard des programmes d'ajustment structurel, ainsi qu'un rééchelonnement de la dette ou un consortium de financement, sans perdre de vue l'objectif d'un développement durable.

Le Canada souscrit aussi à une étude de faisabilité sur la création d'une banque mondiale de la conservation qui travaillerait de concert avec la Banque mondiale. C'est là une recommandation originale de la Commission Brundtland qui mérite toute notre considération. Il est déjà encourageant que la Banque mondiale ait accepté récemment d'incorporer le principe du développement durable dans ses politiques et ses programmes.

L'ACDI fait aussi du bon travail, notamment en Afrique de l'Ouest. L'an dernier, par exemple, j'au vu à l'oeuvre au Sénégal un important projet de reboisement qui permet de reprendre au désert des terres fertiles qu'il avait envahies.

Nous croyons qu'il n'y a pas de limites à la croissance économique, à part celles qui sont imposées par notre propre imagination, mais nous nous rendons bien compte qu'il y a des limites réelles aux systèmes et aux ressources naturels. Il ne s'agit pas que de notre atmosphère ou de notre environnement, mais bien de l'avenir de la planète même.

Et pour apporter des solutions valables aux problèmes environnementaux, il ne suffit pas de mener des recherches et de produire de l'information; il faut aussi qu'il y ait partout dans le monde des hommes et des femmes qui fassent preuve d'initiative et de leadership politique. Nous avons besoin du genre de vision qu'a manifesté le Premier ministre Brundtland. Nous avons besoins du genre de vision mondiale qu'avait le père fondateur de mon parti et de notre pays. Sir John A. Macdonald a été le premier homme politique canadien à comprendre l'importance de protéger l'environnement. Il y a un peu plus d'un siècle, en 1885, il a créé le premier parc national du Canada à Banff en Alberta. Et en 1887, à Last Mountain Lake en Saskatchewan, il a créé la première réserve faunique jamais aménagée en Amérique du Nord, refuge qui est devenu une aire de reproduction internationale pour les oiseaux aquatiques migrateurs. À cette époque, l'Ouest canadien était une terre de pionniers, un territoire encore vierge en quête de peuplement. L'environnement n'était pas encore un enjeu électoral, mais Sir John A. Macdonald a alors fait preuve du même genre de vision qu'au moment de la fondation du pays. Aujourd'hui, les questions environnementales nous concernent tous directement, car nous appartenons tous à une seule et même famille humaine.

Je tiens à vous remercier de l'intérêt que vous manifestez pour cette Conférence et du travail que vous y accomplirez. Soyez assurés que le gouvernment et le Premier ministre du Canada sont tout à fait conscients des problèmes de l'environnement et qu'ils sont résolus à faire leur part pour les résoudre. Le gouvernement du Canada et ceux du monde entier attendent avec impatience les recommandations que vous leur soumettrez.

OUR COMMON FUTURE - A CLIMATE FOR CHANGE

The Honourable Gro Harlem Brundtland
Prime Minister of Norway

As we near the end of the twentieth century, humanity faces a crucial question: Will we devote our abilities, our energy, and our efforts to further short-term material well-being, or will we commit ourselves to enhancing life on planet earth? Many of us are convinced what our choice should be. Millions more will have to follow.

"Our Common Future", the report of the World Commission on Environment and Development is the political consensus of commissioners from 21 countries. Through a broad process of experience, learning and debate we arrived at a common analysis of the global issues we all face.

Canada was one of the Commission's midwives, one of its strongest political supporters. Few other countries have contributed so greatly to the report as Canada; Commissioner Maurice Strong and the Commission's Secretary General Jim MacNeill brought all their vast experience, dedication and knowledge and helped decisively to forge "Our Common Future", its analysis and its call for action. And Canada reacted most strongly and positively to our report, not least by establishing the Task Force on Environment and Economy, a unique body in modern policy-making.

It is therefore with a sense of profound gratitude that I have come to Canada to address this conference, which could prove to be one of the most important conferences of the 1980s. I thank the Canadian people and institutions who supported us. I thank the Canadian government, in particular Prime Minister Mulroney and Minister of the Environment McMillan for their commitment and for the example they have been setting for other industrialized countries.

Our Common Future has analysed the threats to environment and to development. And our analysis is clear. Present trends and policies cannot continue. They will destroy the resource base on which we all depend.

Poverty continues to tie hundreds of millions of people to an existence that cannot be reconciled with human dignity and the need for solidarity. And in a world where poverty is endemic, the environment and natural resources will always be prone to overuse and degradation.

Many of the threats to the environment are truly global in scale and raise crucial questions of planetary survival. The complexity, the magnitude and the apparent irreversibility of these trends surpass all previous conceptions.

Our Commission found that there is no contradiction between environment and development. Environmental degradation and the unequal distribution of wealth and power are different aspects of the same set of problems.

Changes must be made if disastrous mistakes are to be avoided, but we also believe that it is possible to make these changes. Human resources, knowledge and capabilities have never been greater. We have the power to create a future that is more prosperous, more just and more secure for all.

Time has come to start the process of change. We in the North have a special responsibility. For too long have we neglected that we have been playing lethal games with vital life-support systems.

- For too long have we used the atmosphere, soil and water as the ultimate sink of our industrial excesses.
- For too long we have disregarded the warning that global heating caused by industrial emissions may disturb the global climate, and agricultural and settlement patterns.
- For too long we have overlooked the devastating effects of acidification, of overuse of chemical products and pesticides.
- For too long we have exported our first generation of environmental problems to the Third World and maintained an economic system that leads to environmental decline in developing countries.

It is time that we realize that we all share a common future. Maybe it is the notions, North, South, East and West that lure many into believing that we may choose to separate ourselves in a world that has become so interconnected. The need to take a holistic view of the world is becoming more and more obvious day by day.

Take the drought in Africa. Is it a separate climatic phenomenon? Is it due to agricultural practices? What are the impacts of the world economic system? How much is man-made, and who are the people who make it?

We need new concepts, and new values to mobilize change. What we call for is a new global ethic.

We need a new political approach to environment and development, where economic and fiscal policies, trade and foreign policies, energy, agriculture, industry and other sectoral policies all aim to induce development that it not only economically but also ecologically sustainable.

We need to create more awareness and to mobilize people in all corners of the globe and in all walks of life. We need to have a sense of mission and to offer a common framework and a vision for a better future.

The Commission defines the overriding political concept of sustainable development as such a common framework, as a broad concept for social and economic progress and change.

Sustainable development as defined by the Commission requires a fairer distribution of wealth within and among countries. It requires political reforms, fair access to knowledge and resources, and real, popular participation in decision-making.

Sustainable development recognizes that there are thresholds imposed by nature, but not limits to growth itself. Forceful economic growth is the only feasible weapon in the fight against poverty. And only economic growth can create the capacity to solve environmental problems.

However, the contents of growth must be changed. Growth cannot be based on overexploitation of resources. Growth must be managed to enhance the resource base on which we all depend.

In order to change the contents of growth, fundamental changes in the international economy are necessary. We in the industrialized countries will play a critical role. We will have the responsibility of ensuring that the world economy enhances rather than hinders the potential for sustainable development.

Less than a week ago here in Toronto, the Economic Summit for the first time endorsed the concept of sustainable development. That decision brings new hope and belief in international cooperation, not least for the Third World.

In the 1980s, however, the developing countries have witnessed a reversal of the earlier hopeful trends in growth performance globally. Sharp deterioration in the international economic environment has played by far the major role in triggering the acute crisis that now afflicts the Third World.

Indicators of this critical situation are unsustainable, crushing burdens of external debt; the substantial decline in export earnings due to acutely depressed commodity prices and increasing protectionism; the steeply declining flows of resource transfers; and the chronic instability of the international currency market, as well as the abnormally high real interest rates.

In this harsh reality, developing countries have had little alternative but to tax their natural resources, often beyond the limits of recovery, to get funds to service foreign debt, not to speak of their futile efforts to maintain necessary imports. It is absurd that Africa is transferring more to the industrialized countries than it receives.

These trends will now have to be reversed, not only because the situation is in itself unacceptable, but also because it is in the self-interest of the developed countries.

Isn't it a perverse situation that there is a net transfer of resources from the poor countries to the rich, which over the past few years have totalled over a hundred billion dollars? Isn't it appalling that while close to a billion people are living in poverty and squalor, the per capita income of about 50 developing countries declined last year?

There is a need for a fresh impetus in international cooperation. Development aid and lending must be increased, and the debt crisis must be resolved. The ultimate goal must be to forge an economic partnership based on equitable trade and to achieve a new era of growth, one that enhances the resource base rather than degrades it. The mission must be to make nations return to negotiations on the global issues after years of decline in real multilateralism. The decisions at the summit bring new hope that this may soon happen.

The theme of this conference may have a mission far beyond its stated topic. It may be an awareness-creator. It may erect a pillar of wisdom in the much needed global educational campaign on environment and development. It may finally open our eyes to the fundamental fact that the earth is one even if the world of man is still divided. The atmosphere knows no boundaries. We cannot act as if nature does.

For too long we have thought of the atmosphere as a limitless good. We have been burning fuel and emitting pollutants, pressing aerosol buttons, and blowing foam to our heart's content.

But recently we have begun the painful process of discovering our past mistakes. We are struggling with the costs of acidification, and with the complexities of dealing with NO_x. We are now realizing that we may be on the threshold of changes to our climate, changes that are so extensive and immediate that they will profoundly affect the life of the human race.

While theories about the physical effect of CO_2 on the climate were presented more than a hundred years ago, what is new is the certainty that it will happen unless we take decisive corrective action now!

As far back as 1969 we in Scandinavia discovered that the acidification of our lakes and rivers was related to growing sulphur emissions in central Europe. Today acid rain has become a major environmental issue in Europe and North America, and a rapidly growing threat in other parts of the world. Canada, we all know, has been on the receiving end for years.

When the Convention on transboundary air pollution was adopted in 1979 after long years of struggle for necessary support, and then followed in 1985 by the protocol on 30% reduction of sulphur emissions, the problems seemed to be manageable. The control technologies were known and widely available.

With nitrogen oxides, however, the problem has proved to be far more complex. The number of sources is greater. Abatement measures, although known and tested for a number of years, have, in the case of mobile sources, severe drawbacks.

Even so, a NO_x protocol for the ECE region will be signed later this year. The first step includes a commitment to freeze total NO_x emission in ECE countries before the end of 1994. The second step contains an obligation to renegotiate the first step six months after the protocol enters into force, using nature's own absorptive capacity as a basis for negotiations.

The regional acidification problem has proved to be more and more complicated while scientific knowledge has matured. The lesson we are learning in the ECE region should sound an alarm in other parts of the world. It is essential that such air pollution problems be dealt with in all regions. They cannot wait until the damage is as widespread as in the ECE regions. By then it may be too late.

In 1974, when scientists put forward the theory that chlorofluorocarbons could destroy our globe's protective ozone layer, they could not point to actual damage. On the contrary, they thought that any damage that might appear would not occur before the next century. Research showed that once released there was no way for the atmosphere to recover. And it would take many years from the time of release until the actual damage appeared.

The news of the ozone hole over Antarctica changed attitudes in many countries. If we were to protect future generations from ever-increasing amounts of harmful ultraviolet radiation, we had to take corrective action. We had to, and in fact we did, give nature the benefit of the doubt.

General adherence to the Montréal protocol is needed. The European Community in particular has a special responsibility. I am pleased to announce that today, in New York, Norway is ratifying this milestone in international cooperation.

Yet there are indications that the situation is more serious than ever. Recent scientific findings show that the ozone layer has been depleted over the Northern Hemisphere as well. We cannot ignore this evidence. Stronger measures are clearly called for. Steps must be taken now to secure a new commitment when we revise the protocol in 1990.

We know from our Norwegian action plan that about 90% of our national CFC consumption can be eliminated before 1995 without disrupting the economy. In fact the cost in Norway of such reductions is estimated at around 8 dollars a year per capita. We in the developed countries: how can we even discuss whether we can afford it. We have no choice.

The awareness of the threat of climate change has increased significantly since international work on the ozone layer started. It is popular to talk about the "greenhouse effect", but shouldn't we talk about the "heat trap" instead?

We know now that not only CO_2 but a number of other gases as well contribute to global heating. Presently these other trace gases cause one third of the total global warming. And unless something is done, their contribution in the next 50 years will double the effect of CO_2.

Scientists still have no unanimous view on the magnitude of the climate change problem, but it is established beyond any doubt that we <u>will</u> experience a global change in climate. An average global temperature increase over the next 50 years of 1.5 to 4.5 degrees Celsius is enormous. It took between 10,000 and 20,000 years for the world's temperature to increase about 5 degrees. The impact of climatic change <u>may</u> be greater and more drastic than any other challenges that mankind has faced with the exception of the threat of nuclear war.

The effects on the whole ecological balance will be drastic. The time span needed for plants to adjust to a new climate is normally hundreds of years. The deserts will expand. The crops in today's marginal areas will be lost. Extremes of weather - storms, rainfalls, frost or heat - may become more common. The sea-level may rise 1 metre or more, and with one third of the world's population living in low-lying coastal areas, such a development would have dramatic consequences. Political stability may be threatened in many parts of the world, and the number of ecological refugees may increase. In sum, climatic change will affect us all profoundly, regardless of where we live. And as always, the poorest countries will be the ones most severely affected.

All of this may not happen, or not that severely. But the potential risks are so high that we cannot sit back hoping that problems will go away. We are the ones who must take the initiatives. We must set the limits and we must prevent the potential disasters for the sake of future generations, from whom we have borrowed this earth.

The time has come to develop an action plan for protecting the atmosphere. Acid rain, depletion of the ozone layer and climate change are not separate problems. They are strongly interlinked with each other. We have come to a threshold. If we cross this threshold, we may not be able to return.

For our common future, drastic action has to be taken. My question is: Will the improved relations between East and West release the human and financial potential that will be needed to address these common challenges? Will internationalist endeavours prevail over narrow-mindedness? Will hostile attitudes to internationally negotiated arrangements and institutions yield to a coalition of reason? In 1988, when it was decided to dismantle the INF-missiles, when President Reagan and General Secretary Gorbachev walked the red square together, will we be able to deal with vital issues of environment and development, in a real climate for change?

As one step towards reaching that goal together - I propose an international action plan for protecting the atmosphere and, in particular, for preventing climate change.

1. Firstly, we should launch immediate international discussions on the feasibility of adopting regional strategies for stabilizing and reducing energy consumption and use, before the end of the century.

If we are serious in our attempts, we must be prepared to tackle the myth that energy consumption must be allowed to grow unchecked. In Norway we have considered our options very carefully. We are now aiming at a stabilization in energy consumption by the year 2000.

A second step should aim at altering the composition of energy use and at reducing energy consumption to reduce environmental costs. Important means might be to implement correct energy pricing, including environmental costs, and to tap the potential of energy efficient technologies and conservation measures.

A change in Norwegian production and consumption patterns will only contribute marginally to solving the global problem. Presently, developing countries must be allowed time for adaption and the chance to increase their consumption. Industrialized countries have a special obligation. We must be the first to change our production and consumption patterns.

Our readiness to do so will be the acid test that will indicate to the developing countries that the industrialized countries are serious about their responsibilities.

2. Secondly, we should establish a comprehensive international research and information program on renewable energy.

The Commission recommended that renewable energy should form the foundation of the global energy structure during the twenty-first century.

An international research and information programme should be set up. It should provide information about availability, regularity, efficiency and the costs involved.

3. Thirdly, we should establish an extensive technology transfer programme with particular emphasis on the needs of the developing countries.

Funds must be forthcoming to help developing countries choose a safe and sustainable energy pathway. Easy access to modern and low polluting technologies is vital to all countries, and especially to the developing countries.

Unless developing countries are given access to clean technologies, we will all have to deal with the consequences.

4. Fourthly, we must increase scientific research.

Several international scientific programmes have already been established, including those under the framework of WMO and UNEP. It is vital that such scientific programmes are open for participation from all countries, and that countries are urged to join international scientific programmes.

The effects of climate change on global and regional scales should be a priority topic for a specific programme.

5. Fifthly, we should consider establishing a global convention on the protection of the climate to coordinate scientific activity, technology research and transfer, information exchange and concrete measures to reduce the emissions of harmful substances.

Mr. Chairman,

The themes I have addressed are critical for Our Common Future. To secure that future we must take action, even before we have full knowledge of the problems we are dealing with. The task is huge. The action I have outlined is the minimum response required. The setting is urgent. The threats are real.

We have come to a point in the history of nations when we can no longer act primarily as citizens of any single nation state. We are irreversibly entangled in the same destiny, but together we also have enormous possibilities.

We stand at a cross-roads in the evolution of the political culture of humankind. About 40-70 thousand years ago humankind took up its struggle with the biosphere; 200 years ago we seemingly gained the upper hand in that struggle. Now it is time to take a giant leap forward in the upgrading of civilization.

NOTRE AVENIR A TOUS - UN CLIMAT PROPICE AU CHANGEMENT

Premier ministre
Gro Harlem Brundtland

Au moment où le vingtième siècle tire à sa fin, l'humanité se trouve confrontée à un choix crucial : continuerons-nous de consacrer notre talent, notre énergie et nos efforts à l'amélioration à court terme de notre bien-être matériel, ou nous engagerons-nous à promouvoir la qualité de la vie sur la planète Terre? Nous sommes nombreux à avoir fait notre choix. Des millions d'autres devront nous suivre.

Le rapport "Notre avenir à tous" de la Commission mondiale sur l'environnement et le développement a fait le consensus politique des délégués de 21 pays. Tirant parti de notre expérience et de nos connaissances, nous sommes parvenus après avoir débattu la question à analyser en commun les problèmes mondiaux auxquels nous faisons tous face.

Le Canada a été l'un des partenaires de la Commission, l'un de ses plus grands appuis politiques. Peu d'autres pays ont collaboré de si près à l'établissement du rapport. Par leur vaste expérience, leur dévouement et leurs connaissances, le commissaire Maurice Strong et le secrétaire général de la Commission, Jim MacNeill, ont contribué de façon décisive à l'élaboration du rapport "Notre avenir à tous", à l'analyse qui en a été faite et à l'appel à l'action qui s'est ensuivi. La réaction du Canada a été énergique et déterminée, comme en fait foi la mise sur pied du Groupe d'étude sur l'environnement et l'économie, organisme dont le rôle en matière d'élaboration de politiques n'a pas son pareil.

C'est donc animée d'un sentiment de gratitude profonde que je suis venue au Canada m'adresser à cette assemblée, qui pourrait se révéler l'une des plus importantes conférences des années quatre-vingt. J'aimerais remercier le peuple et les organismes canadiens qui nous ont apporté leur soutien. Je voudrais remercier le gouvernement canadien, et plus particulièrement le premier ministre, Brian Mulroney, et le ministre de l'Environnement, T.M. McMillan, pour leur engagement et l'exemple qu'ils donnent aux autres pays industrialisés.

Nous avons analysé dans notre rapport les menaces qui pèsent sur l'environnement et le développement. Et nos conclusions sont on ne peut plus claires. Nous ne pouvons poursuivre les tendances et les politiques actuelles, car nous allons détruire les ressources fondamentales dont nous sommes tous tributaires.

La pauvreté continue de maintenir des centaines de millions de gens dans un état qu'on ne peut concilier avec la dignité et la solidarité humaines. Dans un monde où la pauvreté est endémique, l'environnement et les ressources naturelles seront toujours sujets à la surexploitation et à la dégradation.

Bon nombre des menaces qui pèsent sur l'environnement ont définitivement une portée internationale et soulèvent des questions cruciales pour la survie de la planète. La complexité, l'ampleur et l'apparente irréversibilité de ces tendances surpassent tout ce que nous avions pu imaginer.

La Commission ne voit pas de contradiction entre l'environnement et le développement. La dégradation de l'environnement et la répartition inégale de la richesse et du pouvoir ne sont que des aspects différents du même problème.

Des changements s'imposent si l'on veut éviter des erreurs désastreuses, et nous croyons qu'il est possible de réaliser ces changements. Les ressources, les connaissances et les capacités de l'homme n'ont jamais été aussi grandes. Nous avons le pouvoir de créer un avenir plus prospère, plus juste et plus sûr pour tous.

Le temps est venu d'enclencher ce processus de changements. Le Nord a une responsabilité spéciale à cet égard. Il y a trop longtemps que nous fermons les yeux devant les jeux dangereux que nous imposons à des systèmes indispensables à la vie.

- Il y a trop longtemps que nous déversons nos déchets industriels dans l'atmosphère, le sol et l'eau.
- Il y a trop longtemps que nous faisons la sourde oreille au cri d'alerte voulant que la chaleur dégagée à l'échelle mondiale par nos émissions industrielles risque de bouleverser le climat, l'agriculture et le peuplement de la planète.
- Il y a trop longtemps que nous ignorons les effets dévastateurs de l'acidification, de l'utilisation massive de produits chimiques et de pesticides.
- Il y a trop longtemps que nous exportons aux pays du Tiers-Monde nos problèmes environnementaux de première génération et que nous maintenons en place un système économique qui favorise la dégradation de l'environnement dans les pays en voie de développement.

Il est temps de réaliser que nous partageons tous le même avenir. Les notions de Nord, de Sud, d'Est et d'Ouest ont pu égarer bon nombre d'entre nous et nous faire croire que nous pouvions nous diviser dans un monde où tout est si étroitement lié. La nécessité d'adopter une vue holistique du monde est de jour en jour de plus en plus évidente.

Prenons la sécheresse en Afrique. S'agit-il d'un phénomène climatique isolé? Les méthodes d'agriculture en sont-elles la cause? Quels sont les effets du système économique mondial? Quelle fraction de ces effets sont un produit de l'homme et quels en sont les responsables?

Nous avons besoin de nouveaux concepts et de nouvelles valeurs pour mettre en train les changements voulus. Il nous faut une nouvelle éthique mondiale.

Il nous faut adopter une nouvelle approche politique en ce qui concerne l'environnement et le développement. Nos politiques économiques et fiscales, nos politiques commerciales et étrangères, nos politiques relatives à l'énergie, à l'agriculture, à l'industrie et à d'autres secteurs d'activités doivent toutes viser un développement non seulement économique, mais aussi écologiquement viable.

Nous devons sensibiliser davantage la population et mobiliser des gens dans tous les coins de la planète et dans tous les domaines d'activité. Nous avons besoin de nous définir une mission, de jeter les bases d'une structure commune et d'offrir une vision d'un avenir meilleur.

Pour la Commission, le concept politique capital du <u>développement durable</u> constitue une telle structure, un concept général du progrès et de l'évolution social et économique.

Tel que défini par la Commission, le concept du développement durable requiert une distribution plus équitable des richesses à l'intérieur d'un même pays et entre les différents pays. Ce concept nécessite des réformes politiques, un accès équitable aux connaissances et aux ressources, et la participation véritable de la population aux décisions.

Le principe du développement durable reconnait qu'il y a des seuils imposés par la nature, mais qu'il n'y a pas de limite à la croissance. La seule arme véritable dont nous disposons pour combattre la pauvreté est de privilégier une croissance économique énergique. Seule la croissance économique peut nous donner les moyens de résoudre nos problèmes environnementaux.

Mais il nous faut modifier la teneur de cette croissance. La croissance ne peut reposer sur la surexploitation des ressources. Elle doit plutôt viser à améliorer les ressources fondamentales dont nous sommes tous tributaires.

Pour modifier la teneur de la croissance, il nous faut apporter des changements fondamentaux à l'économie internationale. Les pays industrialisés ont un rôle important à jouer à ce chapitre. Nous avons la responsabilité de voir à ce que l'économie mondiale accroisse au lieu de freiner le potentiel du développement durable.

Il y a moins d'une semaine les participants au Sommet économique de Toronto ont entériné pour la première fois le concept du développement durable. Cette décision est le gage d'un nouvel espoir et d'une confiance renouvelée dans la coopération internationale, surtout en ce qui concerne le Tiers Monde.

Toutefois, au cours des années quatre-vingt, les pays en voie de développement ont vu s'évaporer les espoirs fondés sur les tendances antérieures en matière de croissance mondiale. La détérioration marquée qu'a subi le milieu économique international a été de loin le facteur le plus important dans le déclenchement de la crise aiguë qui secoue actuellement le Tiers-Monde.

On peut voir des indices de cette situation critique dans le poids insoutenable de la dette extérieure, la diminution substantielle des revenus tirés de l'exportation, qu'on attribue à la baisse marquée du prix des produits et à la hausse du protectionnisme, la chute vertigineuse des transferts de ressources, l'instabilité chronique du marché international des devises et le taux anormalement élevé de l'intérêt réel.

Cette dure réalité ne laisse d'autre choix aux pays en voie de développement que de grever leurs ressources naturelles, souvent jusqu'au point de non-retour, de se procurer des fonds pour amortir la dette extérieure, sans parler des efforts futiles qu'ils font pour maintenir un taux minimum d'importation. Il est absurde que l'Afrique transfère plus de ressources aux pays industrialisés qu'elle n'en reçoit de ces derniers.

Il faut renverser ces tendances, non seulement parce que la situation est devenu inacceptable, mais également parce qu'il en va de l'intérêt des pays nantis.

N'est-il pas aberrant de constater que les pays pauvres transfèrent nettement plus de ressources aux pays riches que ceux-ci ne le font envers eux, et que la somme de ces transferts a atteint plus de cent milliards de dollars au cours des dernières années? N'est-il pas révoltant que le revenu par habitant de quelque 50 pays en voie de développement ait accusé une baisse l'année dernière, alors que près d'un milliard de gens vivent dans la pauvreté et la misère?

Il faut donner une impulsion nouvelle à la coopération internationale. Il faut accroître les prêts et l'aide au développement, et résoudre la crise de l'endettement. Le but ultime doit être de bâtir une association économique fondée sur des échanges équitables et d'instaurer une nouvelle ère de croissance, qui améliore les ressources fondamentales au lieu de les dégrader. La mission poursuivie doit être de restaurer les négociations entre les pays sur les questions d'intérêt mondial aprés des années marquées par le déclin du véritable multilatéralisme. Grâce aux décisions prises au Sommet, nous avons bon espoir d'atteindre sous peu cet objectif.

La mission qui se dégage de la présente conférence pourrait bien avoir de plus grandes implications que le thème ne le laisse supposer. Il pourrait bien s'agir d'engendrer une prise de conscience, d'insuffler un vent de sagesse dans l'indispensable campagne internationale sur l'environnement et le développement. Enfin, de reconnaitre la vérité fondamentale que la planète ne forme qu'une seule entité, même si les hommes sont toujours divisés. De même que l'atmosphère, la nature ne connaît pas de frontières et, cela, ne l'oublions pas.

Nous avons trop longtemps considéré l'atmosphère comme une ressource illimitée. Nous consommons du combustible et c'est à coeur joie que nous émettons des polluants dans l'atmosphère et que nous pulvérisons des produits sous forme d'aérosol et de mousse.

Mais nous avons commencé récemment à nous pencher douloureusement sur nos erreurs passées. Nous sommes aux prises avec les coûts de l'acidification et la complexité du problème des oxydes d'azote (NO_X). Nous réalisons que notre climat est sur le point de changer et que ces changements sont si vastes et si soudains qu'ils vont altérer profondément la vie de la race humaine.

Même si les théories sur les effets de l'anhydride carbonique (CO_2) sur le climat ont été diffusées il y a plus de cent ans, nous savons maintenant qu'à moins de prendre immédiatement des mesures correctives décisives ces effets vont se réaliser.

Dès 1969, nous avons découvert que l'acidification de nos lacs et de nos rivières en Scandinavie était liée aux émissions croissantes de soufre en Europe centrale. Les pluies acides constituent aujourd'hui un problème environnemental de taille en Europe et en Amérique du Nord, et un spectre qui menace de plus en plus les autres parties du globe. Nous n'ignorons pas que le Canada figure depuis des années au rang des victimes.

Lorsque la Convention sur la pollution atmosphérique transfrontière a été adoptée en 1979 après de longues années passées à obtenir l'appui nécessaire, suivie en 1985 par la signature du protocole sur la réduction de 30 % des émissions de soufre, le problème ne semblait pas insoluble. Les techniques de contrôle étaient connues et facilement accessibles.

Cependant, les oxydes d'azote ont compliqué sensiblement le problème. Il y a un plus grand nombre de sources d'émission. Bien que les mesures de réduction soient connues et qu'elles aient été mises à l'épreuve depuis plusieurs années déjà, elles ne sont pas tout à fait efficaces pour contrer les sources d'émission mobiles.

Malgré tout, un protocole sur le contrôle des oxydes d'azote dans la région de la CEE sera signé au cours de l'année. Les pays de la CEE s'engagent dans un premier temps à stabiliser les émissions totales d'oxydes d'azote d'ici la fin de 1994. Dans un deuxième temps, les pays sont tenus de renégocier les premiers termes du protocole six mois après son entrée en vigueur, en se fondant sur la capacité d'absorption de la nature.

Plus nous étendons le champ de nos connaissances scientifiques, plus le problème de l'acidification régionale nous parait complexe. Les leçons que nous tirons de notre expérience dans la région de la CEE devraient donner l'alarme dans d'autres régions du monde. Il est essentiel que toutes les régions s'attaquent au problème de la pollution atmosphérique. Elles ne peuvent s'offrir le luxe d'attendre que les dommages soient aussi répandus que dans les pays de la CEE. Il sera peut-être alors trop tard.

Lorsqu'en 1974 des scientifiques ont avancé la théorie que les chlorofluorocarbones pouvaient détruire la couche d'ozone protectrice de la planète, ils ne pouvaient démontrer que des dommages avaient été effectivement causés. Au contraire, ils croyaient qu'aucun dommage ne se manifesterait avant le vingt et unième siècle. Les recherches indiquaient qu'une fois que des chlorofluorocarbones avaient été relâchés dans l'atmosphère, le mal était fait. Par contre, les dommages réels n'apparaitraient qu'au bout de nombreuses années.

Bon nombre de pays changèrent d'attitude lorsqu'on apprit qu'il y avait un trou dans la couche d'ozone au-dessus de l'Antarctique. Si nous voulions protéger les générations futures de rayonnements ultraviolets nocifs toujours plus nombreux, il nous fallait prendre des mesures correctrices. Nous nous devions de laisser le bénéfice du doute à la nature. Et c'est ce que nous avons fait.

Il est essentiel que le respect du Protocole de Montréal se généralise. La Communauté européenne a notamment une responsabilité particulière à cet égard. J'ai le plaisir d'annoncer que la Norvège ratifie aujourd'hui, à New York, cette convention importante pour la coopération internationale.

Pourtant, il semblerait que la situation soit plus grave que jamais. De récentes études scientifiques concluent que la couche d'ozone s'est également amincie au-dessus de l'hémisphère Nord. Nous ne pouvons négliger ce fait. Il ne fait pas de doute que des mesures plus énergiques s'imposent. Il nous faut prévoir dès maintenant les nouvelles mesures que nous voulons mettre en oeuvre lorsque nous réviserons le Protocole en 1990.

Nous savons, d'après notre plan d'action en Norvège, qu'il est possible d'éliminer environ 90 % de la consommation nationale de chlorofluorocarbones d'ici 1995, sans que l'économie en souffre. En fait, le coût de ces réductions en Norvège a été estimé à environ 8 dollars par an par habitant. Comment les pays nantis peuvent-ils hésiter à prendre ces mesures alors qu'ils en ont parfaitement les moyens? Nous n'avons pas le choix.

Depuis que des recherches sur la couche d'ozone ont été entreprises à l'échelle internationale, les gens sont de plus en plus conscients des risques présentés par le changement climatique. Nous entendons souvent parler de l'"effet de serre", mais il serait peut-être plus juste de parler d'un "piège thermique".

Nous savons maintenant que le réchauffement de la planète est attribuable non seulement à l'anhydride carbonique, mais également à bien d'autres gaz. Ces autres gaz à l'état de traces causent à l'heure actuelle un tiers du réchauffement total de la planète. Si nous n'agissons pas, l'effet de ces gaz doublera celui de l'anhydride carbonique au cours des 50 prochaines années.

Les scientifiques ne sont toujours pas unanimes sur l'ampleur de ces changements climatiques, mais ils sont absolument sûrs que le climat de la planète subira effectivement des changements. Une augmentation de la température moyenne de la planète de 1,5 à 4,5 degrés Celsius au cours des 50 prochaines années est un changement énorme si l'on pense qu'il a fallu entre 10 000 et 20 000 ans pour que la température de la planète s'élève d'environ 5 degrés. Les effets du changement climatique pourraient être plus importants et plus graves que tous les autres spectres que l'humanité a dû affronter, exception faite de la menace d'une guerre nucléaire.

La modification du climat aura des effets considérables sur l'équilibre du milieu écologique. Il faut normalement des centaines d'années pour que les plantes s'adaptent à un nouveau climat. La désertification s'intensifiera. Les récoltes dans les régions actuellement marginales disparaîtront. Les conditions météorologiques extrêmes, comme les tempêtes, la pluie, le gel ou la chaleur, risquent de devenir plus courantes. Le niveau de la mer pourra s'élever d'un mètre ou plus, ce qui aura des conséquences désastreuses puisqu'un tiers de la population du globe vit près des côtes, sur des terres basses. Il se peut que la stabilité politique soit menacée dans de nombreuses régions du monde et que le nombre des réfugiés écologiques s'accroisse. Bref, la modification du climat nous touchera tous intensément, peu importe l'endroit où nous vivons. Et comme toujours, les pays les plus pauvres seront les plus durement touchés.

Toutes ces prévisions peuvent ne pas se produire ou la situation sera peut-être moins sombre. Mais les risques sont si élevés que nous ne pouvons pas attendre que les problèmes disparaissent d'eux-mêmes. C'est à nous de prendre l'initiative. Nous devons fixer les limites et empêcher que les générations futures, au nom de qui la planète nous a été prêtée, ne se trouvent confrontées à des désastres.

Le temps est venu d'élaborer un plan d'action pour protéger l'atmosphère. Les pluies acides, l'affaiblissement de la couche d'ozone et les changements climatiques ne sont pas des problèmes isolés, mais sont intimement liés entre eux. Nous sommes parvenus à un seuil. Si jamais nous franchissons ce seuil, nous risquons de ne plus pouvoir revenir en arrière.

Pour le bénéfice de notre avenir à tous, nous devons prendre des mesures énergigues. La question que je me pose est si l'amélioration des relations entre l'Est et l'Ouest engendrera le potentiel humain et financier nécessaire pour surmonter ces problèmes communs? L'internationalisme l'emportera-t-il sur l'étroitesse d'esprit? L'hostilité manifestée à l'égard des ententes et des institutions internationales fera-t-elle place à une coalition sensée? En cette année 1988, au cours de laquelle on a pris la décision de démanteler les missiles de portée intermédiaire et pendant laquelle le président Reagan et le secrétaire général Gorbachev ont arpenté ensemble la Place Rouge, serons-nous en mesure de venir à bout des problèmes vitaux qui touchent l'environnement et le développement, dans un monde véritablement propice au changement?

Pour que nous fassions un premier pas vers la réalisation de cet objectif, je propose l'établissement d'un plan d'action international visant à protéger l'atmosphère et, notamment, à prévenir la modification du climat.

1. Premièrement, nous devrions entamer des discussions internationales afin d'étudier l'éventualité d'adopter des stratégies régionales pour stabiliser et réduire la consommation d'énergie d'ici la fin du siècle.

Si nous prenons la question au sérieux, nous nous attaquerons au mythe selon lequel il ne faut pas freiner la consommation d'énergie. En Norvège, nous avons étudié très attentivement les choix qui s'offraient. Nous prévoyons à l'heure actuelle être en mesure de stabiliser notre consommation d'énergie d'ici l'an 2000.

Une deuxième mesure consisterait à modifier la composition de l'énergie utilisée et à diminuer notre consommation d'énergie dans le but de réduire les coûts associés à l'environnement. Les principaux moyens pour parvenir à cette fin pourraient être de déterminer correctement les prix de l'énergie, y compris les coûts liés à l'environnement, et d'exploiter tout le potentiel de la technologie énergétique et des mesures d'utilisation rationnelle de l'énergie.

La modification des modes de production et de consommation d'énergie en Norvège ne serait qu'une infime partie de la solution du problème global. Il importe à l'heure actuelle de laisser aux pays en voie de développement le temps de s'adapter et de leur donner la chance d'accroitre leur consommation. Les pays industrialisés ont un devoir spécial : celui d'être les premiers à modifier leurs modes de production et de consommation.

Notre empressement à agir fera la preuve aux pays en voie de développement que les pays industrialisés prennent leurs responsabilités au sérieux.

2. Deuxièmement, nous devrions mettre en oeuvre à l'échelle internationale un programme de recherche et d'information complet sur les énergies renouvelables.

La Commission recommande que les énergies renouvelables forment la base du système énergétique mondial au cours du vingt et unième siècle.

Un programme de recherche et d'information international devrait voir le jour. Ce programme fournirait de l'information sur les ressources disponibles, leur régularité, leur efficacité et leurs coûts.

3. Troisièmement, nous devrions mettre sur pied un programme intensif de transfert de technologie axé principalement sur les besoins des pays en voie de développement.

Il faut libérer des fonds afin d'aider les pays en voie de développement à choisir une voie énergétique sûre et durable. Il est primordial que tous les pays, et notamment les pays en voie de développement, aient facilement accès à une technologie moderne et peu polluante.

Si les pays en voie de développement n'ont pas accès à une technologie propre, nous en subirons tous les conséquences.

4. Quatrièmement, nous devons accroitre la recherche scientifique.

Plusieurs programmes scientifiques internationaux ont déjà été mis sur pied, notamment dans le cadre de l'OMM et du PNUE. Il est essentiel que tous les pays puissent participer à ces programmes scientifiques internationaux et qu'on les exhorte à le faire.

Un de ces programmes devrait traiter en priorité des effets du changement climatique à l'échelle mondiale et régionale.

5. Cinquièmement, nous devrions envisager de créer une convention mondiale sur la protection du climat grâce à laquelle nous pourrions coordonner les activités scientifiques, la recherche, les transferts de technologie, l'échange d'information et la prise de mesures concrètes, et ce dans le but de réduire l'émission de substances toxiques.

Monsieur le Président, les thèmes que je viens d'aborder ont une importance cruciale pour notre avenir à tous. Il nous faut, pour assurer cet avenir, prendre des mesures, même si nous ne maitrisons pas parfaitement les problèmes auxquels nous sommes en butte. L'entreprise est de taille. Les mesures que j'ai esquissées représentent une intervention minimale. La situation est urgente. La menace est réelle.

Nous sommes rendus à un point de notre histoire où nous ne pouvons plus agir uniquement en notre qualité de citoyens d'un pays donné. Nous sommes irréversiblement enchainés à une même destinée, mais ensemble nous avons des possibilités énormes.

Nous sommes parvenus à un tournant de l'évolution de la culture politique de l'humanité. Il y a 40 000 à 70 000 ans, l'homme commençait son combat contre la biosphère. Il y a 200 ans, nous avions apparemment le haut du pavé. Il est maintenant temps de faire un pas de géant dans la marche de la civilisation.

CLOSING ADDRESS

The Honourable Tom McMillan, P.C., M.P.
Minister of the Environment, Canada

Mr. Chairman, distinguished colleagues, ladies and gentlemen, friends.

I address you now as the final speaker of what has been a landmark conference. For four days, we have discussed, virtually non-stop, the great issues confronting humanity while the last decade of the twentieth century approaches. By any standard, the conference has been successful. Never before have so many well-informed people from so many different backgrounds been brought together in one place to wrestle with such a complete agenda of environmental issues.

The success of our efforts owes much to the meticulous and creative work of the Planning Committee, headed by Canada's chief meteorologist, Howard Ferguson. On behalf of all of you, I thank them and the members of the Secretariat as well. I pay particular tribute to a special person whose conference, in many ways, this is. I refer to Diane MacKay, a senior employee of Environment Canada. She provided leadership for the conference until her untimely death last July. The memory of that outstanding public servant continues to inspire those of us who worked with her.

The United Nations Environment Programme and the World Meteorological Organization - which supported our conference - also deserve thanks. Finally, allow me to express my heartfelt appreciation to Ambassador Stephen Lewis. He brought to the chair the human qualities that make him one of Canada's most respected public figures - eloquence, compassion, ability and sensitivity, not to mention commitment and resolve. Now, if he were only a Progressive Conservative, he would be perfect!

The sheer number and quality of the participants have set our Conference apart from most others. The outcome set it apart from all others. Those of you who brought your knowledge to bear on the complex subjects at hand have rendered great service to the world community. It remains to be seen whether your progress was a one-conference wonder or a stride towards securing the future of the planet.

Gary Larson, creator of the syndicated Far Side cartoon, captured, I think, the essence of our situation. He envisioned a conference theatre much like this one filled with dinosaurs at convention. From the podium, one dinosaur addressed the assemblage. "Delegates," he said, "the outlook is bleak. We face extinction, an ice age is advancing, meteorites threaten our planet; and we have a brain the size of a walnut."

At our own Conference, we, too, are telling ourselves the outlook is bleak. But we have one advantage over the dinosaurs: our brain is not the size of a walnut; it is nature's highest achievement. Unlike that of the dinosaurs, our brain is capable of logic, reason, foresight and judgment.

Will we use those faculties to ensure our survival? The answer has yet to be given. But, at this Conference, at least the question has been asked. The task ahead is to provide the answer. And to ensure that it is yes.

Although we might need to know more about some details, the problem itself is clear enough. For the first time in history, the human species is fundamentally altering the conditions for life on the planet. Human forces - once overwhelmed by nature - now are nature's match. Through fossil fuels and nuclear power, people spread more energy than the sun. Through agriculture, people erode more soil than nature. Through forestry, people eradicate more trees than fire, disease and pests combined. People spoil more water than the planet can naturally replenish. When we are not skinning the planet alive, we are choking and drowning it.

Certainly, the chemistry of the earth's atmosphere is being profoundly changed. Three phenomena have drawn particular concern at this Conference: ozone depletion, global warming and acid rain. In the first case, we are attacking the thin layer of gases around the earth that protects the human race and all other life forms from the most lethal of the sun's rays. In the second case, the buildup of CO_2 and other greenhouse gases are trapping heat near the earth, causing the atmosphere to warm - with potentially devastating effects. In the third case, we are acidifying vast areas of the planet.

Billions of years ago, the earth was a hostile place. Through evolution, it has become the hospitable planet we know it to be. Human interference in our time threatens to make our world once again a barren space. Our planet does not support a rich and complex web of life because it is ideally suited to that purpose. It is ideally suited to that purpose because of the rich and complex web of life. Without the moderating effects of vegetation, of gas exchanges and of the recycling of materials conducted by billions of invertebrates, the planet earth would be as unlikely a site for the Garden of Eden as the planet Mars. For 200 years, we have been conquering nature. Now we are beating it to death. But that victory is as temporary as it is pyrrhic.

In the early days of the environmental movement, a popular bumper sticker warned: "Nature Bats Last". Humankind may exploit the environment and, even for a time, subdue it. But ultimately, nature does bat last. Life-threatening increases in ultra-violet radiation, global warming and acidification show Mother Nature at the plate.

The problems we have focused on at this Conference will compromise the health and quality of life not only of future generations but also of all of us. In fact, the effects are already being felt. Problems that just a few years ago appeared speculative must now be recognized for what they are - reality.

Part of the reality is that environmental problems can no longer be viewed as exclusively domestic. The major threats have, in every case, global implications. If not every country is a villain, every country is definitely a victim. Just as the problems are global, so also must be the solutions. And yet we have not developed the instruments required to deal globally with the consequences of such problems, let alone to prevent them in the first place.

Progress in the last year, however, gives us cause to believe the world community is capable of seeing beyond national borders. The report of the World Commission on Environment and Development, released a year ago, was itself an exercise in global vision. The Montréal Protocol, concluded in September, demonstrated that countries with very different ideologies and economic interests can agree on actions to combat a common threat - ozone depletion. One week ago, in this very convention complex, the leaders of the world's seven wealthiest western countries agreed upon an unprecedented statement of environmental principles, including sustainable development. What is more, they signalled that the environment-economy partnership will be on their agenda at future summits. This Conference accelerates the momentum. The 35 members of the Economic Commission for Europe have laid the groundwork for a historic international protocol to freeze nitrogen oxide emissions that contribute to ground-level ozone, to acid rain and to global warming. The agreement may well be signed in October. Each of those events was significant in its own right. Cumulatively, they were impressive. None, however, was more than a step in the right direction. And even together, they do not bring us far enough.

An ancient Chinese proverb goes something like this: "If we don't change our course, we will end up where we're headed." Ladies and gentlemen, we do not want to be where we're headed. This past year, we have been trying to change our course. We must complete the change and follow the new direction.

The famous dictum of René Dubos - "think globally, act locally" - is even more relevant today than when he first said it a decade and a half ago. Sluggish progress on the international front is no excuse for inaction within our respective countries, any more than lack of progress by national governments justifies complacency in individuals. Action is required at all levels.

For our part, we Canadians consistently rank the environment among the three most urgent issues facing the country. And our federal and provincial governments are, finally, beginning to respond. It is as though they are saying, to paraphrase Mahatma Gandhi: "We must catch up to our people, for we are their leaders." It was heartening for all of us at this Conference to see not one, Prime Minister, but two, in addition to numerous other senior policy makers. In his opening address to the Conference on Monday, Prime Minister Brian Mulroney indicated that his government's Environmental Protection Act would likely become law this week. Since then, that key legislation was given Royal Assent. Today, it has been proclaimed into law. Among other things, it gives to the Canadian government the various authorities required to implement the Montréal Protocol. I am pleased to announce that, at the United Nations in New York, even as I speak, Canada is ratifying the Ozone Protocol, becoming the fourth country to do so.

As important as the domestic agenda is to us, we Canadians consider global environmental issues equally urgent. Indeed, the two are inextricably linked in this era when most forms of pollution carry no passport, bow to no nation's flag, respect no boundary. By the same token, the felling of tropical forests in countries thousands of miles from our own shores is, ultimately, as much an assault against our environment as it is against theirs. If those forests are the lungs of the planet, they are our lungs, too. We recognize that the rapid devastation of the earth's tropical forests will not abate until the root economic causes are addressed. If impoverished nations are forced to devour their resources merely to put bread on the table and heat on the hearth, environmental theology from the wealthy nations will not blunt the environmental assault. The vicious circle in which less developed countries find themselves - resource depletion because of poverty; poverty because of resource depletion - must be broken. And we in the mink and caviar part of the world must help break that vicious circle.

This past year alone, Canada has forgiven \$670 million in development debt owed by some of the poorest nations in Africa. But such is a pebble on the beach in the context of total debt. Just as the Marshall Plan rebuilt the war-shattered economies of Europe, so also we need a global plan to rebuild the debt-shattered economies of the less developed countries.

One of our Conference sessions recommended a world atmosphere fund for that very purpose. We need more such creative thinking. But, for any approach to work, it must reflect a genuine partnership among all concerned. However noble the goal, the tropical forest countries must not have things done to them; they must be helped to do things for themselves. In fact, co-operation must characterize the relationship between rich and developing countries on all global environmental problems.

I said earlier, this must not be allowed to stand as a one-conference wonder. The Government of Canada is passionately committed to the concept of an International Law of the Air. It would tie together, and build on, milestone agreements like the nuclear weapons test-ban treaty, the Helsinki Accord and the Montréal Protocol. Canada hopes the world community will accept our invitation to come here in 1992 both to advance the Law of the Air and to take stock of sustainable development around the world. Meanwhile, early next year, we will host a meeting of international legal experts to follow up on the work of this week's Conference.

But let me stress that, committed as we are to the Law of the Air concept, we will support any effective global instrument to achieve our common purpose. Whether our approach is a global warming convention called for by Prime Minister Brundtland or a broader international law of the air envisioned by Prime Minister Mulroney, the objective remains the same: a better way to a safe world. This week in Toronto, humanity has done much to help achieve that goal. Now, let's complete the job.

ALLOCUTION DE CLÔTURE

L'honorable Tom McMillan, C.P.
Député, ministre de l'Environnement du Canada

Monsieur le Président, distingués collègues, mesdames, messieurs, chers amis.

Je suis le dernier à m'adresser à vous au cours de cette Conférence qui fera date dans l'histoire. Depuis quatre jours, nous discutons presque sans interruption des grandes questions auxquelles l'humanité se heurte à l'approche de la dernière décennie du vingtième siècle.

Cette Conférence a été un succès à tout point de vue. Jamais auparavant autant de gens bien informés, venus d'horizons si divers, ne s'étaient trouvés réunis pour débattre d'une gamme aussi complète de questions environnementales.

Le succès de nos efforts est attribuable en grande partie au travail méticuleux et novateur du comité de planification, dirigé par le météorologue-en-chef du Canada, Howard Ferguson. En votre nom à tous, je remercie les membres du comité et les membres du secrétariat.

Je tiens à rendre hommage à quelqu'un dont on peut dire que la Conférence est son oeuvre. Je veux parler de Diane MacKay, cadre d'Environnement Canada, responsable de la Conférence jusqu'à son décès prématuré en juillet dernier. Le souvenir de cette fonctionnaire exceptionnelle continue à inspirer ceux qui ont travaillé avec elle.

Je tiens aussi à remercier le Programme des Nations Unies pour l'Environnement et l'Organisation météorologique mondiale, qui nous ont fourni pour cette Conférence leur précieux concours.

Permettez-moi enfin d'exprimer ma sincère reconnaissance à Monsieur l'ambassadeur Stephen Lewis. Il a su montrer les qualités humaines qui ont fait de lui l'une des personnalités les plus respectées du Canada : éloquence, compassion, compétence et sensibilité; sans oublier son engagement et sa détermination. Il ne lui manque plus que d'être Progressiste Conservateur pour être parfait!

Le nombre et la qualité des participants distinguent cette Conférence de la plupart des autres. Les conclusions la distinguent de toutes les autres. Ceux d'entre vous qui ont mis tout leur savoir aux sujets abordés ont rendu un service considérable au monde.

Il reste à voir si ce progrès restera sans lendemain ou si, selon l'intention du gouvernement du Canada, il aura été le premier pas dans la bonne direction pour assurer l'avenir de la planète.

Gary Larson, le créateur du dessin humoristique intitulé "The Far Side", a bien capturé, je crois, l'essence de notre situation.

Il a imaginé une salle assez semblable à celle où nous sommes, peuplée de dinosaures réunis en congrès. De la tribune, un dinosaure s'adresse à l'assemblée.

"Chers délégués," dit-il, "l'avenir est sombre. L'extinction nous guette, la glaciation approche, les météorites menacent de détruire notre planète et nous avons un cerveau gros comme une noisette."

Ici, à cette Conférence, nous disons nous aussi que l'avenir est sombre. Nous avons un avantage sur les dinosaures cependant : notre cerveau n'est pas de la taille d'une noisette, il est même ce que la nature a fait de mieux. Contrairement à celui des dinosaures, notre cerveau fait de nous des êtres doués de logique, de raison, de jugement et capables de prévoir.

Utiliserons-nous ces facultés au bénéfice de notre survie? La question reste posée. Mais du moins, l'a-t-elle été. Trouver la réponse : voilà la tâche qui nous attend. Et surtout, faire en sorte que la réponse soit positive.

Nous pourrions bien avoir besoin de connaître la question plus en détail, mais le problème lui-même est assez clair. Pour la première fois dans l'histoire, l'espèce humaine modifie fondamentalement les conditions de vie sur la planète. L'humanité - jadis écrasée par la nature - est maintenant de taille à lutter contre elle. En utilisant les combustibles fossiles et la force nucléaire, nous dépensons plus d'énergie que le soleil. Par l'agriculture, nous causons davantage d'érosion que la nature elle-même. Par notre exploitation forestière, nous supprimons plus d'arbres que le feu, la maladie et les ravageurs réunis. Nous gaspillons plus d'eau que la planète n'en peut fournir naturellement.

Nous écorchons la planète vive, ou bien nous l'étouffons, ou bien nous la noyons.

A coup sûr, la chimie de l'atmosphère est profondément modifiée. Trois phénomènes ont particulièrement retenu notre attention : l'appauvrissement de la couche d'ozone, le réchauffement mondial et les précipitations acides.

Dans le premier cas, nous attaquons la fine couche de gaz qui entoure la terre et protège la race humaine et toutes les autres formes de vie des rayons solaires les plus nocifs.

Dans le deuxième cas, l'accumulation de gaz carbonique et des autres gaz à effet de serre retient la chaleur près de la terre, ce qui réchauffe l'atmosphère, et risque d'avoir des conséquences dévastatrices.

Enfin, nous acidifions de vastes régions de la planète.

L'humanité semble enfin comprendre que notre planète n'est pas intrinsèquement hospitalière. Ce n'est pas parce qu'elle est parfaitement adaptée que notre planète porte un réseau de vie riche et complexe. C'est en raison du réseau de vie qu'elle porte qu'elle est parfaitement adaptée à son but. Sans l'effet modérateur de la végétation, des échanges gazeux et du recyclage des matériaux mené par des milliards d'invertébrés, la terre ressemblerait aussi peu au paradis que Mars.

Dès les débuts du mouvement écologique, un auto-collant qui a connu beaucoup de succès disait : "La nature a le dernier mot". L'humanité peut exploiter l'environnement et, même, un certain temps, le conquérir. Mais en fin de compte, c'est bien la nature qui a le dernier mot. Et c'est son tour maintenant, comme le montre la menace que posent l'accroissement du rayonnement ultra-violet, le réchauffement mondial et l'acidification.

Les problèmes sur lesquels nous avons concentré notre attention ici vont compromettre non seulement la santé et la qualité de la vie des générations à venir, mais aussi les nôtres. En fait, les conséquences se font déjà sentir. Les problèmes qui, il y a quelques années encore, semblaient hypothétiques, ne peuvent plus désormais être pris pour autre chose que la réalité.

Nous ne pouvons plus non plus considérer nos problèmes environnementaux comme des questions qui ne regardent que nous. Les menaces les plus sérieuses ont chaque fois des implications mondiales. Tous les pays ne sont peut-être pas coupables, mais tous sont bel et bien des victimes. Pour régler des problèmes mondiaux, il faut des solutions mondiales. Mais nous ne disposons même pas des outils voulus pour trouver une solution aux conséquences mondiales, et encore moins pour prévenir les problèmes.

Cependant, les progrès accomplis l'année dernière nous donnent à croire que le monde est capable de voir par-delà les frontières nationales. Le rapport de la Commission mondiale sur l'environnement et le développement, publié voilà un an, avait des visées mondiales. Le Protocole de Montréal, conclu en septembre dernier, a démontré que même lorsqu'ils prônent des idéologies diverses et ont des intérêts économiques différents, les pays peuvent s'entendre sur des mesures à prendre pour combattre une menace commune : en l'occurrence, la destruction de l'ozone.

La semaine dernière, dans ce même Palais des congrès, les dirigeants des sept pays occidentaux les plus riches se sont mis d'accord sur une déclaration sans précédent de principes environnementaux qui tiendraient compte d'un développement durable. Qui plus est, ils ont mentionné que l'association environnement-économie serait à l'ordre du jour des prochains sommets.

L'environnement gagne du terrain sur la scène mondiale et la Conférence le prouve. Les trente-cinq pays de la Commission économique pour l'Europe ont préparé le terrain en vue d'un protocole international historique visant à freiner les émissions d'oxyde d'azote qui contribuent au réchauffement de la planète, à la formation de l'ozone en surface et aux précipitations acides. L'entente pourrait être signée en octobre. Chacun de ces événements a une certaine importance. Mais pris ensemble, ils sont impressionnants. Chacun pourtant n'est qu'un pas dans la bonne direction. Et même ensemble, ils ne nous mènent pas encore assez loin.

Un ancien proverbe chinois dit à peu près ceci : "Si nous ne redressons pas le cap, nous ferons fausse route." Mesdames et messieurs, nous ne voulons pas faire fausse route. Depuis un an, nous essayons de changer de cap. Nous devons poursuivre la manoeuvre et maintenir la nouvelle direction.

La phrase célèbre de René Dubois, "Penser à l'échelle mondiale, agir à l'échelle locale" prend encore plus de sens aujourd'hui qu'elle n'en avait il y a quinze ans. La lenteur des progrès sur le front international ne justifie nullement l'inaction dans nos pays respectifs. De même, l'inaction des gouvernements ne peut justifier la complaisance des particuliers. Il faut agir à tous les niveaux.

Quant à nous, Canadiens, nous plaçons régulièrement l'environnement parmi les trois questions les plus urgentes auxquelles le pays doit s'attaquer. Et les gouvernements se mettent enfin à réagir. C'est comme s'ils disaient, pour paraphraser le mahatma Ghandi : "Il nous faut rattraper notre peuple. Nous sommes les dirigeants." Il a été très réconfortant de voir à la Conférence non pas un premier ministre mais deux, en plus des nombreux autres hauts responsables.

Dans son discours d'ouverture lundi, le Premier ministre du Canada, a signalé que la <u>Loi sur la protection de l'environnement</u>, présentée par son gouvernement, serait sans doute promulguée cette semaine. Ayant depuis reçu l'assentiment royal, elle a été, en fait, promulguée aujourd'hui. Entre autres choses, Le gouvernement canadien est maintenant investi du pouvoir nécessaire pour mettre le Protocole de Montréal en application. J'ai le plaisir d'annoncer qu'aux Nations Unies, à New-York, au moment même où je vous parle, le Canada est en train de ratifier le Protocole sur l'ozone, ce qui fait de lui le cinquième pays à agir ainsi.

Les questions environnementales internes ont beau avoir de l'importance pour nous au Canada, nous considérons les questions mondiales tout aussi urgentes. En fait, les deux sont intimement liées, à notre époque où la plupart des formes de pollution ne s'embarrassent pas de passeport, ne s'inclinent devant aucun drapeau, ne respectent aucune frontière.

De même, l'abattage des forêts tropicales dans des pays situés à des milliers de milles de nos côtes est, en fin de compte, une agression contre notre propre environnement au même titre que contre celui des pays intéressés. Si ces forêts sont les poumons de la planète, elle nous font respirer nous aussi.

Nous reconnaissons que la rapide dévastation des forêts tropicales ne diminuera que lorsque l'on s'attaquera aux causes économiques premières. Si les nations appauvries sont forcées d'engloutir leurs ressources naturelles uniquement pour pouvoir nourrir et chauffer leur population, ce ne sont pas les discours environnementaux des pays riches qui arrêteront cet assaut.

Il faut briser le cercle vicieux dans lequel se trouvent pris les pays en voie de développement : destruction des ressources imposée par la pauvreté; pauvreté entraînée par la destruction des ressources.

Et nous qui sommes les favorisés du monde, nous devons contribuer à briser le cercle vicieux.

L'année dernière, le Canada a effacé des dettes de 670 millions de dollars qui frappaient quelques-unes des nations les plus pauvres d'Afrique. Mais en regard de la dette totale, ce n'est là qu'une goutte d'eau dans la mer. Tout comme il a fallu le plan Marshall pour rebâtir l'économie des pays d'Europe anéantie par la guerre, il nous faut aussi un plan mondial pour rebâtir l'économie anéantie par les dettes des pays les moins développés.

La création d'un fonds mondial pour l'atmosphère a été proposée pendant la Conférence. Nous avons besoin de ce genre d'idées novatrices. Mais pour qu'une méthode réussisse, quelle qu'elle soit, elle doit refléter une véritable association de tous les intéressés. Aussi noble que soit l'objectif, il ne faut pas agir à la place des pays à forêt tropicale, il faut les aider à agir eux-mêmes.

En fait, la coopération sur tous les problèmes environnementaux mondiaux doit caractériser la relation entre pays riches et pays en voie de développement.

J'ai dit plus tôt qu'il ne fallait pas que cette conférence reste sans lendemain. Le gouvernement du Canada défend avec passion le concept d'un droit international de l'atmosphère. Un tel droit viendrait s'ajouter à des accords fondamentaux comme le Traité sur l'interdiction des essais nucléaires, l'Accord d'Helsinki et le Protocole de Montréal.

Le Canada espère que la communauté mondiale acceptera notre invitation à la recevoir en 1992 pour faire progresser l'idée d'un droit de l'atmosphère et faire le point sur l'évolution vers le développement durable.

Entre temps, au début de l'année prochaine, nous accueillerons une assemblée d'experts juridiques internationaux pour poursuivre le travail de la Conférence de Toronto.

Mais je tiens à souligner que nous défendons si ardemment l'idée du droit de l'atmosphère que nous appuierons tout moyen efficace d'atteindre un objectif commun. Qu'il s'agisse d'une convention sur le réchauffement mondial comme le demande le premier ministre Brundtland ou d'un droit de l'atmosphère de plus grande portée, comme l'envisage le premier ministre Mulroney, l'objectif demeure inchangé : trouver une meilleure façon de protéger notre planète.

Nous avons deux options : ou faire comme si les problèmes n'existaient pas et accepter le sort de l'humanité, ou agir maintenant et sauver notre avenir à tous. Cette semaine à Toronto, des hommes et des femmes du monde entier ont choisi la voie de la survie.

Alors, mettons-y tous du nôtre.

DINNER ADDRESS

The Honorable Timothy E. Wirth
U.S. Senate, Washington, D.C., U.S.A.

Prime Minister Brundtland, Minister McMillan, Ambassadors, Friends, I am delighted to be here in Toronto tonight.

The timing of this conference on "The Changing Atmosphere" could not be better. Several events have occurred during the past two weeks that have moved the greenhouse effect into the forefront of scientific and public policy debate. In particular, the drought that is ravaging vast segments of the American agricultural community is forcing our people to think about climate, global warming and the greenhouse effect. The topic is even hotter than the Tyson-Spinks fight, rumors of Governor Dukakis's running mate, or even the most recent advice of Nancy Reagan's astrologer.

Agricultural leaders are faced with what, in all likelihood, will be the most devastating drought in U.S. history, surpassing the Dust Bowl days of the 1930s. The most productive soils and some of the mightiest rivers on earth are literally drying up. Already, more than 50% of the wheat, barley and oat crops in parts of the great American plains have been destroyed and the situation could get much worse. Last week, the Mississippi River sank to the lowest point ever recorded. And in my home state of Colorado, snow pack flows are among the lowest on record and reservoir levels are alarmingly low.

As widely reported in the press, Dr. James Hansen, the Director of NASA's Goddard Institute for Space Studies, and one of the world's leading climatologists, testified last week at another in a series of hearings we have held in the Senate Energy and Natural Resources Committee, and which I was again privileged to chair. Dr. Hansen had an ominous new warning. According to his studies, we now can say, with 99% certainty, that the greenhouse effect is upon us and that events such as the North American drought are increasingly likely to occur.

Dr. Hansen's stunning and broadly quoted testimony revealed that during the first five months of this year, the earth is warmer than it has been during any comparable period since measurements began 130 years ago. Dr. Hansen also testified that 1988 will be the warmest year on record and that the four previous records all occurred during the 1980s.

The press of events continues; less than two weeks ago, the European Economic Community approved a program to control emissions of chlorofluorocarbons. And members of the Japanese Diet told me this morning that their legislature has just approved the Montréal Protocol, and Japan will soon join the United States and Mexico in ratifying that treaty. Our host, Canada, will ratify the treaty this week, and Norway presented their ratification to the United Nations today.

Several weeks ago, the World Meteorological Organization and the United Nations Environment Programme issued an important joint report on climate change. Their report confirms that we face a problem of potentially enormous dimensions.

The result of all of these developments is that the debate on this issue has passed from a small community of dedicated scientific researchers to the world's decision-makers. With events converging at such a rapid pace, concerns about global warming among policy makers will grow each day. The issue is as hot as the American Midwest.

My message to you tonight is simple and urgent. It is time for the nations of the world to act. This urgency is felt on the Floor, in the cloakrooms, and in the Committees of the United States Senate.

Senators of both political parties are aggressively investigating the entire issue of climate change. A number of committees are examining the growing buildup of greenhouse gases in the atmosphere, and the depletion of the ozone layer, and before long I believe that we will see hearings in the Agriculture Committee and the Space Committee as well. Congress is starting to move, and I can detect not only deep concern but widespread agreement on a number of issues. For example, the Senate unanimously ratified the Montréal Protocol on Ozone Depleting Substances. The drought, coupled with Dr. Hansen's testimony last week, has sparked an explosion of interest among my Senate colleagues and other government policy-makers.

The Senate Energy and Natural Resources Committee, of which I am a member and where I have the lead responsibility for fashioning our policies on global warming, has a special interest in this issue. Our committee maps the future of government-owned fossil fuel resources, selects energy research and development priorities, and provides an overall regulatory framework for U.S. energy policy. The central response to the greenhouse effect will involve fundamental changes in the way the United States and - if we fashion our coordinated strategy properly - all the nations of the world craft energy policy. Our committee also has responsibility for creating and overseeing our system of National Parks and Wildlife Preserves. For decades, our country's policy has been to maintain our finest natural areas "in perpetuity for future generations". Now we must ask ourselves if global warming will devastate our nation's finest natural treasures, which are a key part of the legacy we leave to future generations.

That is why I called for hearings to examine the Bellagio findings and to examine the relationship between the current drought and the greenhouse effect. Unfortunately, we no longer have to wait for a doubling of CO_2 to observe the phenomenon of early snowmelt and rapid loss of soil moisture in the mid-continent. It is occurring now in the corn belts of Canada and the United States. And, as all of our witnesses testified, the probability of such occurrences has been increased by the emission of greenhouse gases into the environment.

Whether or not the drought of 1988 is itself the direct result of greenhouse warming is irrelevant: it demonstrates the vulnerability of North America's breadbasket to climate change. And it provides us with a very good picture of what the world of the future might look like. The 1988 drought is a warning we must heed. The speed of the agricultural collapse, and the escalation of food prices in the United States over recent weeks, are clear indicators of the power of sudden climate changes.

As I read it, the evidence from the world's leading scientists is compelling: the global climate is changing while the earth's atmosphere gets warmer. Assessments of the greenhouse effect and its far-reaching consequences, developed over the past 10 years, have all reached the same scientific conclusion. Reports by the U.S. Environmental Protection Agency and the National Academy of Sciences in 1983 are similar to the Villach Statement of 1985 and Atmospheric Ozone, 1985 published by the World

Meteorological Organization. The fundamentals of the greenhouse problem have remained consistent for a decade, and similar results have been found independently in Boulder, Colorado, East Anglia, England, and in research conducted in the U.S.S.R.

The trend is both troubling and reassuring: reassuring, because it lowers the uncertainty of the need for major policy choices - it is certain that we must change course; troubling because the implications of the greenhouse effect are so vast. I hope that history will record that at the end of the twentieth century, mankind recognized and began to meet its greatest environmental, economic and political challenge.

Without recognition and action, we will continue on a course that is rapidly and fundamentally altering the composition of the atmosphere. By doing nothing we risk the planet's future. We must change directions.

Our short-term objective must be to slow the rate of change of the atmosphere. Political leadership is needed now at the highest levels to halt the global experiment that is currently under way. The governments of both industrialized and developing nations must begin now to implement policies to deal with this enormous environmental problem.

In March of this year I joined 41 of my colleagues in urging President Reagan to raise the greenhouse issue first with General Secretary Gorbachev in Moscow and then at the Seven-Nation Economic Summit held last week here in Toronto. Specifically, we urged President Reagan to:

> "...call upon all the nations of the world to begin the negotiation of a convention to protect our global climate...Such a convention could address our scientific understanding of the problem, the need for and limits of adaptation as a response to future climate change, as well as strategies to stabilize atmospheric concentrations of greenhouse gases at safe levels."

This idea was endorsed this morning by Prime Minister Brundtland, as well as by our host and good friend, Prime Minister Brian Mulroney.

I am pleased to report that the first meetings of a year-long cooperative program between the U.S. and the U.S.S.R. took place last month. And while we must step up our efforts among all countries, and should establish such a greenhouse convention, we can immediately take a number of other steps that make sound public policy sense.

The <u>first</u> is for all signatory nations, joining to Canada, Mexico, Norway and the U.S., to ratify the Montréal Protocol on Substances that Deplete the Ozone Layer. CFCs account for 15 to 20% of the greenhouse warming of the 1980s. This agreement is an important but very modest first step. When the parties to the Montréal Protocol reconvene next year, they should place at the top of their agenda plans to urgently work with our industries to develop and market economic and efficient substitutes, and to entirely phase out CFCs by the year 2000, if not sooner.

A <u>second</u> step should be the completion of the nitrogen oxide, or NO_x protocol now being negotiated under the direction of the United Nations. Ozone in the troposphere acts as a greenhouse gas. Recent measurements indicate that tropospheric ozone levels are rising at 1% per year, in large part as a result of rising nitrogen oxide emissions. Since emissions are predicted to rise rapidly, the NO_x protocol is a very important global agreement to control the greenhouse effect. That opportunity is within weeks of fruition.

Third, we should immediately begin to reduce CO_2 emissions. The developed CO_2-producing nations should take the first step by agreeing to reduce CO_2 emissions by 20% by the year 2000.

The process of reducing emissions of greenhouse gases is going to be controversial and, no doubt, very painful for many nations. But as global warming trends continue, the major industrialized nations will have to collectively alter the ways in which we organize our societies and conduct our business in much more drastic ways.

Those same nations must provide guidance and assistance to developing nations. Economic development is consistent with protection of the earth's climate, so the industrialized nations must aggressively assist the non-industrialized nations to develop sustainable, energy-efficient, vibrant economies. Economic growth and energy efficiency can, and must, go hand in hand; in fact, done properly, economic development designed to be energy efficient will leave scarce resources available for other, non-energy investments.

All nations can begin now to make those changes needed to reduce CO_2 emissions that make sense in and of themselves. For example, improved energy efficiency is good environmental policy, good energy policy, good economic policy, and for the U.S., good for our national security.

The efficiency improvements the United States has made since 1973 have reduced CO_2 emissions by one third of what they would have been. But we still have a long way to go in reducing our energy costs, our CO_2 emissions and, I might add Mr. Minister, our contributions to the problem of acid rain. All of these steps we must and we will take. The United States can save more than $200 billion dollars on our annual energy bill by making energy efficiency improvements in the transportation, building and government sectors. Clearly, energy efficiency is an economic and environmental strategy that makes sense for all nations and we must make energy efficiency, once again, a top priority of our energy policy.

The major industrialized nations also should step up research and development programs for alternative sources of energy that will not contribute to emissions of greenhouse gases. Photovoltaic solar energy is one of the technologies that, again, has multiple benefits. Solar energy is environmentally benign and can be used to benefit the lives of citizens of the developing nations by providing flexible sources of electricity in crucial economic, health care and other sectors, especially in rural areas. We can also bolster the world's research and development efforts on wind energy and other renewables.

It is also time to re-examine the nuclear option in the U.S. We probably must start all over again with nuclear, strengthening our research efforts to see if we can develop a new generation of passively-safe, economical nuclear power plants. The nuclear question is one of the hard ones that we face. Just as those nations that have been talking about expanding the use of coal are going to have to be very careful, and become cleaner and more energy efficient now, those nations that have halted the nuclear option are going to have to reconsider. We must go into this debate with our eyes open. We must be prepared to tell the public and utilities that safety must be the highest priority - and we must re-establish in the United States a commitment to safety, quality and cost-effectiveness within the nuclear industry.

Fourth, the developed and developing nations must work together to halt the devastating rise in tropical deforestation, the other force driving increases in atmospheric CO_2 concentrations. More than 7.5 million hectares of closed forests and 3.8 million hectares of open forests are cleared in the tropics each year. Rapid rates of deforestation reduce carbon storage and increase the inventory of atmospheric CO_2.

For several years, conservationists have been urging the multilateral lending institutions to give much greater environmental scrutiny to loans to developing nations. All too often, these projects yield small economic benefits and very great environmental costs. International representatives to the multilateral lending institutions must exercise their responsibilities to ensure full consideration of the environmental impacts or projects before approving loans to developing nations. Further, the United States and other lending countries should expedite the use of debt instruments in exchange for preservation of rain forests - such a policy is good for everyone. Our goal should be sustainable economic development - and we must recognize that good environmental policy is good economic policy.

As an aside, I should add that we in the United States have to set a good example by halting the dreadful ripping down of the Tongass National Forest in Alaska - the last great rain forest in North America. On this and other issues, my government should proudly match its deeds with its words.

Fifth, we must prepare international institutions to help manage the greenhouse problem. We can begin by substantially strengthening the resources of the United Nations Environment Programme, the World Meteorological Organization, and the International Geosphere-Biosphere Programme. These and other international institutions will be vital to the process of building an international consensus on addressing the greenhouse effect in the future.

My last suggestion is to make a large and immediate investment in the scientific research and data collection that is needed to improve our knowledge of the global trends, source and removal processes of the greenhouse gases. Our insufficient understanding of the sources and sinks of methane, nitrous oxide and tropospheric ozone make it difficult to find a clear path to controlling these gases. There is a substantial scientific research agenda, but those investments must be made immediately to increase the precision of our response.

I do not hold out hope that reliable and uncontested predictions of climate change will be available to us in coming years - such as precise projections of climate patterns in the years 1990, 2020 and 2040. By the time we gain the absolute, incontrovertible evidence to confirm some of the staggering implications of global warming, it may be too late. We only know that the future holds more - not less - of the same. The fate of the earth's twentieth-first century global environment rests with us - and especially with the decisions we make to control the growth of greenhouse gases.

As I noted earlier, I have been asked to take the lead on this issue by Senator Bennett Johnston of Louisiana, the Chairman of the Energy Committee. His committee has the primary responsibility for crafting energy policy in the United States Senate. We held hearings last fall and again last week, and have been working with a variety of energy, environment and conservation groups. Out of these deliberations has come a comprehensive bill, which I will be introducing shortly after the fourth of July. Obviously we cannot outlaw global warming, but we can and must sharply increase our efforts in energy conservation and research, provide broader incentives for alternative energy sources, develop better data, examine the power of economic incentives for change, embark upon national and international efforts in reforestation, and challenge ourselves to a markedly stronger cooperative effort around the globe. I hope that we can have the benefits of your ideas and suggestions on this legislation, and I look forward to welcoming many of you as witnesses, participants, or observers during the course of our hearings this summer, this fall and beyond.

Further, it is imperative that as we in the United States build the foundation for national and international action, we do so based upon a strong coalition between the public and the private sectors. Our history tells us that this kind of cooperation ultimately makes our programs stronger and more successful. I can imagine that just as our government must start planning for a changing climate, so must such industries as insurance, agriculture, energy, aerospace, transportation, communications, finance, construction and recreation. There will be opportunities for individuals, corporations and governments to innovate, to mobilize and create new products and to adapt old products and services that will be economically important and promote the good of the global commons and the economic development of all nations.

While we forge unprecedented cooperative efforts between nations and between interests within those nations, our leadership will be tested as perhaps never before. I trust that we will be up to the challenge. To do so, we must have our constituencies with us. The size and scope of the global warming issue must be brought home to everyone on the globe. I hope we can do it before the crisis or tragedy of further drought, growing starvation, or coastal flooding bring what can be a gruesome message.

Perhaps we can learn from the experience of the Antarctic ozone hole. Hundreds of millions of the world's citizens became alarmed and called for action. Some have suggested that the alarm went off when Secretary Hodel called on us to don dark glasses, hats and suntan lotion. But fortunately the concern reaches much more deeply - our constituents understand that human beings are rearranging the planet's natural systems in dangerous and threatening ways.

They are <u>starting</u> to tell us that we must work together to reverse our current direction or we will have abdicated our opportunity to control the climate of the future.

Let me close by discussing some of my own history, and the legacy of those events that led to the creation of my home state, Colorado. Settlement of the American West was undertaken to fulfil the needs and aspirations of a growing young nation. Our nation mobilized to address those needs and aspirations by exploring new frontiers that would make life better for the next generation, as our forefathers had done for their children.

We have a similar responsibility for the future: to prevent the occurrence of dramatic climate change. We must forge new energy, economic and political changes, so that we have a chance of preserving the integrity of the global environment for future generations. The implications of global warming are so enormous that we have to consider what kind of world we will leave to our children's children and our great-great grandchildren and generations on into the more distant future.

Last year, one of our witnesses before the Senate told us that, "The inhabitants of the planet earth are quietly conducting a gigantic experiment. So vast and so sweeping will be its impacts that were it brought before any responsible council for approval, it would be firmly rejected as having potentially dangerous consequences. Yet the experiment goes on with no significant interference from any jurisdiction or nation".

This week, you, as Conference participants, must summon your collective resources to develop strategies for the nations of the world to instigate that "significant interference". Not only do you have a special opportunity but you also have an obligation to develop a global response to these daunting issues.

It is essential for all of us attending this Conference to clearly state the risks that confront us and to lay out the responses that we must pursue. And we must do it now. Thank you very much - we look forward to working with you all.

LUNCHEON ADDRESS

RESPONSIBLE CARE : FORMULA FOR OUR CHANGING ATMOSPHERE

David T. Buzzelli
President and Chief Executive Officer
Dow Chemical Canada Inc.

It is an honour to be asked to speak to you today about our changing global atmosphere - an issue we share as world leaders in government, industry, science and academia.

It is significant that leaders with various interests are meeting in an atmosphere of cooperation. Today there is a similar atmospheric change taking place in Canada. The atmosphere I am referring to is the cooperation between the chemical industry and our publics - how we are listening to and addressing their concerns.

That atmosphere is also exhibited by the Canadian National Task Force on Environment and Economy of which I am a member. It is the architect of Canada's response to the Brundtland Commission Report entitled "Our Common Future." When I was invited to serve on the Task Force, I admit I was apprehensive. The Task Force included six provincial ministers of the environment and the Honourable Tom McMillan, Federal Minister of the Environment, and our host today. In addition, there were seven representatives from industries including Alcan, Dow, Inco and Noranda, two environmental organizations and two associations. My first thought as I walked into the first meeting was there sure is an opportunity for conflict sitting in the room! Though the potential for the group to self-destruct was high, it did not. The reason - we agreed to focus our efforts on areas where we could agree instead of focusing on areas of disagreement. Surprisingly, we found many of these areas, including the basic premise of our report - that long-term economic growth depends on a healthy environment and conversely, that a healthy environment depends on economic development.

Sustainable development is the Brundtland Commission's term for this balance. It calls for global development that makes sure our use of resources and the environment today does not damage them for future generations. We must take this responsibility seriously if the world is to survive as the legacy of our children and grandchildren. The Canadian Chemical Producers' Association, or CCPA, has embarked on this journey through an industry-wide commitment called "Responsible Care."

I hope an overview of this program will persuade you to help incorporate Responsible Care for all industries around the world into the groundwork for "the Law of the Atmosphere." Through a commitment of this kind the chemical industry, and industry in general, can become an integral part of the solution to our global problems instead of being seen as an uninvolved contributor to them.

The Brundtland Commission raised a number of challenges for governments, industries and academics. Three of these are of great significance to the chemical industry. They are - "Become Responsible", "Inform and Involve All" and "Invest in Our Future". I believe the initial steps our industry association has taken in Canada begin to answer these challenges.

Let me first give you a little background on the chemical industry to put the development of Responsible Care into perspective. Why does the world need chemicals at all? Well, chemicals, both natural or synthetic, are truly the essence of life. Chemicals make up the air we breathe, the water we drink and the earth we stand on. And, of course, human beings are just an elaborate combination of chemicals! But synthetic chemicals are relatively new. Most of the chemicals we take for granted today appeared in the past few decades. They provide us with the means to feed, shelter and clothe our growing human race. They have helped improve the health and life expectancy of our global population, and they have enhanced our quality of life.

But chemicals also cause public concern. Today people worry about acid rain, groundwater contamination and holes in the ozone layer. They worry about the combination of chemicals in the atmosphere, about their synergistic effect on human health and the health of the environment. As an industry association, the CCPA shares these concerns. We want to ensure that the benefits of chemistry are maximized. At the same time we want to ensure that every step is taken to minimize the risks chemicals pose to people and the environment. We are committed to identifying these risks. We are working diligently to establish practices that eliminate adverse effects on human health and the environment. This commitment is called Responsible Care.

In the fifties and early sixties, the world's post-war economy faced a major shortage of consumer durables. The chemical industry made tremendous capital investments in technology and new facilities to meet the ever-expanding consumer demands. Those were heady days for the chemical industry! As we moved into the sixties and seventies the focus shifted from unbridled consumption toward greater interest in the quality of life, and that quality of life included quality of the environment. This transition gave rise to an environmental movement that pitted environmentalists against industry. To quote the Brundtland Report, "At the extremes, environmentalists saw industrial managers as near-monsters; corporate leaders viewed environmentalists as ill-informed anarchists, trying to destroy, indiscriminately, the benefits of industrialization." As a result, the environment and the economy became polarized. The public perceived that you could have either one or the other, but one is at the expense of the other. Instead of building bridges to solve common problems, industrialists and environmentalists stayed in their corners awaiting the bell to begin the next round of confrontation.

In the 1970s, public perception of the chemical industry became increasingly negative. People's fear of chemicals and the impact on their health and the environment gave rise to chemophobia. We had lost the trust and confidence of the public. Our industry recognized that we had to change our performance. We had to stop being invisible. And we had to become publicly accountable. In short, we had to be part of the solution instead of being seen as most of the problem.

In today's climate, North Americans demand to know how the chemical industry affects them. They want to know whether the risks associated with chemicals and the chemical industry outweigh the benefits.

In 1986 our industry commissioned a study of Canadians' opinions of the chemical industry. We learned that two thirds of Canadians believe we know the risks associated with our products and operations but we don't tell. We learned that the public unanimously supports governments getting tougher on polluters. And perhaps most humbling for the leaders of our industry, we learned that leaders of chemical companies have less credibility than environmental groups, the media and government officials. It was not all negative, however. The public was almost equally divided in terms of its favourable opinions of the industry. We were given good marks for our economic role and for creating useful products.

Nevertheless, the chemical industry had to change course. For too long, we in industry operated as though our activities and what was going on in the world were in two separate spheres - with reactions going on in each but never touching each other. Of course, what we do affects everyone else - we are all connected. And how others feel affects us.

So we knew we couldn't continue to operate by the same formulas that were successful years ago, when we ran our business close to the vest and kept the world outside our plant gates. The formula for operating in this new "aware" society had changed and we knew that if we didn't adopt the new formula we would continue to suffer the consequences of negative public reactions. We would perpetuate the polarization of economy and environment. And we would never become part of the solution.

So what is the new formula? We must actively demonstrate by our actions that we are socially responsible and responsive to the public's needs and concerns. We must convince people that we are working diligently to protect human health and the environment. We must show that we are willing to lift the veil of secrecy and talk with people, in their terms, about what we are doing. We must tell people about the risks associated with our products and processes, about how we manage these risks, and about our unwavering concern for the health and safety of our employees and the community. In a word, we have to be accountable to the public for our deeds.

In Canada we have taken major steps toward implementing this new formula for public accountability. In 1984 the CCPA asked all member company presidents to sign a statement of Responsible Care. Each pledged that his company was:

> "committed to taking every practical precaution toward ensuring that our products do not present an unacceptable risk to our employees, customers, the public or the environment."

We have made formal endorsement a condition of membership.

In December 1984 the risks associated with our industry were magnified by the tragic accident at Bhopal. We responded by forming a team of our best industry experts. Their job was to create a process for examining the integrity of our plants in case of a major incident. This process, called Safety Assessment, also called for examination of individual plant emergency response procedures as well as those in the community. At the same time a task force was formed to determine how we could improve our overall approach to the management of chemicals. This became the forerunner to a set of Codes of Practice. Seven Codes of Practice are being developed to ensure that our products travel a path of human and environmental safety from their inception at the research lab to their final disposal.

Basically, Responsible Care has three elements - the Codes of Practice based on our Guiding Principles; an implementation process for each Code, which includes manuals, seminars and support materials; and a means for individual companies to measure their progress and report back to the CCPA.

The first Code of Practice is CAER, which stands for Community Awareness Emergency Response. It is a program developed by the Chemical Manufacturers' Association in the United States. CCPA adopted it in 1986. CAER marks the first time we have had a coordinated effort in North America to reach beyond our plant gates and establish emergency response procedures and ongoing communications with the communities in which we have operations.

In Canada we have 73 member companies with over 200 plants in 110 communities. Over three quarters of these sites have begun the process of developing coordinated emergency plans. We want to make sure that all our plant communities have effective emergency response plans. We involve civic leaders, emergency response people and our neighbours in developing and testing these plans.

CAER is truly reaching out to the community in response to three of their fundamental concerns - their fear of chemicals; their concern about the impact of a chemical incident on their community; and their fear of the unknown. Many of our plants are open to the community. We invite people in to see what we do and respond to their questions and concerns. CAER is Responsible Care in action at the community level.

Both CAER and TRANSCAER, our second Code of Practice, are founded on the principle of right-to-know. TRANSCAER addresses Responsible Care through transportation. We launched our TRANSCAER program with a seminar held this past January. We believe people in communities along major transportation routes have the right to know the risks associated with the products being transported - as well as the chemicals made and used in their communities. They need to understand the safety precautions being taken by the carrier. Most importantly, they should know about the contingency plans that are in place in case of an emergency.

Other Codes being developed cover distribution, waste management, manufacturing, research and development and the generation and transmittal of hazard information. Our Codes are available to anyone who wishes to examine them. In fact, they are developed with public input. We know they must meet public scrutiny because, as an industry, we will be measured against them. Over time, the Codes will become our public report card.

Our goal is to have all the Codes of Practice finalized by February, 1989. We plan to have all the requirements under these seven Codes completed by 1994.

The second challenge the Brundtland Commission called for is "To inform and Involve All". In its recommendations, the Canadian Task Force on Environment and Economy recognized that:

> "There are many points-of-view and many interests in economic and environmental issues. Each of these is important. No single point-of-view, in isolation, can adequately reflect the complexity of the interests involved."

The CCPA has learned from experience that the best solution to issues is building consensus. It takes time and patience by all parties, but it also builds a bond of trust among the many stakeholders of the issue. If we are sharing the same global village, we must learn to talk to each other and to hear each other's concerns. And we must seek solutions so all can gain instead of feeling defeated by traditional win-lose scenarios. We have taken public involvement seriously. For two years CCPA has been advised by a panel of environmental activists from across Canada. Their interests range from occupational health and safety to environmental law. The panel has given us much guidance on our initiatives and validated many of the efforts we have under way. They have also provided candid input on the development of all the Codes of Practice - and in fact, have brought us up short when our program designs have not taken into account the needs of our stakeholders. We believe this validation by a panel of our toughest critics is essential if the Codes are to withstand public scrutiny.

We have also found the multipartite process is the best way to approach the development of legislation and regulations. A recent example was the development of procedures for workplace right-to-know. For over two years, representatives from labour, government and industry sat down to work out the best approach. This consultation involved many adjustments and compromises, but in the end we came up with a solution that was acceptable to all. This solution is called WHMIS which stands for Workplace Hazardous Materials Information System. WHMIS is a process that balances worker right-to-know with the manufacturer's right to protect confidential business information.

A similar multipartite consultative approach was used to draft the basis for the Canadian Environmental Protection Act. Over the past five years we have worked with environmentalists and people from government, industry and academia to arrive at mutually acceptable legislation and regulations. The multipartite process has proven to be one of the most effective ways to achieve workable solutions to the problems we share with other stakeholders.

The final challenge is "Invest in Our Future". What better way to do this than through education. The National Task Force on Environment and Economy recommended a high priority be placed on the education of future generations. We said,

> "We believe that our children should have a better understanding of the environment so they can treat it with respect when they become decision-makers in their own right."

In 1986 the CCPA made an eight-year commitment to a group called SEEDS which stands for Society, Energy, the Environment Development Studies. The goal is to get balanced information about chemicals and the environment into primary and secondary schools across Canada. Last summer thirty teachers from across the country attended the first symposium on chemicals and the environment, held in Sarnia, Ontario. They spent a week discussing issues with people from government, industry, environmental groups and the media. They also toured a number of plants to learn first-hand about chemical operations and the safety and environmental controls we have in place. Plans are well under way for the second symposium, to be held this August. Out of that session a group of teachers have been chosen to begin writing curricula. The goal is to get SEEDS materials to 1.5 million students across Canada by 1996. SEEDS has also developed an energy literacy series that is being used by 600,000 students across Canada. It addresses such topics as energy systems, and energy and the future, which touch on the theme of sustainable development. Incidentally, SEEDS has presented its energy materials to educators in Sweden and India. Both countries have shown interest in developing similar programs. Besides SEEDS, many of our member companies have additional school programs.

To conclude, I would like to suggest how my association, the CCPA, and you in the room today can invest together in the common future of our global village. The Canadian Chemical Producers' Association believes that our Responsible Care commitment provides a framework on which to foster continuously improving performance. It builds stakeholder consultation into our decision-making. It gives us a system to set priorities and meet our shared goals. And ultimately, it provides a public report card on our performance - it makes us accountable. But what if we took this challenge to the next level? What if we challenged all industry sectors to define global rules of the road? What if all industries shared a global commitment to Responsible Care?

In the chemical business, the globe is a small place. We are closely connected to all chemical manufacturers around the world through our multinational members, through the marketplace we share, and yes, through the atmosphere we all depend on. So we have taken Responsible Care on the road. We are talking to our colleagues in other nations about this commitment.

The Chemical Manufacturers' Association of the United States is considering adopting Responsible Care. The New Zealand Chemical Producers' Association has accepted most of the principles of Responsible Care and has made endorsement a condition of membership. And our colleagues in Britain, the Chemical Industries Association, recently visited the CCPA to learn more about our programs. They were most interested in our advisory panel and the SEEDS project.

An international commitment to Responsible Care by chemical associations around the world would go a long way toward restoring the credibility of our industry. It would demonstrate to all of our publics that the chemical industry is founded on strong ethical principles and that we intend to take the actions necessary to live up to them.

I urge you to consider Responsible Care when you lay the groundwork for the "Law of the Atmosphere" later this week. Imagine the potential of getting industry around the world on side - not just the chemical industry, but all industry. Imagine the power of a global industrial commitment to Responsible Care! I can envision industry collectively working first to improve its performance, particularly on the environmental front. We would have to use existing technologies, develop new technologies, and get the world's stakeholders involved. I can envision industry becoming actively involved in education - in the education of their employees, the people in their communities and the students in schools and universities around the world. And ultimately I can envision a global village where public information, involvement and industry accountability are the standard.

Let's look beyond this to the ultimate vision - a world in which environment and economy are one. How do we get there? From an industrialist's perspective, I believe we can arrive at our common destination only if we work together. Invite industry around the world to become part of the solution. Provide us with a blueprint of your expectations. And use the CCPA's Responsible Care commitment as the framework for that blueprint.

You face an immense challenge while you work together to put in place the foundation for the "Law of the Atmosphere". And as you begin this task, I am reminded of the prophetic words of John F. Kennedy:

> "All this will not be finished in the first 100 days. Nor will it be finished in the first 1000 days, nor in the life of this administration, nor even perhaps in our lifetime on this planet. But let us begin."

As a representative of the chemical industry and industry in general, I urge you to let us begin <u>together</u> in an atmosphere of cooperation. Let us, together, be part of the solution.

LUNCHEON ADDRESS

THE ROLE OF CITIZENS IN SUSTAINABLE DEVELOPMENT

Sister Aida Velasquez, OSB
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Secretariat for an Ecologically Sound Philippines

Many citizen groups hailed the final report of the World Commission on Environment and Development when Prime Minister Brundtland presented it. It calls for greater public participation in decision-making processes regarding environment and development issues, among others. As a first response to the report, entitled "Our Common Future", the Environment Liaison Centre International (Global Coalition for Environment and Development) came out with the pamphlet "Joining Hands". This gives specific recommendations to citizen groups all over the world who will "join hands to create people power and, through that, the political will to promote sustainable development". This they will do together with public authorities in the North and the South.

In the Philippines, environmentalists realize that, in order to survive as a people, Filipinos need to understand that our island-house is fragile and our natural resources are limited. With a population projected at 111 million by the year 2000, we hope to learn to pursue all our activities within the carrying capacity of the natural resources of our archipelago and to protect and conserve its diverse genetic species. The gifts of our islands must be used judiciously to satisfy the basic needs of all and provide them with livelihood and employment opportunities while assuring that future generations will also be able to meet their needs. Obviously a vigorous ecological education program is imperative.

With this in mind, a citizen's group, The Secretariat for an Ecologically Sound Philippines, has embarked on helping popularize the concept of sustainable development (SD). Copies of the overview of "Our Common Future" and "Joining Hands" were printed and disseminated. A newsletter issue was devoted to SD and a campaign was launched for the adoption of a Philippines Charter for Nature that is based on the World Charter for Nature and that incorporates the WCED's emphasis on anticipation and prevention of environmental damage.

A series of ecological orientation seminars has begun and we are reaching out to the village level. This introduces the participants who are mostly leaders of communities to the urgency of working for SD. To assist people to realize the inseparability of ecology and economics, a whole-day seminar-workshop for a small group of ecologists, economists and lawyers has been scheduled. We believe this can help provide people with insights as to how to push for SD.

The Association of Southeast Asian Nations agreed last December 1987 to promote SD. Popularizing the principle of SD seems simple and not too difficult. Far from it. Let me illustrate with an example.

Marcopper Mining Corporation (MMC), a subsidiary of Placer Dome Inc., a Canadian firm, has been operating a copper mine since 1969 in Marinduque, a small island south of Manila. For almost 13 years now, it has been dumping mine tailings into a shallow bay. In effect, it has crushed and powdered about half of a mountain (lying almost at the centre of the island) and transferred this into Calancan Bay. With Mr. Marcos owning 48% of its shares, MMC has transformed a once bountiful fishing ground into a desert with the compacted mine tailings. In the process, fishermen and their families, numbering about 20,000, have been impoverished. There is less food, especially for the growing children, schooling was cut short for most of the youth and young people must leave their village and be separated from their families to look for employment.

Since 1974, the fishermen, foreseeing what would happen, protested against the MMC plan to dump mine tailings into their fishing ground. A long series of protests, most of which fell on deaf ears, was answered at long last on April 1988 by the order of the Department of Environment and Natural Resources (DENR) for MMC to stop polluting the bay. MMC appealed to the Office of the President (OP) to reverse the order of the DENR. The legal department of the OP sustained the DENR order and the fishermen were happy. Within 24 days the water in the bay cleared up and the fish catch started to increase. However, the same legal department of the OP later buckled down to economic pressure (reinforced, most probably by creditor banks) and a second decision overturned the order of the DENR and in effect let the Company continue polluting Calancan Bay. The last remaining portion of the fishing ground of the subsistence fishermen is now being covered with mine tailings. MMC is also endangering the other fishing grounds of the province and probably foreclosing the marine livelihood possibilities for the 250,000 residents of Marinduque Island. While it employs a thousand workers, the copper mine is almost exhausted and MMC owes the Philippines government some $40 million in back taxes.

It is obvious how a government, saddled with economic problems and pressured by sly businessmen and politicians and sadly lacking in ecological consciousness, can throw out the principle of SD. Such an unecological and uneconomic decision obstructs SD from being understood.

What are the other obstacles aside from those coming from a government that would exchange short-term benefits with ecological destruction? There is also the indifference and lack of ecological consciousness among the majority of the citizens, the vested interests of local officials, the lack of resources of the poor to match the high-powered disinformation campaign and manoeuvering of vicious corporations, and principally, the poverty of the majority that can lead them to destroy the natural resources. For example, the destruction of the mangroves by charcoal-makers or of the forest by slash-and-burn farmers. To balance the picture, you may want to know that despite our poverty, the citizens waged a ten-year campaign against a $2.1 billion Westinghouse nuclear power plant and the Aquino government decided against its operation after the Chernobyl accident occurred.

In addition, at present, foreign governments do not require their citizens engaged abroad in industrial activities to observe the same environmental practices that they require of them in their own countries. The ideas of a comprehensive environmental impact assessment, environmental corporate licenses for firms and an environmental representative on corporate boards may be of help.

What makes the concept of SD very attractive to concerned citizens in poor countries? It is the fact that the Brundtland Commission pin-points inequality as the main environmental as well as the main development problem and recommends that "an overriding priority be given to the need of the world's poor".

To make people discuss and act for SD effectively, a citizen must wake up to the reality of the situation of poor countries, and grapple with it. In a panel discussion on foreign debts in the recently concluded International Forum on SD sponsored by Pollution Probe, it was mentioned that the real settlement of these foreign debts is for the creditor-countries to write them off. It is laudable that Canada is one of those countries that has started to do this. Mr. Morris Miller of the World Bank, appearing on that panel, compared the condition of developing countries to that of a person running up an escalator that is going down. He went on to say that debts are part of a much bigger problem, which means that the whole economic system is sick. And that there is a need for very severe readjustments for the global economy to grow. The officials of the United States, the leader of consumerism, must be convinced to initiate this restructuring of the global economy. Mr. Miller concluded, "A systemic solution is needed for a systemic problem."

A much greater reality than this systemic economic problem that citizens need to grasp, according to Fr. Thomas Berry, is the fact that "our industrial economy is closing down the life-support systems of the planet - the air, the water, the soil and the vegetation. The immediate danger is not 'possible nuclear war' but actual industrial plundering. For the first time, humans are determining the destinies of the earth in a comprehensive and irreversible manner". Our very Conference on The Changing Atmosphere attests to this and underlines the urgent task needed. "If humans will not stop the industrial plunder of the earth, then no economic viability nor improvement of life conditions for the poor can be realized", writes Fr. Berry.

In the pursuit of SD, we hope to grow in the realization that - in the words of Fr. Berry - "the primary objective of economic sciences, of the engineering profession, of technological invention, of industrial processing, of financial investment, and of corporation management must be the integration of human well-being within the context of the well-being of the natural world. This is the primary purpose of economics. Only within the ever-renewing process of the natural world is there any future for the human community". And growing in this understanding, we hope to act accordingly more and more.

Ultimately, the battleground for SD is in the human heart. Mrs. Brundtland says that nothing less than a conversion of heart is needed to bring about the change of pattern of consumption and production that will enchance the resource base and implement the other recommendations of the WCED. This change of heart invites us, humans, to relinquish the idea that we are master of creation and acknowledge that we belong to the total earth community. It will mean also for you and for me listening intently to the tribal people and to their wisdom of relating harmoniously with the earth. It means respecting and doing justice to them and to the rest of the species. It means recovering our awe and reverence for the earth - our primary teacher and our first encounter with the divine.

May the pursuit of SD lead us on to this realization and so discover that the creative powers of the earth is in each of us, and so celebrate with the earth that very creativity.

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THEME PAPERS

EXPOSES THEMATIQUES

THE GLOBAL GREENHOUSE EFFECT

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1. INTRODUCTION: RISE OF THE IDEA

In this paper I shall put forward the view that the greenhouse effect is the most important environmental problem facing the world. It is an old conjecture that has suddenly become central to international strategy.

In 1938 a British air pollution specialist, G.S. Callendar (1938), put forward the view that the carbon dioxide concentration in the atmosphere was increasing because of fossil fuel burning. This must lead, he argued, to a rise of surface temperatures, and hence to world-wide climatic change. I mark Callendar's 1938 paper as the point at which climate began to move centre-stage in world affairs. We are thus celebrating a sort of half-centenary.

I was a student at the time, working under Sir David Brunt. He didn't much like carbon dioxide, a gas that complicated the calculation of radiative transfers in the atmosphere - and which provided the raw material for photosynthesis, and hence life on earth. David Brunt's sense of the niceties was that biology was a troublesome field, and life a regrettable phenomenon. When I began with him (in 1938) he advised me to read James Clerk Maxwell's Theory of Heat, and to avoid all biological works as being sure to mislead. Fortunately I ignored his advice.

Soviet scientists may adopt a different chronology. In the West, however, the next landmark was Gilbert N. Plass's (1956) paper in which he proposed a refinement in Callendar's ideas. He wrote on the eve of the International Geophysical Year, which led in 1957 to the establishment of the long Mauna Loa monitoring series for carbon dioxide, led by C. David Keeling (1978).

The realization that global air pollution - which is what the carbon dioxide increase amounts to - would have profound political implications was slow in coming. In 1964-65 Roger Revelle (1965) led a U.S. White House study of the burning of fossil fuels, and its relation to the steadily rising carbon dioxide concentration, which by then was a measured fact. From thence it was an easy step into the International Biological Programme, which took the carbon cycle as one of its de facto themes. I recall a landmark paper by George Woodwell in a popular journal, Scientific American (1970), which made it clear that atmospheric scientists could no longer ignore the role of the living cover of the earth as a control of world climate.

The 1960s and 1970s marked the change from physics-based meteorology (of which climatology was a very lowly part) to interdisciplinary atmospheric science with climate as the central problem. And now we are sailing into even stormier waters - those of global change, in which we face the challenge of bringing all the sciences of the inhabited earth together within a manageable framework.

But these were advances in scientific outlook. In spite of the 1973-1974 food crisis, in spite of the Sahelian desiccation, in spite of the near-death of the Peruvian fisheries, all climate-triggered events, the political, economic and technological implications of climate remained little realized. In 1979 the first World Climate Conference was held in Geneva. I had the job of compiling the papers for the event, and recall sitting in an office in Geneva biting my fingernails because we could get little response from business men, engineers, doctors, farmers and fishermen; and little or none from politicians.

So this great Toronto event is a most welcome initiative. We owe much to Minister McMillan for tirelessly advocating the coming together of science, technology and politics, and to Mrs. Brundtland and her Commission for having created nothing short of a new paradigm within which we can now work (World Commission on Environment and Development, 1987). We have been convened because it is now realized that the major climate-related social issues - greenhouse effect, acid deposition, the ozone problem, desertification, rising population, energy alternatives and polar problems - are all interconnected, and call for concerted international action. Hence our Toronto agenda.

2. WHAT IS THE GREENHOUSE EFFECT?

Most of the gases of the atmosphere - notably nitrogen and oxygen making up 99% by volume - have little effect on the earth's energy balance. Solar and terrestrial radiation alike can pass through them without much hindrance. If these gases were the only constituents, the earth would be a far harsher place, with hotter days and colder nights and a quite different geography of world climate.

Certain minor gases change all this. They have a vital property in common: they allow the sun's energy to penetrate to the earth's surface, but retard the return upward flow of the infrared radiation. The active greenhouse gases - so-called because their role is in some ways like that of a glass roof - include water vapour (less than 4% by volume), carbon dioxide (nearing 350 parts per million by volume, ppmv) and various less abundant substances, notably nitrous oxide, ozone and methane. All play critical roles in the maintenance of life on earth. Of importance hence is that they combine to resist the upward flow of heat to space. Hence they warm the earth's surface.

This purely natural greenhouse effect raises surface temperatures to a global average of 288 K, or 15°C (59°F), which is about 35°C warmer than would be the case if they were not present. Water vapour is the key constituent, notably because it may condense as cloud - and clouds act even more effectively as resistances to the escape of heat (though they also retard the inward flow of sunlight). The attractiveness of this planet to life depends overwhelmingly on the natural greenhouse effect.

Here at this Conference, however, we shall be concerned more with the effects of the observed increase in the concentrations of these gases (Rasmussen and Khalil, 1986) i.e., with an augmented greenhouse effect. We have not detected any increase in water vapour, though it has almost certainly occurred. Ozone may actually be undergoing a small overall decrease (as well as a shift in vertical distribution). But carbon dioxide is increasing by about 0.4% per annum, or 15 ppmv per decade (Figure 1). Methane is increasing even more rapidly (Figure 2; Bolle et al., 1986), at about 1% per annum (Blake and Rowland, 1988). Nitrous oxide's increase is slower, but quite unmistakable (Figure 3).

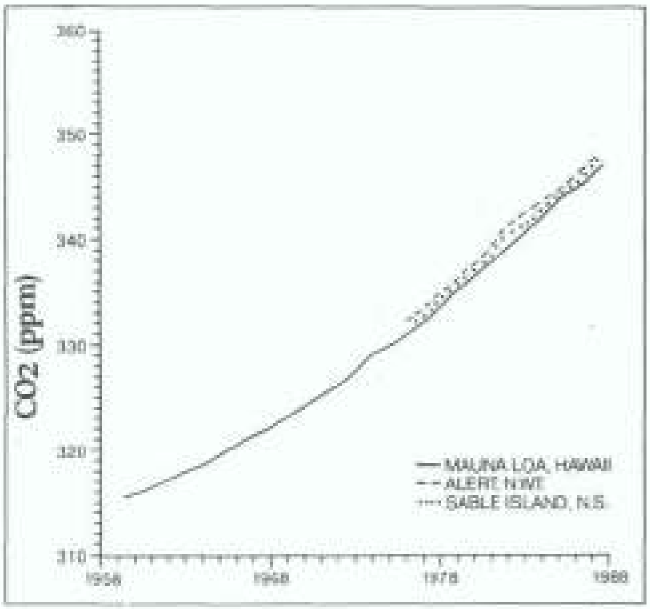

Figure 1.
Atmospheric CO_2 concentrations measured at Mauna Loa, Hawaii, Alert, Northwest Territories and Sable Island, Nova Scotia.

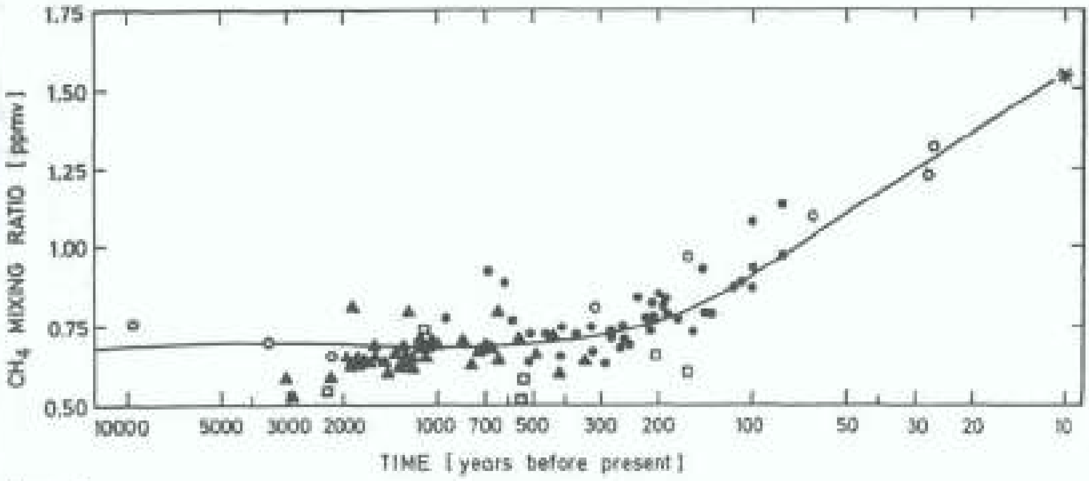

Figure 2.
CH_4 mixing ratios measured in air trapped in ice cores as a function of time (Bolle et al., 1986).

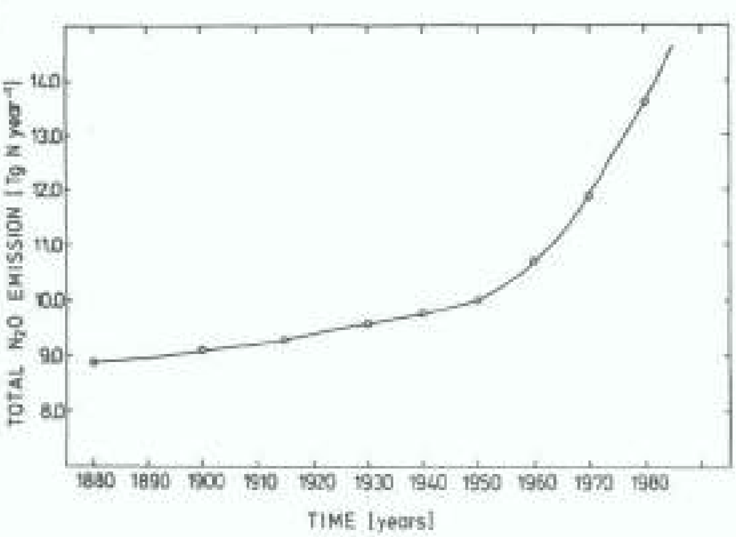

Figure 3.
Trend of estimated total N_2O emission rates between 1880 and 1980 (Bolle et al., 1986).

These increases are due to human activities. Carbon dioxide comes largely from fossil fuel burning, and to a lesser extent from land and forest clearing, and soil wastage. Methane we associate with various kinds of wetland agriculture, such as rice cultivation, and possibly with changes in high-latitude marshlands. Nitrous oxide - the least effectively studied - is probably coming off farmland. The legitimate human search for necessities such as warmth, industrial energy and food is thus altering the optical properties of the atmosphere, thereby threatening world climate and the well-being of all living things.

But human interference does not stop with things desirable and legitimate. We are adding synthetic substances to the atmosphere at a great rate. Most are harmless, as far as we know. Sulphur hexafluoride, for example, is essential to electrical switching gear. Most of it is released in the Northern Hemisphere, yet it has been detected at great altitudes in the Antarctic. It is inert, and does no known harm. Quite different are the chlorofluorocarbons (CFCs), the primary refrigerant gases, which are also wholly synthetic in origin. Their role in attacking ozone in the stratosphere is already notorious, as the next speaker will emphasize. What is not so well known is that they are powerful greenhouse gases; in spite of their low concentrations, they are highly effective in raising surface temperatures. The recent international protocol aiming at their replacement will not quickly diminish this role.

As concern about these changes has mounted, major efforts have been launched to get a grip on what is happening. The sponsoring international agencies of this Conference - the World Meteorological Organization and the United Nations Environment Programme - together with the International Council of Scientific Unions organize occasional international assessments. The most recent of these was held at Villach, Austria, in 1985. Thanks to the initiative of Gordon Goodman and the Beijer Institute, this was followed in 1987 by policy-oriented workshops at Villach and Bellagio, Italy.

As these assessments have shown, the best evidence for the greenhouse effect comes from monitoring results plus large-scale scientific modelling. The monitoring results are still ambiguous. The modelling results differ greatly according to the initial assumptions (themselves debatable), and the choice of atmosphere-ocean models used to derive the results. Thus there is a large measure of uncertainty. But there is nevertheless a growing near-consensus on certain broad conclusions. I shall summarize its main elements.

These results, while clouded with uncertainty, are at least as firm as those of econometric analysis and prediction. If decision-makers are willing to listen to economists, they should be at least as ready to listen to the natural scientists as regards future outcomes; complex as it is, the natural system is probably more predictable than the human economy.

3. HOW BIG A CHANGE IN CLIMATE IS LIKELY?

Here I am guided by the conclusions of Villach 1985, which I paraphrase briefly below:

i) Time-Scales. The augmented greenhouse effect is currently due about half to rising carbon dioxide levels, and half to the other greenhouse gases - chiefly the chlorofluorocarbons, nitrous oxide, methane and ozone. All are known to be increasing (ozone in the lower layers only) as the result of human activities. The combined future effect may be the equivalent of the carbon dioxide doubling by the 2030s - i.e., in less than a half century.

ii) Expected Warming. Such a doubling may induce a global surface temperature increase of between 1.5 and 4.5°C, according to existing atmosphere-ocean models. The slowness of the oceans to warm up may, however, delay the effect by some decades. Values outside the cited range cannot be excluded. Indeed, recent modelling results, e.g., Wetherald and Manabe (1988), tend to increase the estimated changes.

iii) Unequal Effects. The impact of this warming is likely to be geographically non-uniform. High latitudes will warm the most, especially in autumn and winter. Equatorial regions will experience a lesser but still formidable warming.

iv) Effects on Water. Less can be said about rainfall and the hydrologic cycle, but it appears likely that available soil moisture may be less abundant in Northern Hemisphere mid-latitudes - which include the world's chief wheat and corn growing areas. Water demand will increase generally.

v) Sea-Level. Sea-level may rise between 20 and 140 cm during a warming of the sort foreseen in (ii) above, chiefly because of expansion of the ocean water column (and only secondarily of glacial melting). A rise in the upper part of this range would seriously affect low-lying coastal areas, especially in the world's great deltas. More catastrophic rises due to major disruptions of the Antarctic and Greenland glaciers are unlikely in the next century.

These five predictions rest on direct measurement, on estimates of future energy use and technological change, and on elaborate modelling of both the economic and ocean-atmosphere systems. The greenhouse effect has become the central research problem of the field. It has attracted large resources of time, money and talent.

The calm recital of these ideas may mislead a listener unaccustomed to geophysical magnitudes. In fact, the five predictions, if realized, will amount to a revolutionary change in world climate, of a sort not rivalled in the history of civilization. Not since the abrupt end of glacial climates a little over 10,000 years ago have temperatures changed as much, or so rapidly. The next century may therefore see large impacts on the human economy, the first signs of which may already be upon us. It will also see, if these changes are realized, a potentially dangerous disequilibrium between soil, vegetation and climate. The world's ecosystems will be destabilized, in a fashion that cannot yet be predicted in detail. I have no doubt that we are discussing the central environmental problem of our times.

In practice the greenhouse warming will show itself in subtle ways. Climate is naturally variable: droughts follow floods, heat waves follow cold waves, winds, storms and calm conditions are interspersed. Some of these variations may last for years, and be economically damaging. In any given decade the effect of such anomalies will hide the slow changes of the greenhouse effect. The latter has been likened to a faint signal behind the noise that afflicts AM radio reception. In all probability, the warming in mid-latitudes will show itself mainly by increasing numbers of dry, hot summers and mild winters - of the sort already common in the 1980s, most notably the present time in North America. The entire year 1982/83, for example, was of this sort in many parts of the world, because of a huge anomaly - the so-called El Niño/Southern Oscillation effect - in the Pacific Ocean (not itself a consequence of the greenhouse effect). Here in Canada the Great

Lakes barely froze (Assel et al., 1985). We already get entire years, in fact, that resemble what will be normal five decades from now. We are allowed to rehearse the greenhouse warming, and to examine its potential economic impact by direct inspection. We get glimpses of the probable future from such events (though we still have to improvise strategies to cope with it).

4. HAS THE GREENHOUSE WARMING SHOWN ITSELF YET?

The past two decades have seen many climatic anomalies. The worst has been the vast African desiccation, a much broader process than the so-called Sahelian drought. Analyses by many climatologists, notably Nicholson and Lamb, have demonstrated that this devastating process began in the 1960s, and continues to this day with consequences well-known to us all. There have been many other major anomalies of other sorts. Several years of the 1980s have been the warmest in recorded history, on a world scale, most notably 1987 (Jones et al., 1988). It is hence reasonable to ask: Is this the greenhouse effect at work?

Because of the skittish behaviour of climate just referred to, this has been a hard question to answer. The problem is to identify the measurable properties most likely to point unmistakably to the greenhouse effect. What, for example, should we look for in the outgoing radiative characteristics of the planet, as detected by satellites, as my colleague Wayne Evans likes to do? How should we expect stratospheric temperatures to respond? Should they fall as analysis seems to show? Can sea-level measurements offer firm evidence? And can we detect the greenhouse signal in existing climatic records?

None of these approaches has yet given an unequivocal answer. But painstaking examination of the global surface air and sea temperature records over the past century and a quarter has begun to yield good results. Analysis by Jones et al. (1986), for example, shows a global rise of temperature between 1860 and 1980 of approximately 0.5 to 0.6°C. Villach 1985 estimates that the greenhouse effect over the past century should have raised temperatures between 0.3 and 0.7°C. The observed signal is thus compatible with the predicted greenhouse warming.

Firmer answers to this question will have to wait a few years. But I should like to express the personal view, based on long experience rather than personal research, that we are indeed witnessing the beginnings of the process, and that the delegates did not come to this Conference to chase a will-o'-the-wisp.

5. WHAT IS THE SIGNIFICANCE OF THE GREENHOUSE EFFECT?

Do these predictions have a major significance for the future of humankind? Here we encounter a real divergence of view. Most of my scientific colleagues feel certain that the answer must be "yes". They have mounted large world research efforts to specify the problem, and to identify potential socio-economic impacts. Since before the 1972 U.N. Conference on the Human Environment in Stockholm, in fact, they have been driven by the sense that the biological and physical sciences of the environment have growing predictive powers, and that these should be used to influence the future course of human action.

But the world-views of statesmen, politicians and business people have been hard to change. For the most part large-scale policies on the national and world scales have ignored the possibility that major environmental change may be ushered in by climatic change, and specifically by the greenhouse effect. With great respect to Mrs. Brundtland, Our Common Future makes too little of the climatic factor. Beyond admitting that weather-related variations in food supply may continue, the report rarely touches on climate, except in the context of energy technologies. In so not doing, it is moving parallel to the great bulk of social, economic and political comment.

Yet there is abundant evidence of the sensitivity of various aspects of the human economy to climatic impact - and to the reverse phenomenon, the impact of human activities on climate via the greenhouse effect and other mechanisms. The World Climate Impacts Programme has produced a long literature on the climate-economy links. Here I refer, for example, to the excellent series emerging from IIASA, under the leadership of Martin Parry (1988), and to the series of impact studies completed here in Canada (Climate Change Digest, 87, 3-4; 88, 1-2) on such diverse fields as agricultural yields, Great Lakes water levels and the effects of sea-level rise. These interdisciplinary studies had one common aspect: that they were conceived, sponsored and to a large extent conducted by atmospheric and ocean scientists like myself (with the help, it must at once be added, of engineers, economists and agricultural scientists). The stimulus did not come from senior government or top corporate management.

This Conference shows that such indifference is at an end. It has brought people in the midst of the political struggle together with the scientists who perceive the problem. The Beijer Institute workshop in Villach and Bellagio in 1987 neatly identified the gaps we have to bridge here in Toronto. I shall not repeat the list. Instead I shall make some comments and pose some questions that I believe demand an answer:

i) The question of scale is paramount, when action is being sought. The greenhouse effect is world-wide, both as to causes and as to impacts. Any conceivable action to control, mitigate or adapt to the effect must be taken on the world scale, by the world community. The same applies, in my view, to the questions of ecological impact to be discussed by Michael McElroy this afternoon. Do the political means exist, or can they be devised, to tackle so broad a problem? This is an issue like those raised in Our Common Future - and poses the same challenge.

ii) A second class of global, climate-induced issues arises from such things as desertification, energy policy and the condition of the seas and fisheries. If not global, they are all widely dispersed - and defy international solution. All are in any case related to the greenhouse effect.

iii) Questions of acid deposition, and more generally of toxic air pollution, tend to be more limited in area (international or regional), to involve a more limited number of states, and to be amenable to specific technical solutions. Yet Europe and North America have found them hard to handle, in spite of a large degree of scientific consensus. How can we move beyond stalemate? Is a Law of the Atmosphere a feasible aspiration?

Beyond these questions the scientific community sees grounds for deep concern about the condition of the world's ecosystems, fresh water, food supply and human health - all on our later agenda. The greenhouse effect touches deeply on these concerns.

How can we close the gap between the scientific and the political mind-sets in this vast environmental arena? Are the scientists wrong in asserting that the world must be ready for the impending changes? Are these issues outranked by a dozen others? We have an opportunity to get the answers at this Conference. I have been talking about revolutionary change in the world's natural environment - a change induced by inadvertent human action. It is not too much to expect an equally revolutionary change in political attitudes. The presence of two Prime Ministers at the Conference's start, and of five ministers in the closing session, shows that things have at least begun to move.

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ABSTRACT

THE GLOBAL GREENHOUSE EFFECT

The global greenhouse effect derives from the action of certain gases that are being added to the atmosphere by human economic activity. The presence of water vapour and carbon dioxide in the atmosphere warms the earth's surface by about 3.5°C, as the result of normal exchange processes with the oceans and the living cover. Carbon dioxide is now increasing by 4 per cent per decade, chiefly from fossil fuel burning. Methane is increasing by 1½ per cent per annum, and other gases - nitrous oxide and various synthetics, the chlorofluourocarbons - at lower rates. The overall concentration of such gases will double in the first half of the twenty-first century, leading to equilibrium temperature rises at the earth's surface of 1½ to 4°C, with largest effects in high northern latitudes. This change should induce accelerated rises of sea-level (though not catastrophically), various stresses in the natural ecosystems, and big changes in agriculture (also because of expected changes in soil moisture availability). There will also be major impacts on energy consumption, and on navigation in high latitudes. The effects will be very unequal from country to country. As the economic impact grows, there will be a need for effective intervention by governments and international agencies. The level of certainty about these inequalities of impact is, however, lower than the near-consensus that the global effect will be unmistakable within a few years.

RÉSUMÉ

L'EFFECT DE SERRE À L'ÉCHELLE MONDIALE

L'effet de serre qui menace la planète trouve son origine dans l'action de certains gaz ajoutés dans l'atmosphère par suite de l'activité économique humaine. La présence de la vapeur d'eau et du dioxyde de carbone dans l'atmosphere réchauffe la surface de la terre d'environ 3,5°C, conséquence des processus d'échange normaux avec les océans et le couvert vivant. La concentration du dioxyde de carbone dans l'atmosphère s'accroit actuellement du rythme de 4 p. 100 par décennie, et cette augmentation est attribuable principalement à l'utilisation des combustibles fossiles. Celle du méthane augmente de 1,5 p. 100 par année tandis que celle d'autres gaz - surtout l'oxyde nitreux et divers gaz synthétiques dont les chloroflourocarbones - augmente moins rapidement. La concentration globale de ces gaz doublera au cours de la première moitié du XXI^{e} siècle, entrainant une augmentation de la température d'équilibre de la surface terrestre de 1,5 à 4°C, les effets les plus importants se faisant sentir sous les latitudes élevées nordiques. Cette modification de la température devrait avoir pour conséquence une augmentation accélérée, quoique non catastrophique, du niveau de la mer, l'apparition de divers facteurs de stress dans l'écosystème naturel et des modifications importantes de la situation agricole (attribuables également aux modifications prévues touchant la disponibilité de l'humidité dans le sol). On devrait également observer des effets importants sur la consommation d'énergie et la navigation sous les latitudes élevées. Ces effets seront répartis très inégalement d'un pays à l'autre. Au fur et à mesure que les effets économiques se feront sentir, l'intervention efficace des gouvernements et des organismes internationaux deviendra nécessaire. Toutefois, si on s'interroge encore sur l'importance de tous ces phénomènes, il est certain, d'après le consensus presque parfait qui se dégage actuellement, que d'ici quelques années l'effet global deviendra une réalité irréfutable.

ATMOSPHERIC OZONE

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1. INTRODUCTION

It is evident that the earth is a planet characterized by change. We have entered an era in which the human race has achieved the ability to alter its environment on a global scale. The ozone and global greenhouse warming issues that are presently at the centre of attention of many scientists and policy-makers are just two of the interrelated environmental issues we face today.

To gain a scientific understanding of how human activities will affect the earth's environment requires a new approach to earth sciences. We need to obtain a scientific understanding of the entire earth system on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to change on all time-scales. In particular, the immediate challenge is to develop the capability of predicting those changes that in the next decade to century will occur naturally or in response to human activity. This will require a nationally and internationally coordinated program of interdisciplinary research to investigate long-term, 10-100 years, coupled physical, chemical, and biological changes in the earth's environment recognizing that land, atmospheric, oceanic, and biospheric processes are strongly coupled on a variety of temporal and spatial scales.

During this presentation I will describe for you briefly the current scientific understanding of the processes that control the abundance and distribution of atmospheric ozone, and its susceptibility to human-induced changes. While I will focus my discussion on the ozone issue, it is now widely recognized that the ozone and greenhouse warming issues are strongly coupled because changes in ozone are predicted to modify the earth's climate, and because the same gases that are predicted to modify ozone are also predicted to produce a climate warming.

2. BACKGROUND

For several decades scientists have sought to understand the complex interplay among the chemical, radiative, and dynamical processes that govern the structure of the earth's atmosphere. During the last decade or so there has been a particular interest in studying the processes that control atmospheric ozone since it has been predicted that human activities might cause harmful effects to the environment by modifying the total column amount and vertical distribution of atmospheric ozone. Ozone is the only gas in the atmosphere that prevents harmful solar ultraviolet radiation from reaching the surface of the earth. Unlike some other more localized environmental issues, e.g. acid deposition, ozone layer modification, like global greenhouse warming, is a global phenomenon that affects the well-being of every country in the world. Changes in the total column amount of atmospheric ozone would modify the amount of biologically harmful ultraviolet radiation penetrating to the earth's surface with potential adverse effects on human health (melanoma and non-melanoma skin cancer, eye damage, and suppression of the immune response system) and on the productivity of aquatic and terrestrial ecosystems. Changes in the vertical distribution of atmospheric ozone, along with changes in the atmospheric concentrations of other infrared active (greenhouse) gases, could contribute to a change in climate on regional and global scales by modifying the atmospheric temperature structure, which could lead to changes in atmospheric circulation and precipitation patterns. The so-called greenhouse gases are gases that can absorb infrared radiation emitted by the earth's surface, thus reducing the amount of energy emitted to space, resulting in a warming of the earth's lower atmosphere and surface.

The ozone issue and the greenhouse warming issue are strongly coupled because ozone itself is a greenhouse gas, and because the same gases that are predicted to modify ozone are also predicted to produce a climate warming. These gases include carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), several chlorofluorocarbons (CFCs), including chlorofluorocarbon 11 ($CFCl_3$), 12 (CF_2Cl_2) and 113 ($C_2F_3Cl_3$), and Halon 1211 (CF_2ClBr) and 1301 (CF_3Br). CH_4, N_2O, the CFCs, and the Halons, respectively, are precursors to the hydrogen, nitrogen, chlorine, and bromine oxides that can catalyse the destruction of ozone in the stratosphere by a series of chemical reactions. Concentrations of these gases in the parts per billion range control the abundance of ozone whose concentration is in the parts per million range, e.g. one molecule of a chlorofluorocarbon destroys thousands of molecules of ozone. CO and CO_2 can affect ozone directly. CO controls the concentration of the hydroxyl radical in the troposphere, which itself controls the atmospheric concentrations of some of the gases that can affect stratospheric chemistry. CO_2 plays a key role in controlling the temperature structure of the stratosphere, which itself is important in controlling the rates at which the hydrogen, nitrogen, chlorine, and bromine oxides destroy ozone.

There is now compelling observational evidence that the chemical composition of the atmosphere is changing at a rapid rate on a global scale (see Table 1). The atmospheric concentrations of CO_2, CH_4, N_2O, and CFCs 11 and 12 are currently increasing at rates ranging from 0.2 to 5.0% a year. The concentrations of other gases, including CFC 113 and Halons 1211 and 1301, important in the ozone and global warming issues are also increasing, some at an even faster rate. These changes in atmospheric composition reflect in part the metabolism of the biosphere and in part a broad range of human activities, including agricultural and combustion practices. It should be noted that the only known source of the CFCs and Halons is industrial production. They are used for a variety of uses, including aerosol propellants, refrigerants, foam blowing agents, solvents, and fire retardants. At present one of our greatest difficulties in accurately predicting future changes in ozone or global warming is our inability to predict the future evolution of the atmospheric concentrations of these gases. We need to understand the role of the biosphere in regulating the emissions of gases such as CH_4, CO_2, N_2O, and methyl chloride (CH_3Cl) to the atmosphere, and we need to know the most probable future industrial release rates of gases such as the CFCs, Halons, N_2O, CO, and CO_2 which depend upon economic, social and political factors.

One important aspect of the ozone and global warming issues is that the atmospheric lifetimes of gases such as N_2O, $CFCl_3$, an CF_2Cl_2 are known to be very long. Consequently, if there is a change in atmospheric ozone or climate caused by increasing atmospheric concentrations of these gases the full recovery of the system will take several tens to hundreds of years after the emission of these gases into the atmosphere is terminated.

3. MODEL PREDICTIONS

Numerical models are used as a tool to predict to what extent human activities will modify atmospheric ozone and climate. One-dimensional models are used to predict changes in the column content of ozone and the vertical distribution of ozone and temperature, but cannot predict variations in ozone or temperature modification with latitude, longitude, or season. Major progress has been made over the past few years to develop two-dimensional models that can predict the variation of ozone and temperature change as a function of season and latitude. Three-dimensional models that include longitudinal variations are being developed to study the coupling between the chemical, radiative, and dynamical processes that control the distribution of ozone and temperature, but these models are not yet ready to perform perturbation calculations.

Because it is now well recognized that the chemical effects of these gases on atmospheric ozone are strongly coupled and should not be considered in isolation, the most realistic calculations of ozone change take into account the impact of simultaneous changes in the atmospheric concentrations of CO_2, CH_4, N_2O, the CFCs, and possibly other gases such as CO, oxides of nitrogen (NO_X), and bromine-containing substances. The effects of these trace gases on ozone are not simply additive. Increased atmospheric concentrations of CFCs and N_2O are predicted to decrease the column content of ozone, whereas increased atmospheric concentrations of CO_2 and CH_4 are predicted to increase the column content of ozone. Therefore, it can be seen that the effects of increasing concentrations of CFCs and N_2O are to some degree offset by increasing concentrations of CO_2 and CH_4. This is in contrast to the global warming issue where increased atmospheric concentrations of the same trace gases are all predicted to increase the temperature of the atmosphere in an approximately cumulative manner.

One-dimensional model calculations have been performed to predict how ozone would change with time assuming that the atmospheric concentrations of CO_2, CH_4 and N_2O continue to increase at their current rates of 0.5, 1.0 and 0.2% per year, respectively, for the next 100 years, in conjunction with different assumptions for the annual growth rates in the emission of chlorine- and bromine-containing chemicals. Continued growth of CFCs and Halons at 3% a year, which in the absence of a ratified Montréal Protocol is consistent with economic projections, is predicted to yield a globally averaged over head column ozone depletion of about 6% by the year 2040 and more thereafter, which is greater than natural variability and hence significant. In contrast, a true global freeze of the sum of world-wide emissions of all chlorine- and bromine-containing chemicals at or below projected 1990 levels, which, depending on the number of signatures and the growth rate in the non-signatory countries, may be consistent with the Montréal Protocol, is calculated to result in global column ozone depletions of less than 1% by the year 2015 and less thereafter. The results of these calculations demonstrate the strong chemical coupling that exists between these gases, and the time-scale on which ozone changes are predicted to occur. In essence, when the growth rates of the CFCs are less than the growth rates of CH_4 and CO_2, only small column ozone changes are predicted because the CFC effects on ozone are temporarily masked. However, when the growth rates of the CFCs exceed those of CH_4 and CO_2, these gases can no longer buffer the impact of the CFCs and large column ozone depletions are predicted.

It should be noted that even when the predicted column ozone changes are small, as in the case of a true global freeze, and hence little change is expected in the amount of ultraviolet radiation reaching the earth's surface, major changes in the vertical distribution of ozone are still predicted with potential consequences for climate. Ozone is predicted to decrease in the middle to upper stratosphere primarily owing to the increasing concentrations of CFCs, and to increase in the stratosphere primarily owing to the increasing concentrations of CH_4. The large predicted reductions in ozone near 40 km will lead to a local cooling of about 5°C. The consequences of this cooling for climate at the earth's surface are currently unclear.

Two-dimensional models, which do not incorporate a dynamical feedback with ozone change, predict a significant variation in the ozone column decrease with latitude, with the greatest depletions occurring at high latitudes. Depending upon the exact trace gas scenario used to predict ozone change, the pole-to-equator ratio of ozone depletion can range from a factor of 2 to 10. Seasonal effects are predicted but are somewhat less pronounced than the latitudinal effects. In general, two-dimensional models predict somewhat greater amounts of ozone depletion for the same trace gas scenarios than one-dimensional models do. For example, as can be seen in Figure 1, one two-dimensional model calculation (AER) that approximates a true global freeze on the emissions of all halogen-containing chemicals predicts a column ozone depletion at steady state (by the year 20XX which should be sometime in the middle of the next century) in the tropics of 0.5 to 1.5% with little seasonal dependance. Poleward of 45° ozone decreases exceed 3% in all seasons with changes greater than 5% poleward of 60° during spring. In this model calculation it was assumed that the abundances of CH_4 and N_2O would have doubled and increased by 20%, respectively. Figure 2 shows that for the same trace-gas scenario local concentrations of ozone are depleted most near 40-45 km altitude, equatorial losses are about 15 to 20%, whereas high-latitude losses may exceed 40%.

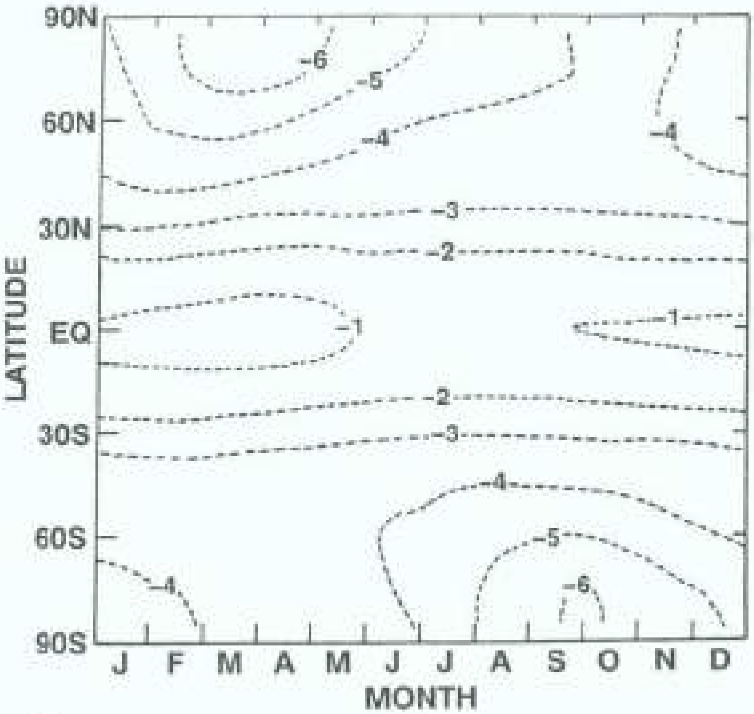

Figure 1.
Dobson map of ozone column changes (%) at steady state from the AER model for an approximate global freeze on the emissions of all halogenated gases at 1986 levels. The atmospheric abundances of methane and nitrous oxide are assumed to have increased relative to their 1986 levels by a factor of 2 and 20%, respectively.

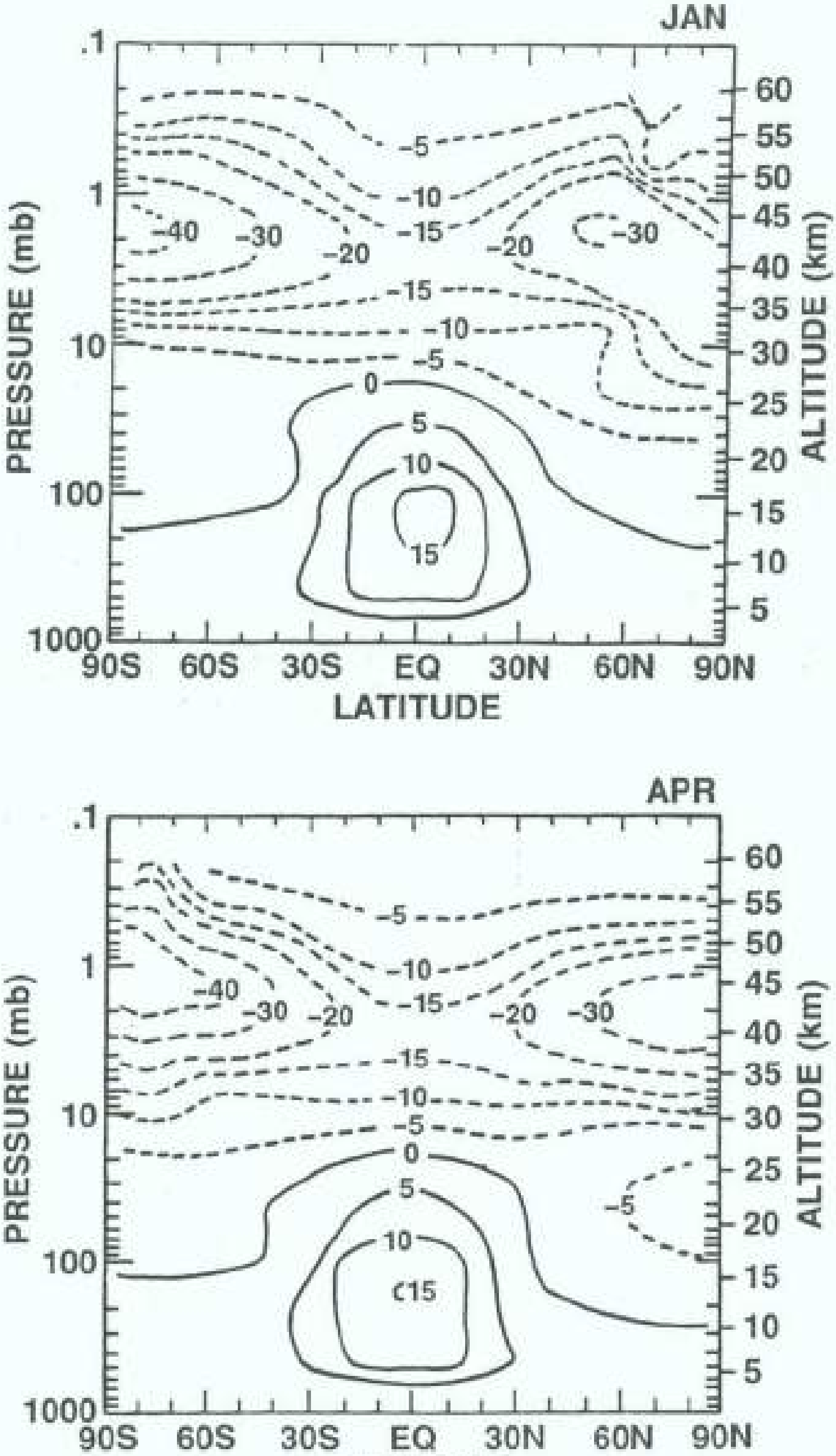

Figure 2.
Ozone profile changes (%) for the months of January and April at steady state from the AER model for the same scenario described in Figure 1.

4. GLOBAL OZONE TRENDS: COMPARISON OF OBSERVATIONS AND THEORY

A crucial question is to assess the extent of changes in global ozone that have already taken place, and to compare the changes with what has been predicted by theory. The search for global ozone trends involves looking for small secular changes amidst large natural variations that occur on many time-scales. Observations of the total column content and the vertical distribution of ozone have been made for several decades using networks having different measurement techniques. Unfortunately, each of these observational techniques have certain limitations, which tends to restrict our confidence in the results. These limitations arise from factors, such as the lack of continuity of reliable calibration and the uneven geographic distribution of stations. Statistical analyses of the data are required to identify small trends, amongst high natural variability, using data from very few stations.

Prior to the signing of the Montréal protocol in September 1987, ground-based observations showed that column ozone generally increased about 3% from 1960 to the early 1970s, remained constant throughout the 1970s, and decreased thereafter by about 4%. In general, statistical analyses for the trends in the total global column content of ozone using data from the ground-based Dobson spectrophotometer network showed no statistically significant trend since 1970, in broad agreement with model predictions for the same period when the changes in all of the trace gases are taken into account. Although the ground-based data do suggest a statistically significant decrease since the late 1970s, it should be noted that total global column ozone since 1982 has exhibited significant variability following the eruption of El-Chichon and the largest El-Niño event of this century. In addition, there was also an unpublished analysis of Nimbus-7 satellite Solar Backscatter Ultraviolet (SBUV) data that indicated that there had been a statistically significant decrease in the total column content of atmospheric ozone between 1978 and 1984 (approximately 1% per year). Further analysis of the data indicated that most of the change had occurred since 1981. A critical question was whether the satellite data had been analysed correctly, and if so whether the observed decreases in total column ozone since the late 1970s are due to natural causes such as a decrease in solar radiation (from solar maximum to solar minimum), the 1982 eruption of El-Chichon, or the 1982 El-Niño event, or whether it is due to human activities such as the use of chlorofluorocarbons.

Also, prior to September of 1987, trend estimates had been made for the altitude profile of ozone from the network of ground-based Dobson stations that used the Umkehr technique. Deriving an accurate trend for changes in the vertical distribution of ozone is much more difficult than for the total column because there are fewer stations and the Umkehr measurements are very sensitive to the presence of aerosols in the atmosphere. After correcting the derived ozone amounts for the aerosol interference, an estimate of the ozone trend in the middle and upper stratosphere (30 to 40 km) gave a 2 to 3% decrease for the period 1970 to 1980. The magnitude of the change is broadly consistent with the predictions of photochemical models, which predict that chlorine will have its maximum effect at this altitude. In addition, an analysis of unpublished SBUV data indicated that there had been a decrease between 1979 and 1984 in the abundance of ozone in the middle and upper stratosphere. A maximum decrease of about 3% per year was reported at around 50 km altitude.

During the fall of 1986, NASA in conjunction with the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA), the World Meteorological Organization (WMO), and the United Nations Environmental Program (UNEP) launched a major review of all ozone data. A panel composed of eminent scientists from federal agencies, research institutions, private industry, and universities formed an Ozone Trends Panel, that involved over one hundred scientists, to study the question of whether carefully re-evaluated ground-based and satellite data would support these findings. The report critically assessed the present knowledge about whether the chemical composition and physical structure of the stratosphere had changed over the last few decades and whether our current understanding of the influence of natural phenomena and human activities is consisttent with any observed change. The report was different from most previous national and international scientific reviews in that it did not simply review the published literature, but performed a critical reanalysis and interpretation of nearly all ground-based and satellite data for total column and vertical profiles of ozone. To aid in the interpretation of the results of the reanalysis a series of theoretical calculations were performed for comparison with the reanalysed ozone data. The executive summary of the scientific assessment was issued on March 15, 1988. The report covers: (a) Calibration Procedures and Instrument Performance; (b) Information Content of Algorithms; (c) Trends in Total Column Ozone; (d) Trends in the Vertical Distribution of Ozone; (e) Trends in Stratospheric Temperatures; (f) Comparison of Observed and Theoretically Predicted Trends of Ozone; (g) Trends in Source Gases; (h) Trends in Minor Constituents; (i) Trends in Aerosol Abundances and Distributions; (j) Observations and Theories Related to the Antarctic Ozone Hole; and (k) Statistical Procedures used to Analyse Trend Data.

The key findings of the Ozone Trends Panel included:

a) Global Total Column Ozone Trends Between 1969 and 1986

Analysis of data from ground-based Dobson instruments, after allowing for the effects of natural geophysical variability (solar cycle and the quasi-biennial oscillation (QBO)), show measurable decreases from 1969 to 1986 in the annual average of total column ozone ranging from 1.7 to 3.0%, at latitudes between 30 and 64° in the Northern Hemisphere (Table 2). The decreases are most pronounced, and ranged from 2.3 to 6.2%, during the winter months, averaged for December to March, inclusive. Dobson data are not adequate to determine total column ozone changes in the tropics, the subtropics, or the Southern Hemisphere outside Antarctica. Calculations using two-dimensional photochemical models predict that the increasing atmospheric concentrations of the trace gases should have caused a small decrease in ozone globally between 1969 and 1986. Predicted decreases between 30 and 60° latitude in the Northern Hemisphere for this period ranged from 0.5 to 1.0% in summer and 0.8 to 2.0% in winter, where the ranges reflect the results from most models. The model calculations are broadly consistent with the observed changes in column ozone, except that the mean values of the observed decreases at mid- and high-latitudes in winter are larger than the mean values of the predicted decreases. The observed changes may be due wholly, or in part, to the increased atmospheric abundance of trace gases, primarily chlorofluorocarbons (CFCs).

b) Global Total Column Ozone Trends Between 1979 and 1986

Satellite instruments on Nimbus-7 (Solar Backscatter Ultraviolet (SBUV) and Total Ozone Mapping Spectrometer (TOMS)) have provided continuous global records of total column ozone since October 1978. Unfortunately they suffer from instrumental degradation of the diffuser plate, the rate of which cannot be uniquely determined. Thus, the data archived as of 1987 cannot be used alone to derive reliable trends in global ozone. The SBUV and TOMS satellite data have been normalized by comparison with nearly coincident ground-based Dobson measurements in the Northern Hemisphere. The resulting column ozone data, averaged between 53°S and 53°N, show a decrease of about 2.5% from October 1978 to October 1985 (Table 3). This period is approximately coincident with the decrease in solar activity from the maximum to the minimum in the sunspot cycle. Theoretical calculations predict that the total column ozone would decrease from solar maximum to solar minimum by an amount varying between 0.7 and 2% depending upon the model assumed for solar ultraviolet variability. Thus, the observed decrease in ozone from the satellite data between late 1978 and late 1985 is predicted to have a significant contribution from the decrease in solar activity during this period.

c) Global Trends in the Vertical Distribution of Ozone Between 1979 and 1986

Analyses of the satellite (SAGE) and ground-based (Umkehr) data obtained since 1979 show small decreases in the ozone concentrations; these decreases peak near 40-km altitude with mean values of 3 and 9%, respectively (Figure 3). These observational values agree within the range of their errors. Theoretical calculations predict that local ozone concentrations near 40-km altitude should have decreased between 1979 and 1985 by 5 to 12% in response to the decrease in solar ultraviolet output and the increased atmospheric abundance of trace gases. This range represents the decreases predicted from the different models for the latitude belt 30 to 60°N for all seasons. Stratospheric temperatures between 45- and 55-km altitudes have decreased globally by about 1.7 K since 1979, consistent with decreases in upper stratospheric ozone of less than 10%.

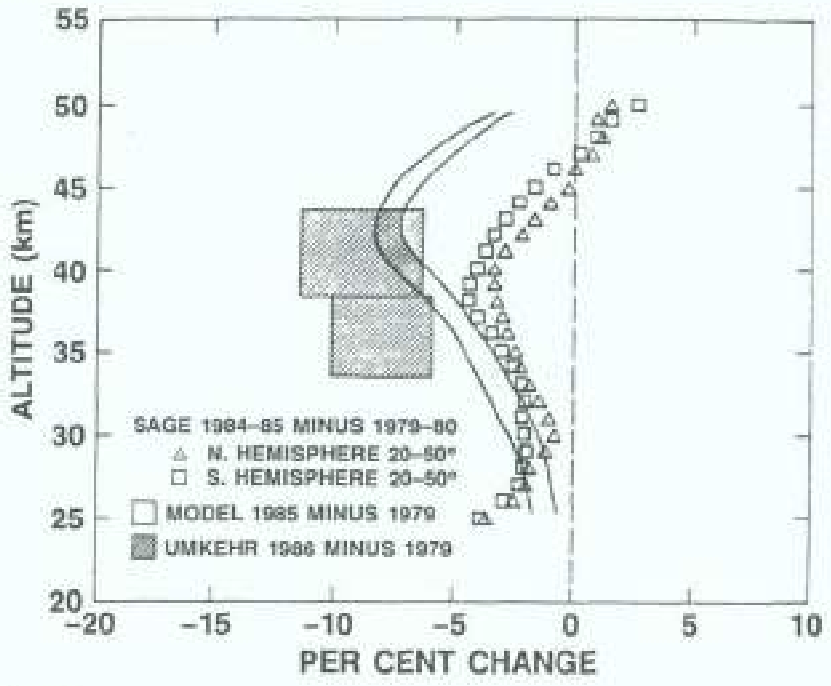

Figure 3.
Changes (%) in mid-latitude ozone concentration profiles from 1979 to 1987. Differences based on SAGE I-II (1979-80 vs 1984-85) averaged over 20x-50x latitude are shown by squares; averaged Umkehr data for the northern mid-latitudes (1979 vs 1986) are denoted by the hatched areas; and model predictions (1979 vs 1985) are given by the band.

5. ANTARCTIC OZONE: OBSERVATIONS AND THEORY

Prior to September 1987 important new observational evidence on ozone changes had been obtained. Data from a single Dobson instrument at Halley Bay (76°S, 27°W) have indicated a considerable decrease (greater than 50%) in the total column content of ozone above the Antarctic during the spring period (late August to early November) since 1957, with most of the decrease apparently occurring since the mid-1970s.

Three basic theories have been proposed to explain the observed decrease in springtime Antarctic ozone that has been occurring since the late 1970s:

A) The hole is caused by the human activity of increasing the atmospheric loading of chlorinated (CFCs) and brominated (Halons) chemicals. These compounds could then efficiently destroy stratospheric ozone because of the special geophysical conditions that exist in the Antarctic atmosphere.

B) There have been changes in the circulation of the atmosphere, which now transports ozone-poor air into Antarctica.

C) Periodically enhanced abundances of the oxides of nitrogen produced by solar activity can cyclically destroy ozone.

A major ground-based field measurement campaign took place at McMurdo between August and November of 1986 to study the ozone layer above the Antarctic. This campaign was cosponsored and coordinated by three U.S. scientific agencies: the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA); and the Chemical Manufacturers Association (CMA). The campaign was exceedingly successful and the data from the four groups of experimentalists have now been published. An extensive set of measurements of the chemical composition was obtained including hydrochloric acid (HCl), chlorine nitrate ($ClONO_2$), chlorine monoxide radical (ClO), chlorine dioxide (OClO), nitric acid (HNO_3), nitrogen dioxide (NO_2), nitric oxide (NO), nitrous oxide (N_2O), hydrofluoric acid (HF), ozone (O_3) and other chemical species. From their data it is clear that the chemical composition of the lower stratosphere over Antarctica is significantly perturbed relative to that expected from theoretical considerations using standard homogeneous chemistry. The abundances of odd nitrogen species are low, while the partitioning of odd chlorine species is significantly different from that observed at mid-latitudes. However, from those data alone it was premature to conclude that the cause of the loss of ozone over Antarctica is due to chlorofluorocarbons. Consequently, while that campaign was a major success, with excellent data on the chemical composition of the springtime Antarctic atmosphere, it was clear that additional scientific data were required for further refinement of our understanding of the processes controlling ozone in and around Antarctica.

Therefore NASA, NOAA, NSF and the CMA mounted a major campaign using ground-based, aircraft and satellite instrumentation during the Antarctic springtime, from mid-August onwards, in 1987. It consisted of two components: (a) the 1987 ground-based campaign, coordinated by NSF at McMurdo, which was somewhat expanded in scope compared to the 1986 NOZE I campaign; and (b) a 1987 aircraft campaign, organized and managed by NASA on behalf of the four agencies, using the NASA ER-2 and DC-8 aircraft as platforms for instruments operated by scientists from NASA Centers, the NOAA Aeronomy Laboratory, the

National Center for Atmospheric Research, universities and private industry. The campaign utilized real-time ozone and meteorological satellite data.

These aircraft were equipped with state-of-the-art instrumentation to determine the chemical composition and physical state of the atmosphere. The scientific payloads for both the ER-2 and the DC-8 were selected to critically test the proposed CFC-halon, solar, and dynamical theories. In addition, the scientific payload was also equipped to obtain a broad base of scientific data in case all currently proposed mechanisms were incorrect. The campaign, which involved over 150 scientists, engineers and pilots, was based in Punta Arenas, Chile, and ran from mid-August until the beginning of October.

The processes controlling the abundance and distribution of ozone in Antarctica are complex and intertwined. However, given the success of this campaign, the scientific community is now in a position to appreciate more fully this exquisite balance between the meteorological motions and the photochemistry.

The key findings are that the unique meteorology during winter and spring over Antarctica sets up the special conditions of an isolated air mass (polar vortex) with cold temperatures required for the observed perturbed chemical composition, and that the weight of evidence strongly indicates that man-made chlorine species are primarily responsible for the observed decrease in ozone within the polar vortex.

5.1 Ozone Observations

Ground-based and satellite data have shown conclusively that the springtime Antarctic column ozone decreased rapidly after the late 1970s. The high degree of interannual variability and the lack of satellite-based ozone measurements precludes an accurate assessment of the magnitude of any ozone decreases prior to the late 1970s. The Antarctic ozone hole develops primarily during September, and the rate of loss of ozone within a given year appears to be increasing. Total column ozone (at all latitudes south of 60°S) was lower in the Antarctic springtime in 1987 than in any previous year since satellite measurements began (late 1978). In October 1987, the monthly zonal mean amount of total ozone at latitudes 50, 60, 70 and 80°S was about 8%, 20%, 40% and 50% lower, respectively, than in October 1979. In 1987, a region of low ozone over Antarctica lasted until late November/early December, which is the longest period since the region of low ozone was first detected (Figure 4). Although the ozone depletion is largest in the Antarctic springtime, normalized TOMS data indicate that total column ozone has decreased since 1979 by more than 5% at all latitudes south of 60° throughout the year (Figure 5). At this time it is premature to judge if this is caused by a dilution of the air from the region of very low ozone, a changed meteorology, or some other unidentified phenomenon. However, at least some of the decrease is likely due to dilution. The magnitude of ozone changes during the polar night are uncertain because there are no TOMS satellite data during this period since the instrument depends upon reflected sunlight for its measurement. Balloon ozonesonde and SAGE II satellite data indicate that the ozone decrease over Antarctica is mainly confined to an altitude region between about 12 and 24 km. The ozone concentrations between 15 and 20 km in October of 1987 have decreased by more than 95% from their values two months earlier (Figure 6).

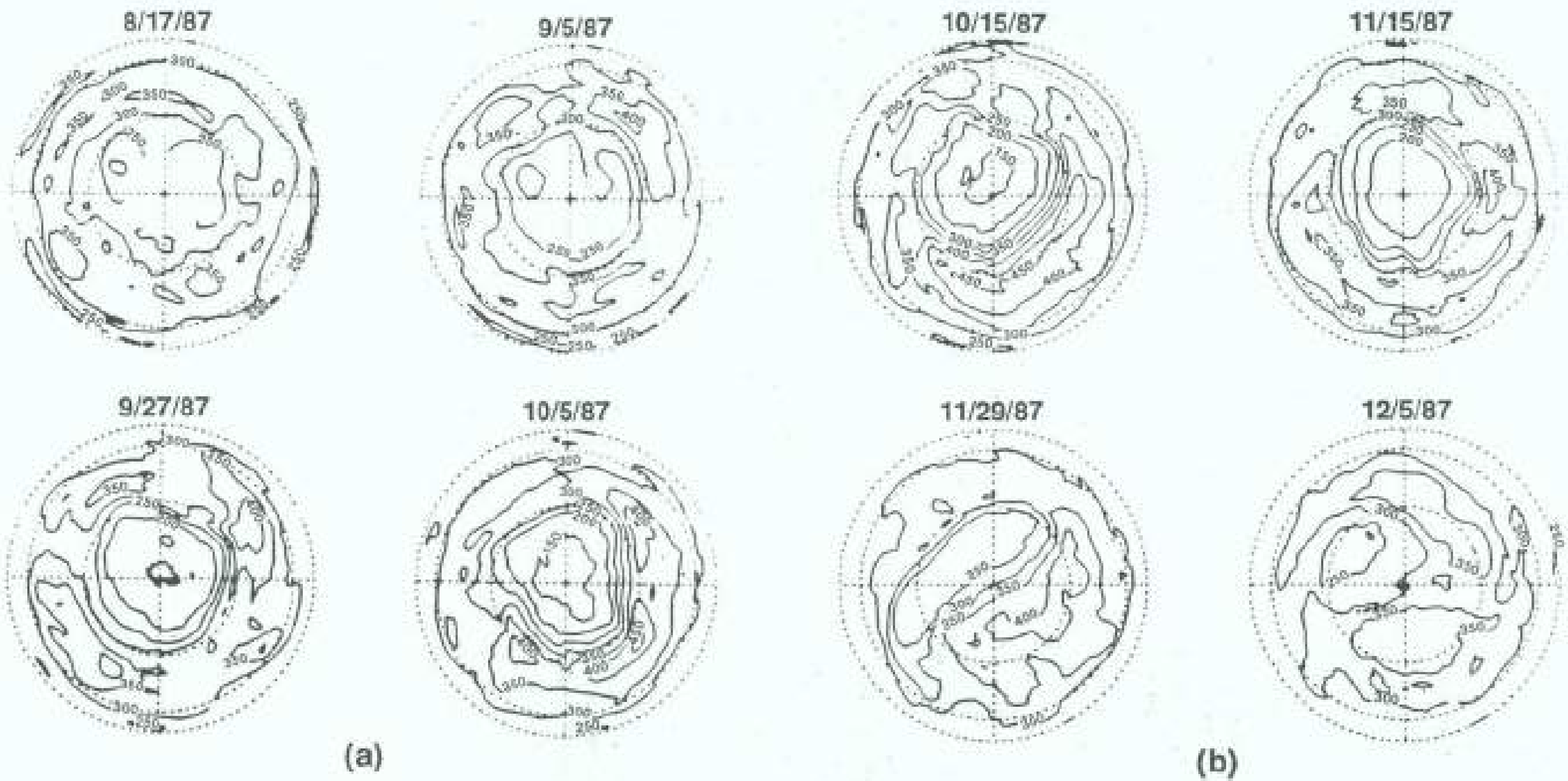

Figure 4.
Daily maps of total ozone measured by TOMS (polar orthographic projection). The periods shown include (a) the formation of the ozone minimum in 1987, and (b) the breakup of the ozone minimum in 1987.

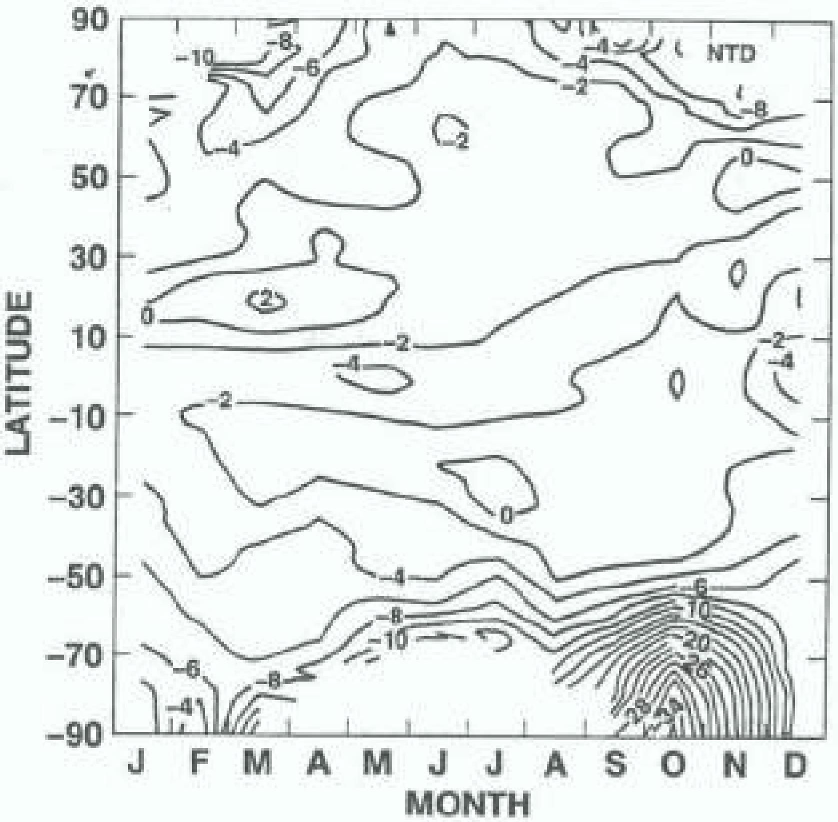

Figure 5.
Changes by month and latitude in total ozone between 1979/1980 and 1986/1987 as measured with TOMS on the Nimbus-7 satellite. (Two-year averages are used to minimize differences originating with the QBO.) Contour plots are given for intervals of 2% change. The TOMS data have been normalized to the Dobson (NTD) ground-based data. The TOMS instrument operates with sunlight scattered from the atmosphere and therefore provides no data from the areas during the polar night.

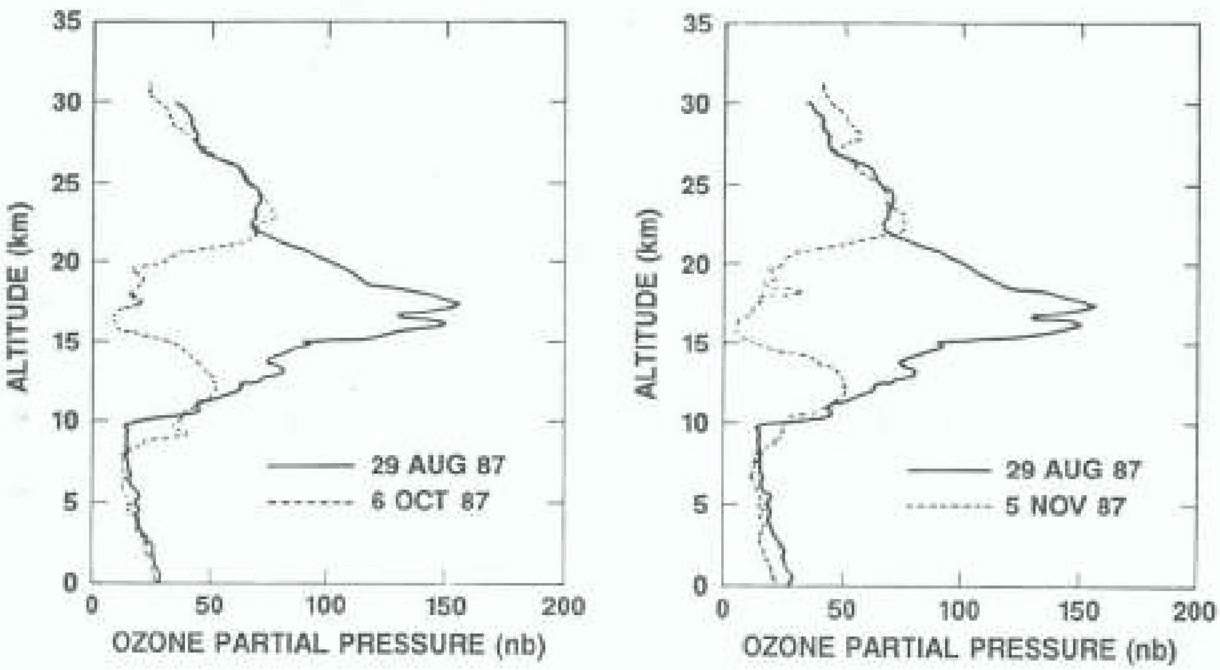

Figure 6.
Vertical profiles of ozone using ECC sondes from McMurdo, Antarctica.

5.2 Polar Stratospheric Cloud Observations

Polar stratospheric clouds (PSCs) form during the winter while the stratospheric air over Antarctica becomes very cold with the long absence of sunlight. The vertical extent of PSCs correlates with cold temperature. The atmospheric temperatures increase during springtime, starting at higher altitudes; this results in the maximum altitude at which PSCs can exist decreasing with time. Satellite observations of PSCs began in late 1978. The persistence of PSCs, which are thought to play a key role in the formation of the "Antarctic ozone hole", has increased since 1984. The 1985 observations show for the first time the occurrence of PSCs at 16 km throughout the month of September and into October. Further, PSCs lasted into October in 1987 at altitudes as high as 18 km.

5.3 Temperature Observations

Substantial evidence has been presented for a decline in the temperature of the lower stratosphere over Antarctica since 1979 in October and November. The downward trends appear most strongly in the month of October when a substantial decline is observed in the middle and the lower stratosphere. During the month of November the trend is confined to the lower stratosphere with a maximum negative trend of about 1 K/year centred at about the 100-mb (16-km) level. August and September temperatures show little or no trend over the 1979-1985 period. The October decline appears in both rawinsonde station data and NMC-gridded data that include satellite information. This suggests that the ozone depletion has a significant impact on the normal spring radiative warming of the Antarctic stratosphere.

5.4 Transport Theories for the Antarctic Ozone Hole

The polar lower stratosphere of the Southern Hemisphere is very different from that of the Northern Hemisphere. The strong zonal symmetry of surface conditions in the Southern Hemisphere produces a circulation that is much more symmetric and undisturbed by planetary wave activity than that of the Northern Hemisphere. This leads to conditions in the lower stratosphere in which the lower stratospheric polar vortex is relatively intense, maintaining its integrity throughout the winter season and well into spring. Dynamical modelling suggests that relatively little mixing with air at other latitudes occurs, at least at altitudes where the vortex is sufficiently intense. The air within the polar vortex thus remains very cold and dynamically isolated. When the sunlight returns to the south pole in springtime, temperatures may be near radiative equilibrium. Solar heating might therefore play a more important role in driving the seasonal change there than it does in the Northern Hemisphere, where temperatures are kept well above radiative equilibrium by stronger wave forcing.

The observed Antarctic ozone decline occurs in the lower stratosphere where transport by atmospheric motions has a major influence on the ozone mixing ratio. It is reasonable to suggest that a relatively small climate shift in the Southern Hemisphere could produce a significant change in the total ozone over Antarctica, since the transport of ozone into that region during winter and spring is limited by dynamical constraints associated with the symmetry of the circulation and is very weak in comparison to the almost complete mixing that occurs in the Northern Hemisphere. It is also conceivable that colder temperatures at the beginning of spring produced by weaker wave forcing, or enhanced solar heating in springtime associated with increased aerosols, could lead to transient upwelling during the spring season that would contribute to the springtime ozone decline. But it is very unlikely that diabatic heating rates would be both sufficiently large and suitably distributed to produce the ozone column reduction observed in 1987.

Evidence from NMC analyses suggests a decline in lower stratosphere temperatures over Antarctica over the period 1979-85 for October and November, and a corresponding decline in the wave driving for September. Calculations of the radiative temperature change associated with the observed ozone decline suggest that the radiative effect of the ozone decline is comparable in magnitude to the observed trend. The radiative temperature change is largest at the 100-mb level and its vertical structure in the lower stratosphere is very similar to that of the NMC trend for November. During October, a middle stratospheric temperature decline is observed in addition to the lower stratospheric decline. This temperature decline in the middle stratosphere is not expected on the basis of radiation alone, but appears more likely to be associated with decreased wave driving during the previous month. Some combination of altered wave driving and radiative response to ozone changes seems necessary to explain the trend observed in NMC data over the 1979-85 period.

Published attempts to model the springtime Antarctic ozone decline purely as a response to changed transport processes require that ozone-poor air be moved into the lower stratosphere from below. Such a movement of air would also requirs local increases of long-lived trace species of tropospheric origin, such as N_2O, CCl_3F (CFC-11) and CCl_2F_2 (CFC-12). Data from the instruments aboard the ER-2 aircraft show that these trace species remain relatively constant at and above the 400-K potential temperature surface (about 15-16 km) during September while the ozone declines significantly, so that the transport of ozone-poor air is unlikely to contribute significantly to the overall decline above this altitude. At lower potential temperatures (i.e. at lower altitudes) the ozone decline may be caused by a combination of chemical and meteorological processes. These data support the hypothesis that a chemical sink of ozone is required within the polar vortex. However, the role of radiative and dynamical processes in establishing the conditions necessary for the ozone depletion and in controlling the temperature, cloudiness and precise degree of isolation of the Antarctic ozone hole must be carefully considered.

5.5 Chemical Theories and Observations for the Antarctic Ozone Hole

Two distinctly different classes of chemical theories have been proposed to explain the observed loss of springtime Antarctic ozone. The first proposes that the abundance of the oxides of nitrogen are periodically enhanced owing to changes in solar activity, while the second proposes that the efficiency of the reactions involving chlorine and bromine species are enhanced. Current theories that attempt to describe the ozone loss in the Antarctic stratosphere by means of catalytic chemical destruction involving chlorine or bromine all have the following features:

1) Conversion of a substantial fraction of the Cl_x contained in the reservoir molecules HCl and $ClONO_2$ into active forms of chlorine such as ClO either by heterogeneous reactions in PSCs or by enhanced OH abundance

2) Cycles that effectively catalyse the recombination of O_3 with itself, involving ClO in the rate-limiting step with HO_2, itself, or BrO, forming HOCl, the Cl_2O_2 dimer, or Cl and Br, respectively

3) Drastic reduction in NO_2 abundance resulting from the removal of NO_y as HNO_3 in the condensed phase of PSCs

Recent laboratory data have shown conclusively that heterogeneous reactions of $ClONO_2(g)$ and $N_2O_5(g)$ with $H_2O(s)$ and HCl(s) are rapid enough to play an important role in the chemistry of the Antarctic stratosphere. In particular, HCl was shown to diffuse readily into water ice crystals at low temperatures forming solid solutions. Dissolved HCl in solid solutions was also shown to be very mobile greatly enhancing its reactivity with reactant species on the crystal surfaces. The HNO_3 formed by $ClONO_2$ reactions with ice and HCl-ice remains in the condensed phase, whereas the chlorinated products desorb into the gas phase.

Our understanding of the chemical composition of the springtime Antarctic atmosphere increased dramatically during 1986 and 1987. Observations of the vertical distribution and column content of a large number of species, including ozone (O_3), water (H_2O), chlorine monoxide radical (ClO), chlorine dioxide (OClO), chlorine nitrate ($ClONO_2$), hydrochloric acid (HCl), bromine monoxide radical (BrO), hydrofluoric acid (HF), nitric oxide (NO), nitrogen dixoide (NO_2), nitric acid (HNO_3), total odd nitrogen (NO_y), nitrous oxide (N_2O), methane (CH_4), carbon tetrachloride (CCl_4), methylchloroform (CH_3CCl_3), and CFCs 11 and 12, were made by ground-based observations from McMurdo in 1986 and 1987, and by in-situ and remote sensing techniques from the ER-2 and DC-8 aircraft based in Punta Arenas, Chile, in 1987. In addition, the size distribution, abundance and composition of particles was determined by instrumentation aboard the ER-2; the vertical distribution of aerosols from 12 to 28 km by the DC-8 lidar; and the size distribution from balloon-sondes from McMurdo, in an effort to understand the role of heterogeneous processes. The data clearly demonstrated that the chemical composition of the Antarctic stratosphere in springtime was highly perturbed compared with that expected at these latitudes based on measurements at mid-latitudes and chemical models that predate these new data. The distribution of chlorine species is significantly different from that observed at mid-latitudes, as is the abundance and distribution of nitrogen species. At present it is not clear whether the abundance of total inorganic chlorine (the summed abundance of chlorine in all chemical forms) is perturbed relative to that expected, or just its partitioning. In addition, it was observed that the amount of total water within the chemically perturbed region of the vortex was significantly lower than that immediately outside it at the same potential temperatures.

Based on the observations made at McMurdo and from the aircraft campaign the weight of observational evidence strongly suggests that chemical mechanisms involving made-made chlorine are primarily responsible for the observed decrease in ozone within the polar vortex at potential temperatures greater than 400 K. It is clear that meteorology sets up the special conditions of an isolated air mass (polar vortex) with very cold temperatures being required for the perturbed chemistry. It is also clear from the ER-2 flights in 1987 that the region of dehydrated and denitrified air maintained a sharply defined latitude gradient throughout most of the campaign. The meteorological flow must therefore have been such as to maintain a kind of "restrainment vessel", in which the perturbed chemistry could proceed without being influenced by mixing in more normal stratospheric air from outside or below. The concept of mixing at the region of sharp latitudinal gradient is important, since it has the potential to supply nitrogen oxides that would tend to decelerate the chlorine chemistry. The meteorology is thus important in the termination phase as well as in the initiation phase.

As stated earlier there is strong evidence that the chemical composition of the springtime Antarctic stratosphere is highly perturbed compared with that of mid-latitudes. The data show that although the abundance of total chlorine is probably consistent with that expected, the partitioning of Cl_x was highly perturbed compared with that observed at mid-latitudes and expected at high latitudes. The concentrations of HCl were low, whereas the concentrations of OClO and ClO were significantly elevated. Somewhat elevated concentrations of $ClONO_2$ were also observed. This is clear evidence that the balance was dramatically shifted from inactive forms of chlorine towards reactive species that can catalytically destroy ozone. In-situ ER-2 and ground-based measurements of ClO showed that its abundance within the chemically perturbed region of the Antarctic atmosphere is a factor of 100 to 500 greater than that measured at comparable altitudes at mid-latitudes, reaching a maximum value of about 1 ppbv near local noon at approximately 18.5-km altitude. The in-situ aircraft data demonstrated that within the chemically perturbed region of the vortex near 18.5 km the abundance of ClO during September 1987 was sufficient to account for the destruction of ozone <u>if</u> our current understanding of the chlorine-ozone ClO dimer catalytic cycle is correct. The rate of decrease in ozone during September at the highest altitudes at which the ER-2 was operated was consistent with simultaneously observed concentrations of ClO. Another line of observational evidence consistent with ozone destruction by chlorine catalysis is that during the month of August, no strong positive, large-scale correlation between ClO and O_3 was observed, whereas by the middle of September, while the ozone concentration was dropping at ER-2 altitudes, a strong anti-correlation developed on the larger spatial scales.

The bromine monoxide radical was observed at abundances of a few pptv within the chemically perturbed region of the vortex at ER-2 flight levels. The abundance of BrO decreased at lower altitudes. Total column measurements of BrO from the DC-8 and from McMurdo in 1987 are currently being analysed. The low measured abundances of BrO mean that the catalytic cycle involving the BrO + ClO → Br + Cl + O_2 reaction is not the dominant catalytic mechanism for ozone destruction, but nevertheless probably accounts for about 10% of the ozone destruction at the ER-2 flight levels.

The in-situ ER-2 observations of the abundance of odd nitrogen, which is the sum of all nitrogen-containing reservoir and radical species, show, like total water, very low values within the chemically perturbed region of the vortex, indicating that the atmosphere has been denitrified as well as dehydrated. Abundances of gas phase NO_y of 8-12 ppbv were observed outside the chemically perturbed region, whereas abundances of 0.5 to 4 ppbv were observed inside the chemically perturbed region. In addition, some of the NO_y observations suggest that NO_y component species are incorporated into polar stratospheric cloud (PSC) particles, and nitrate was observed in the particle phase on some of the filter samples and on some of the wire impactor samples taken in the chemically perturbed region of the vortex. The ground-based and aircraft column measurements of nitric oxide, nitrogen dioxide, and nitric acid exhibit a strong decrease in the abundance of these species towards the centre of the vortex. These low values of nitrogen species are contrary to all theories requiring elevated levels of nitrogen oxides, such as the proposed solar cycle theory.

Observational data that air within the chemically perturbed region of the vortex is dehydrated and that the NO_y abundances are very low are consistent with theories that have been invoked whereby the chlorine reservoir species, $ClONO_2$ and HCl, can react on the surfaces of polar stratospheric clouds to enhance the abundance of active chlorine species, i.e., ClO. The observations also support the picture that the abundance of NO_y is low because odd nitrogen can be removed from the atmosphere by being tied up in ice crystals, which can then gravitationally settle to much lower altitudes. Low abundances of NO_y are needed to prevent the rapid reconversion of ClO to $ClONO_2$.

5.6 Global Implications

Besides its dramatic character and its sudden appearance, a reason for concern about the "ozone hole" is that the processes that appear to play a decisive role in the polar environment and that are not fully understood or included in atmospheric models could be important at other latitudes and contribute to a global ozone depletion. There are two observations discussed in this Ozone Trends Report that suggest that there is an urgent need for additional research:

a) There is evidence of ozone depletions in winter at mid- and high-latitudes in the Northern Hemisphere that are larger than those calculated using photochemical models.

b) Although the column ozone depletion is largest in the Antarctic springtime, ozone appears to have decreased since 1979 by more than 5% at all latitudes south of 60°S throughout the year.

There are two processes currently not included in photochemical models that might provide explanations for these two observations: (1) the observation of winter-time ozone decreases in the Northern Hemisphere might be explained by heterogeneous chemical processes, and (2) the observation of year-round decreases in ozone outside of the polar vortex in the Southern Hemisphere might be explained by a "dilution effect" from the springtime Antarctic ozone hole.

1) Since aerosols are present in the stratosphere at all latitudes, it is important to understand if heterogeneous processes similar to those that are important in Antarctica could occur at other latitudes and possibly lead to ozone destruction in other regions of the atmosphere. At present the importance of heterogeneous processes at other latitudes is unknown. However, it is clear that even though there are significant differences in the meteorology of the Arctic and Antarctic, PSCs are formed in the Arctic and might play an important role in controlling ozone. Arctic temperatures at 70 mb reached -87°C in early February 1984, probably sufficient to cause dehydration. An intensive field measurement campaign similar to that used to investigate the Antarctic ozone hole is required.

It should be noted that both the abundance and catalytic efficiency of the liquid sulphuric acid aerosol particles in the global Junge layer are lower than those of the PSCs over Antarctica. However, some heterogeneous processes might periodically become important and lead to ozone destruction after large volcanic eruptions, when the amount of particles in the stratosphere is enhanced by several orders of magnitude. If heterogeneous processes are important at mid-latitudes then the concentrations of ClO should be elevated in the Junge layer as they were over Antarctica. Measurements of the vertical distribution of the ClO radical at mid-latitudes in the Northern Hemisphere from balloon (24-40 km) and aircraft platforms (15-20 km) show that the abundance of ClO in the peak region of the aerosol layer, i.e., 16-20 km, is not as significantly elevated as in the chemically perturbed region of the Antarctic ozone hole. This indicates that the conversion of inactive reservoir forms of inorganic chlorine, i.e., HCl and $ClNO_3$, to the active form, i.e., ClO, does not appear to be detectably enhanced (less than a factor of 3 to 5) in this region of the stratosphere.

2) The possibility of a "dilution effect" of the polar anomaly observed in spring over Antarctica must be considered as another possible global (or least Southern Hemisphere) implication of the Antarctic ozone hole. Since the chemical lifetime of ozone in the lower stratosphere is of the order of a year, air masses with depleted ozone amounts move toward the equator as soon as the winter vortex ceases to exist (November and December). While volumes of air with extremely low ozone concentrations are transported toward lower latitudes every year, the effects might partly accumulate and a limited change in the total hemispheric ozone content could become noticeable. At present this issue is being addressed using both multi-dimensional theoretical models and the TOMS satellite data by examining changes in total column ozone in both hemispheres.

6. MODEL RELIABILITY

A key question still remains concerning the reliability of the models used to predict ozone change. Given that we cannot directly test the accuracy of a prediction of the future state of the atmosphere, including the distribution of atmospheric ozone, we must test the models by trying to simulate the present state of the atmosphere, including the distribution of atmospheric ozone, or by trying to simulate the evolution of the atmosphere, and of ozone in particular, over the past few years. This is done by comparing model predictions with atmospheric observations.

We should note that nearly all the key chemical constituents that are predicted to be present in the atmosphere, and that are important in ozone photochemistry, have now been observed. In general, the models predict the distribution of the chemical constituents quite well. However, the measurements are not adequate for critically testing the reliability of the photochemical models. Close examination of the intercomparison of measurements and model simulations of the present atmosphere reveal several disturbing disagreements. One of the major disagreements appears to be that modelled ozone concentrations are typically 30 to 50% lower than measured ozone concentrations in the upper stratosphere where it should be easiest to predict the concentration of ozone, and where chlorine is predicted to have its maximum effect. These types of disagreements limit our confidence in the predictive capability of these models. In the end, however, our predictive capability will be tested by measuring the changes taking place in the atmosphere. This will require careful measurements of critical species to be carried out over long time periods, i.e. decades. NASA, NOAA and CMA recently cosponsored a workshop to design a "Network for the Detection of Stratospheric Change". This network would be designed primarily to provide the earliest possible detection of changes in the chemical and physical structure of the stratosphere, and the means to understand them. This network would also provide an invaluable data set of latitudinal and seasonal variations in stratospheric chemical composition to test the validity of multidimensional models. Implementation of such a network is a high priority.

The conclusions from the Ozone Trends Report indicate that depletions in column ozone since 1969 at northern mid-latitudes appear to be greater than predicted. If the discrepancy between models and observations over the past 20 years is significant, then a major question arises as to what uncertainties should be placed on our current predictions for the next 100 years. Potential causes of the larger than predicted decrease in column ozone centre on the lower stratosphere since the calculated changes in the ozone concentrations in the upper stratosphere are consistent with observations. Of the many possible sources of error in the Ozone Trends Report simulations, three may be singled out: (1) errors in the standard gas-phase chemistry involving chlorine in the lower stratosphere; (2) failure to include a heterogeneous chemistry in the Northern Hemisphere that is similar to, but different from, that occurring over Antarctica; and (3) a small long-term trend in lower stratospheric circulation and temperatures. Points (1) and (2) can be addressed directly by a vigorous research program involving theoretical modelling, laboratory studies and, especially, aircraft expeditions to measure the photochemistry of the lower Arctic stratosphere. Such a measurement campaign would be similar to the Antarctic campaign of September 1987, which was led by NASA, involving NOAA, universities and international cooperation. If the unexplained part of the recent decline is associated with point (3), climate change, then it would have been difficult to detect over the last 20 years. Hence, we must work on the feedback of climate change on ozone perturbations.

7. KEY FINDINGS AND CONCLUSION

The composition of the atmosphere is now changing rapidly owing to a variety of influences of both natural and human origin. These changes have implications for a variety of problems and in particular demonstrate the connections among the studies of global tropospheric and stratospheric chemistry, trace gases and climate. The Antarctic ozone phenomenon vividly demonstrates that the environment does not always change slowly, linearly or predictably in response to a perturbation. Consequently, we must realize that a global-scale experiment on the atmosphere of planet earth is being conducted by humankind without our fully understanding the consequences.

After the Montréal Protocol on Substances that Deplete the Ozone Layer was signed in September 1987 there have been two significant scientific findings:

1) The weight of scientific evidence strongly indicates that man-made chlorine species are primarily responsible for the observed decrease in springtime Antarctic ozone within the polar vortex.

2) Analysis of data from ground-based Dobson instruments, after allowing for the effects of natural geophysical variability (solar cycle and the quasi-biennial oscillation (QBO)), shows measurable decreases from 1969 to 1986. The model calculations are broadly consistent with the observed changes in column ozone, except that the mean values of the observed decreases at mid- and high-latitudes in winter are larger than the mean values of the predicted decreases. The observed changes may be due wholly, or in part, to the increased atmospheric abundance of trace gases, primarily chlorofluorocarbons (CFCs).

One ramification of finding (1) is that even if the Montréal Protocol was ratified by all nations of the world the Antarctic ozone hole would remain forever. This conclusion is simply based on the fact that even with a fully ratified Montréal Protocol the atmospheric abundance of chlorine will approximately double from today's level of about 3 ppbv during the next few decades. Assuming our current understanding of the role of man-made chlorine in producing the Antarctic ozone hole is correct then the Antarctic ozone hole will not disappear until the atmospheric abundance of chlorine is reduced to the levels of the late 1960s or early 1970s of about 2 ppbv. This would require a reduction of greater than 85% (close to a complete phase-out) of the present emission rates of the fully halogenated CFCs, and careful consideration of what emission rates of the non-fully halogenated chlorine-containing chemicals, such as CH_3CCl_3, are acceptable. Even with a complete cessation in the emissions of the fully halogenated CFCs, and a cut-back in other gases such as CH_3CCl_3, it would take many decades for the atmospheric abundance of chlorine to decrease to 2 ppbv. It should be noted that the Antarctic ozone hole could disappear if there were to be a significant increase in the temperature of the Antarctic stratosphere thus precluding the formation of the Polar Stratospheric Clouds (PSCs), which are required for the man-made chlorine to produce the Antarctic ozone hole.

One implication of finding (2) is that the theoretical models that were used as the basis of the Montréal Protocol might be underestimating the adverse impact of the CFCs on ozone, especially at high latitudes in winter. This will be examined through a comprehensive scientific campaign to be conducted during January and February of 1989 utilizing ground, aircraft, and satellite data.

Table 1. Updated global trends and tropospheric concentrations of source gases for 1986 (where appropriate and available, lifetimes are also tabulated).

Source Gas	Concentration (1986 pptv)	Rate of increase (1986 pptv/yr)	Rate of increase (%/yr)	Lifetime (years)
CCl_2F_2 (a)	392	16.7	4.3	111^{+222}_{-44}
CCl_3F (a)	226	9.0	4.0	74^{+31}_{-17}
CH_3CCl_3 (a)	139	6.2	4.5	7±1
CCl_4 (a,b)	129	1.8	1.4	~40
CCl_2FCClF_2 (b)	32	3.6	11.3	~90
$CHClF_2$ (b)	92	6.3 (c)	7.1	~20
CH_3Cl	~600	-	-	~1.5
$CBrF_3$ (b)	2.0	0.3	15	~110
$CBrClF_2$ (b)	1.7	0.2	12	~25
CH_3Br (b)	10-15	?		~2
N_2O	$(306-309)\times10^3$	$(0.65-0.8)\times10^3$	0.2-0.3	~150
CH_4 (d)	1638×10^3	$(13-16)\times10^3$	0.8-1.0	~10
CO (b)	103×10^3	(see 8.7)		0.1-0.2
CO_2 (d)	345×10^3	1.2×10^3	0.4	
Total Cl (e)	3185	104	3.3	
Total F (e)	1300	67.5	5.2	
Total Br (e)	14-19	0.5	3-4	

(a) The lifetimes of the first four species have been drived from observations; the others are adopted from World Meteorological Organization, 1986: Atmospheric ozone 1985: Assessment of our understanding of the processes controlling its present distribution and change. WMO Global Ozone Research and Monitoring Project Report No. 16; 3 Volumes.

(b) Calibration uncertain.

(c) Southern Hemisphere.

(d) 1985 data.

(e) The total amounts include all the appropriate compounds listed in this Table, which are thought to be the major species of global importance. Because of its exceedingly long lifetime, CF_4 is not included in total F.

Table 2. Coefficients of multiple regressions to re-analysed Dobson total ozone measurements collected into band averages (total per cent changes for period 1969-1986)+.

Month	Latitude Band 53°-64°N	40°-52°N	30°-39°N
Jan.	- 8.3±2.2	- 2.6±2.1	- 2.2±1.5
Feb.	- 6.7±2.8	- 5.0±2.2	- 1.2±1.9
Mar.	- 4.0±1.4	- 5.6±2.3	- 3.5±1.9
Apr.	- 2.0±1.4	- 2.5±1.7	- 1.7±1.3
May.	- 2.1±1.2	- 1.3±1.1	- 1.7±0.9
June	+ 1.1±0.9	- 1.8±1.0	- 3.3±1.0
July	+ 0.0±1.1	- 2.2±1.0	- 1.3±1.0
Aug.	+ 0.2±1.2	- 2.4±1.0	- 1.0±1.0
Sept.	+ 0.2±1.1	- 2.9±1.0	- 1.0±0.9
Oct.	- 1.1±1.2	- 1.5±1.5	- 0.9±0.8
Nov.	+ 1.5±1.8	- 2.4±1.3	- 0.1±0.8
Dec.	- 5.8±2.3	- 5.5±1.7	- 2.1±1.1
Annual average	- 2.3±0.7	- 3.0±0.8	- 1.7±0.7
Winter average**	- 6.2±1.5	- 4.7±1.5	- 2.3±1.3
Summer average***	+ 0.4±0.8	- 2.1±0.7	- 1.9±0.8
QBO*	- 2.0±0.6	- 1.3±0.6	+ 1.9±0.6
Solar*	+ 1.8±0.6	+ 0.8±0.7	+ 0.1±0.6

* Per cycle minimum to maximum.

** Winter months are December to March, inclusive.

*** Summer months are June to August, inclusive.

\+ All uncertainties given in this table and throughout this report represent one standard error. The total uncertainty in the linear trends for total column ozone (1969-1986) can be calculated by combining the standard errors given in this table with a systematic error of 0.5% by taking the square root of the sum of their squares. The uncertainties shown in this table increase by 0.2% or less.

Table 3. TOMS total column ozone changes+. This analysis represents a linear trend using an autoregressive model through the normalized TOMS data.

Latitude Band	Total Change: Nov. 1978 - Oct. 1985	Nov. 1978 - Nov. 1987
53°S - 53°N	- 2.6±0.5	- 2.5±0.6
0 - 53°S	- 2.6±0.9	- 2.9±0.9
0 - 53°N	- 2.1±1.5	- 1.8±1.4
53°S - 65°S	- 9.0±1.8	-10.6±1.6
39°S - 53°S	- 5.0±1.8	- 4.9±1.8
29°S - 39°S	- 3.2±2.4	- 2.7±2.1
19°S - 29°S	- 2.5±1.9	- 2.6±1.5
0 - 19°S	- 1.1±0.8	- 2.1±0.8
0 - 19°N	- 1.1±1.5	- 1.6±1.3
19°N - 29°N	- 3.5±2.2	- 3.1±1.9
29°N - 39°N	- 3.7±2.0	- 2.5±1.7
39°N - 53°N	- 2.7±1.7	- 1.2±1.5
53°N - 65°N	- 2.4±1.6	- 1.4±1.4

\+ All uncertainties given in this table represent one standard error.

ABSTRACT

ATMOSPHERIC OZONE

There is now compelling observational evidence that the chemical composition of the atmosphere is changing at a rapid rate on a global scale. The atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halons, and several chlorofluorocarbons (CFCs) are currently increasing at rates ranging from 0.2 to 5.0% a year. These changes in atmospheric composition reflect in part the metabolism of the biosphere and are due in part to national and international energy, agricultural and other industrial policies. Effecting a change in policy decisions will require a nationally and internationally coordinated program of interdisciplinary research.

Information acquired by remote sensing provides a unique resource for verifying model experiments on the magnitude of and rate of change in the vertical distribution and total column content of ozone with latitude and season. Satellite data have been used to demonstrate that ozone in springtime over Antarctica has decreased significantly since the mid-1970s and that the decreases were not just confined to an area above Antarctica but extended from the South Pole to about 45°S. Both chemical and dynamical explanations have been advanced to explain the observations.

Ozone is predicted to decrease in the middle to upper stratosphere owing primarily to the increasing concentrations of chlorofluorocarbons, and to increase in the troposphere owing primarily to the increasing concentrations of methane. The impact of changes in ozone and hence ultraviolet radiation reaching the earth's surface will be seen on human health, the productivity of aquatic and terrestrial ecosystems, and climate.

Long-term, continuous, calibrated data sets are needed to improve our documentation and understanding of global-scale changes in the earth's environment.

RÉSUMÉ

L'OZONE ATMOSPHÉRIQUE

Les preuves que nous apportent les observations sont à présent indéniables : la composition chimique de l'atmosphère subit un changement rapide à l'échelle mondiale. Les concentrations atmosphériques du gaz carbonique (CO_2), du méthane (CH_4), de l'oxyde nitreux (N_2O), des haloalcanes et de plusieurs chlorofluorocarbones (CFC) augmentent maintenant à des taux allant de 0,2 à 5% par an. Ces changements de la composition atmosphérique correspondent en partie au métabolisme de la biosphère et en partie au résultat des politiques nationales et internationales dans les domaines de l'énergie, de l'agriculture et de l'industrie. Pour modifier les décisions politiques, on devra mettre en place un programme de recherche interdisciplinaire coordonné à l'échelle nationale et sur la plan international.

Les données de la télédétection sont une ressource unique qui nous permet de vérifier les modèles expérimentaux de l'ampleur et de la vitesse du changement en ce qui concerne la distribution verticale et la teneur de la colonne totale d'ozone en fonction de la latitude et de la saison. On a utilisé les données satellitaires pour montrer que la couche d'ozone diminue fortement au printemps au-dessus de l'Antarctique depuis le milieu de années 1970 et que cette diminution n'est pas localisée au-dessus de l'Antarctique mais qu'elle s'étend depuis le pôle Sud jusqu'à 45°S. On a essayé d'expliquer ces observations par la chimie et aussi par la dynamique.

On prévoit que l'ozone diminuera dans la moyenne et dans la haute stratosphère principalement en raison de l'augmentation de la concentration des chlorofluorocarbones et que l'ozone augmentera dans la troposphère principalement en raison de l'augmentation de la concentration du méthane. Les incidences des changements de la teneur en ozone et par conséquent du rayonnement ultraviolet qui atteint la surface du globe porteront sur la santé humaine, sur la productivité des écosystèmes aquatiques et terrestres et sur le climat.

Nous avons besoin d'ensembles de données étalonnées, continus sur de longues périodes, pour améliorer notre documentation et notre compréhension dans le domaine des changements de l'environnement terrestre à l'échelle mondiale.

LONG-RANGE TRANSPORT OF AIRBORNE POLLUTANTS

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1. INTRODUCTION

Transboundary air pollution became an international political issue in the early 1970s. The United Nations Conference on the Human Environment in Stockholm in 1972 was the first time attention was focused on air pollution in such a broad political arena. At the Conference, a Swedish study on the links between sulphur dioxide emissions and adverse environmental effects was presented.

The question of air pollution had also been discussed in the OECD in 1969. However, it was only from 1972 on that more extensive national and international co-operation on the matter began. This has been pursued continuously since then, with a view to investigating more closely and, if possible, remedying the air pollution problems. International co-operation has grown and has been gradually extended in the areas of control technology, research into effects, and policy. What in 1972 appeared to be a limited problem is now described by many as the most serious environmental problem facing Europe and parts of North America. In 1972 it seemed to be chiefly a matter of the long-range transport of sulphur compounds, with surface water acidification as the main environmental impact. Today more is known. Ever increasing emissions of nitrogen oxides and hydrocarbons have complicated the picture. Novel forest decline has upset numerous theories about what could happen and about how nature would respond to the increasingly heavy burden of air pollution deposition.

2. A LABORATORY IN THE SKY

The air above us seems unlimited. But the feeling of a boundless volume of air is deceptive. The mixing layer in which the majority of air pollutants spread and are chemically converted varies in height between a few hundred metres and two kilometres. It is a limited film of air to live in and share between us.

The atmosphere is a highly advanced chemistry laboratory, in which sulphur and nitrogen compounds, hydrocarbons, ozone, reactive molecule fragments, particles and sunlight are involved in a great number of chemical processes. New substances are constantly being formed and removed. Before being deposited on the ground, gases and particles can travel thousands of kilometres without respecting national borders.

The laboratory in the sky has always existed. Many of the chemical changes are of vital importance to us. The difference between the "natural" state and today's air pollution situation is both one of quantity and of quality. It is the quantities and qualities of the ingredients added that determine the strength and taste of the "pollution cocktail".

The quantities of naturally circulating sulphur and nitrogen are of the same order of magnitude as the amount we are now adding from human activities. The anthropogenic emissions, however, are concentrated to just a few per cent of the earth's surface, in regions such as Europe or North America.

2.1 What Happens to Sulphur?

Most sulphur leaves chimneys as a gas, sulphur dioxide (SO_2). The amounts of sulphur released when oil, coal, and other fossil fuels are burnt depend on the sulphur content of the fuel.

Sulphur dioxide is not stable in the atmosphere and is gradually converted into sulphuric acid (H_2SO_4). This acid, unable to exist in gaseous form, condenses to form droplets.

Acid droplets easily dissolve in moisture in the air (rain or cloud droplets). The acid is then transferred to the ground with precipitation.

Sulphur acid particles may also encounter neutralizing substances in the air, which react with and bind the hydrogen ions. One such neutralizing agent is ammonia gas (NH_3). When sulphuric acid is neutralized by ammonia, ammonium sulphate is formed. The ammonium (NH_4+) ions involved easily bind to sulphate ions.

The haze which is so common over Europe in summer consists mainly of acid sulphate particles formed in the atmosphere as a result of sulphur dioxide emissions.

Unaffected rain water has a pH of 5-6. In Europe and in parts of North America and China the pH of rain is now between 4 and 4.5, and sometimes is as low as 3. (A pH of 3 is 100 times more acid than pH 5.)

2.2 What Happens to Nitrogen and Hydrocarbons?

Flue gases resulting from combustion mainly contain the gas nitric oxide (NO). It reacts with oxygen to nitrogen dioxide (NO_2). The stable end-product of this reaction is nitric acid (HNO_3). Unlike sulphuric acid, nitric acid can exist in gaseous form.

A very large proportion of sulphur is emitted at considerable heights, from tall chimneys. A sizeable proportion of nitrogen oxides and hydrocarbons, on the other hand, originates from road traffic and is thus released at ground level. These ground-level emissions, like those occurring higher above the ground, will be transported long distances. Nitric oxide, NO, is not dry-deposited, nor washed out by precipitation. Nor is nitrogen dioxide deposited particularly quickly after emission. Both of these nitrogen oxides must be converted into nitric acid before they can be effectively deposited. Before this can happen the nitrogen oxides have usually had time to travel a long way and to be well mixed in the mixing layer.

Nitrogen oxides, together with hydrocarbons, are a prerequisite for the formation of photochemical oxidants, the most important of which is ozone (O_3). Complex processes result in the formation of ozone in the troposphere, the lowest layer of the atmosphere.

In the troposphere ozone is regarded as an air pollutant, while in the stratosphere it forms a vital protective layer.

Ammonia (NH_3) is, in a sense, a recently discovered air pollutant. In areas of intense livestock farming, emissions of nitrogen from ammonia are of the same amount as those from nitrogen oxides. Ammonia is of a more local character than sulphur and nitrogen oxides. It is assumed that about 50% is deposited within 100 km of the source. Ammonia neutralizes acid precipitation but in the soil ammonium ions are converted into nitrate ions and hydrogen ions are released causing soil acidification.

3. ACIDIFICATION - THE ACHILLES HEEL OF OUR INDUSTRIAL CIVILIZATION

Up to the end of the 1960s air pollution problems were considered rather local, connected to health effects in urban areas. A policy of building tall chimneys solved the acute air pollution problems of the big cities but at the same time created new problems farther away, affecting other environments and other people.

In 1967 the Swedish scientist, Svante Odén, demonstrated - with data from the European Air Chemistry Network, established in the mid 1950s - that the precipitation over Northern Europe was gradually becoming more and more acidic. He integrated findings from several disciplines and then added data derived from his own observations of surface water chemistry over a period of years. The result was a pattern in which many signs pointed the same way - a clear correlation between sulphur emissions, atmospheric transport of sulphur and the emergence of environmental damage (mainly to fish and lake vegetation) in Scandinavia.

The OECD's Air Management Committee provided the framework for a major international study intended to shed light on the question of local and remote emissions in relation to the observed amounts of sulphur pollutants and acidified precipitation at various places in Europe. Eleven OECD countries took an active part in the project, which started in 1973 and was known as the Co-operative Technical Programme to Measure the Long-Range Transport of Air Pollution. The study included emission inventories in a grid system over Western Europe, ground measurements from 80 stations and observations from aircraft.

In the final report agreed on by scientists in the participating countries it was concluded:

> "... air quality in any one European country is measurably affected by emissions from other European countries".
>
> "... if some countries find it desirable to reduce substantially the total deposition of sulphur within their borders individual national control programmes can achieve only a limited improvement".

3.1 Surface Waters Are Most Susceptible

The first warning signals of environmental acidification came in lakes and watercourses lying in areas with a slow-weathering, low-lime bedrock. Lake-bed sediments in Scandinavia preserve a record of a very rapid change in the direction of acidification beginning in the early 1950s (Figure 1). The picture is further clarified by other measurements and observations on the pH values of lakes and their resistance to acidification, and on fish life and other biological changes. It is true that some of the older figures may be called into question, but even allowing for these reservations the tendency is quite clear.

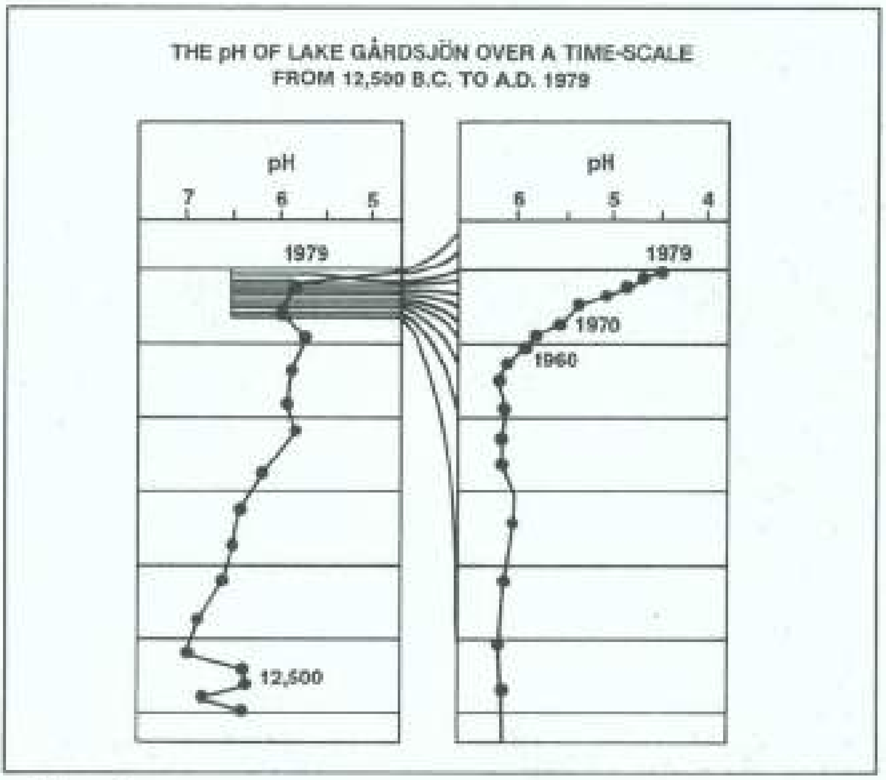

Figure 1.
By plotting the species of diatoms (minute algae) appearing in different layers of the sediment of a lake near the west coast of Sweden, Gårdsjön, it has been possible to trace the pH value of the water from the Ice Age to the present. This can be done because diatoms are variously sensitive to acid. As can be seen from the chart, acidification set in around 1950, and has subsequently continued to get worse.

In ever-increasing areas, ecological changes stemming from lake acidification, e.g. failing fish reproduction, have steadily become more and more evident. We have been able to follow this trend in Scandinavia over almost two decades, and later the same problem, though on an even greater geographical scale, has been demonstrated in the eastern part of North America.

In Norway, Sweden and Finland some 30,000 lakes and running waters with a total length of at least 200,000 km are affected by acidification.

Also in Scotland, England, Denmark, West Germany, East Germany, Poland, Czechoslovakia, streams and lakes have undergone a significant degree of acidification. The freshwater acidification in the Alpine zones in Switzerland and Italy is less serious than in North Europe because of the more favourable geological environment. However, many alpine lakes and tarns are already suffering a deterioration. In Belgium and the Netherlands, acidification has occurred in poorly buffered, oligotrophic waters on mineral sandy soils.

Investigations show that Atlantic salmon are killed during short acidic episodes, when pH decreases and the concentration of ionic aluminium increases rapidly. The fish kill was documented in controlled fish experiments combined with continuous monitoring of pH and daily water sampling.

Such conditions would occur during periods with heavy deposition and low biological activity, e.g., in late fall. Another critical period is during snowmelt when nitric acid stored in the snow also contributes to the acidification.

Another problem connected with acidification of surface water is that the fish pick up large amounts of mercury and therefore are less suitable for consumption. This is the case for 5,000-10,000 Swedish lakes. According to studies in New Zealand, pregnant women are a group at risk since mercury has been shown to cause mental retardation in children when the mothers were exposed to methyl mercury from high fish consumption during pregnancy.

3.2 Groundwater Becoming Acidified

Sulphur deposition also leads to the acidification of groundwater. So far, acidification has been found in the groundwater reservoirs that are relatively close to the surface, but just as with surface water, the acidification is gradually penetrating deeper into the ground and spreading to larger areas, with increasingly serious effects on groundwater. Acidification like this increases the mobility of metals, which are leached out of the ground and end up in the groundwater. Acid groundwater can suffer additional metallic contamination from corroded water pipes.

Cadmium is one of the heavy metals that are beginning to "migrate". If groundwater with increased cadmium concentration is used as drinking water, then the population, which is already heavily burdened with cadmium, gets another unwelcome increment of cadmium, albeit a relatively small one.

3.3 Soil Acidification Not Foreseen

In Europe, acidification has affected soils over large areas, and these soils have become acidified in a short space of time (30-60 years). The effects have not been confined to upper soil layers, but have extended to depths of over one metre. Acidity has increased by a factor of between two and ten.

Soil acidification on the scale now existing was not foreseen at the end of the 1970s. It was not even conceivable.

Higher acidity in the uppermost layer of the soil - the humus layer - is partly due to biological processes. These acidifying processes are reinforced by such practices as whole-tree harvesting and the use of acidifying fertilizers. In the long term, however, increasing acidity at greater depths is a cause for more serious concern, and to a very large extent it is due to acid deposition (Figure 2).

These changes in the soil affect vegetation, groundwater and surface water. If acid deposition continues, larger areas will be affected and the acidification front will penetrate deeper and deeper into the ground. This will have further effects on both surface water and groundwater.

There is evidence to suggest that some of the soil changes that have occurred may be irreversible. A sharp reduction in the deposition of acidic substances is therefore necessary, if the long-term productivity of soils and their ability to buffer surface and groundwater is not to be destroyed altogether.

If nitrogen deposition continues at its present rate, nitrogen saturation will cause growing problems. The principal effects of nitrogen saturation are:

- Nutrients are lost and soils become acidified;
- Trees are affected, resulting in forest damage;
- Soils are over-fertilized, resulting in ecosystem changes;
- More nitrate is carried into lakes and seas, contributing to greater inland and coastal water eutrophication.

As far as forests are concerned, nitrogen saturation can disturb the nutrient balance and make forests more sensitive, for example, to frost and pest attack.

3.4 Forests, Other Vegetation and Wildlife Threatened

A large number of scientific studies strongly indicate that air pollutants - directly or indirectly - are a decisive factor in the occurrence of forest damage at a regional level. Weather conditions also play an important role. Periods of drought and frost have a more severe and longer-lasting impact on trees already exposed to air pollution.

The extent of forest damage in Europe is a matter of very grave concern. In Sweden one spruce in four and one pine in seven has suffered over 20% needle loss. Despite favourable weather for trees in the last few years, forests have recovered very slowly or not at all. Damage has even been recorded in young trees. There is a greater danger of our forests suffering even more serious damage the next time extreme weather conditions, such as drought and low temperatures, occur.

Nitrogen deposition has probably, like efficient silviculture, promoted forest growth areas in many parts of Europe and North America in the last two decades. In areas with high depositions it is likely that the beneficial impact of nitrogen on forest growth will come to an end and give way to detrimental effects.

The pollutant load - primarily the deposition of sulphur and nitrogen compounds and the ozone concentration - must fall substantially if forest vitality is to be maintained.

The effects of acidification and nitrogen deposition on other vegetation and wildlife are not fully understood. However, we can observe that a process is already under way that is modifying fauna and flora over wide areas. Eutrophication - and hence changes in species composition - will gradually spread to increasingly larger areas. These changes are slow and have therefore been difficult to quantify. The changes caused by nitrogen inputs will probably accelerate in the next few decades. As a result, the conservation value of many natural habitats, such as meadows and rough grassland in forest clearings, will be impaired. We are faced with a serious threat to Nature's conservation efforts.

3.5 Limits to Nature's Tolerance

We must work together on a plan of action for Europe and North America. The first step of such a plan is to define ecological target values for air quality and depositions in order to achieve a healthy environment and to compare these values with the present observed values. The second step is to translate the necessary improvements in air quality and deposition into terms of emission reductions. The third step is to agree on the necessary strategies and time schedule to achieve the required emission reductions. The first two steps are scientific tasks, the third is a political one.

A broad international scientific consensus exists about the levels to which pollution must be reduced to allow forests, soils and lakes to survive, or to recover.

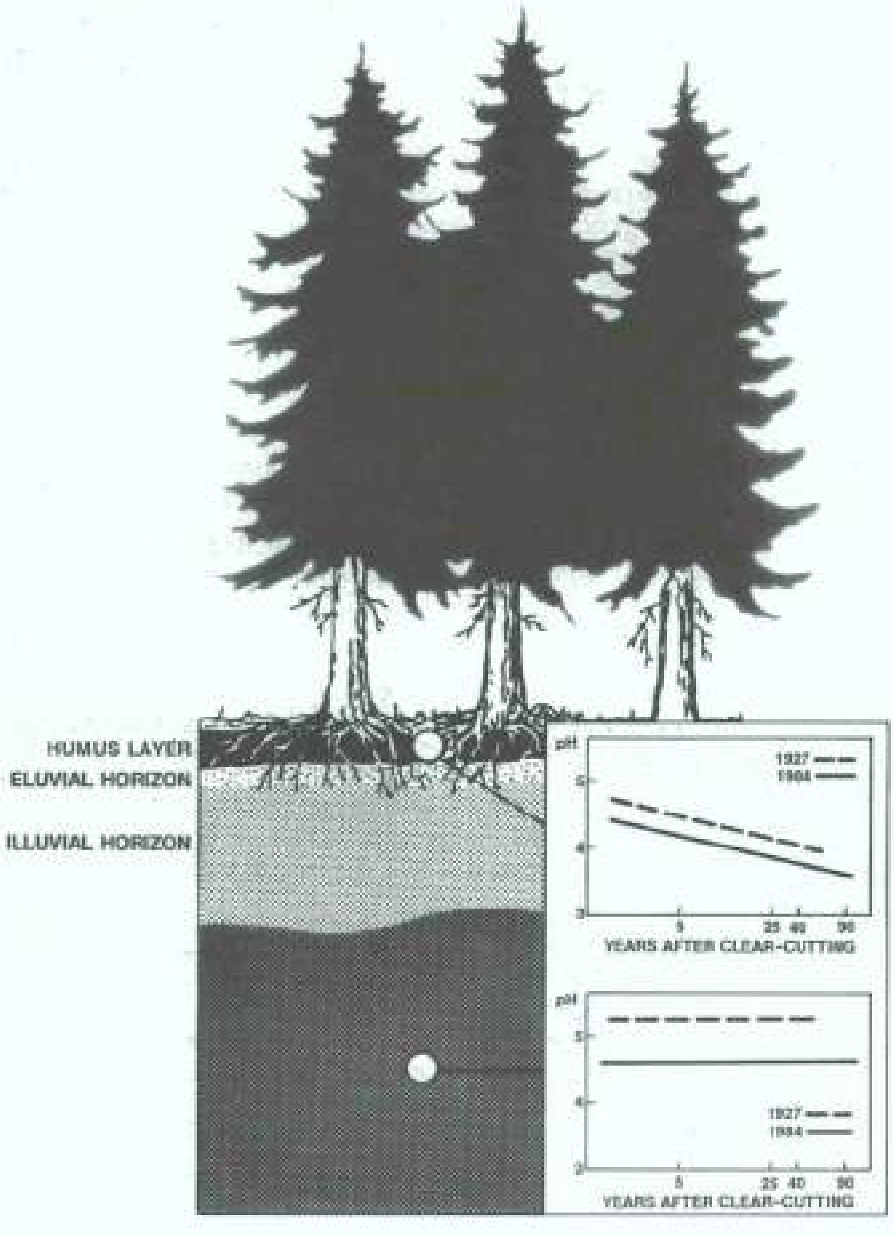

Figure 2.
The first pH measurements of forest soils in southern Sweden had been already made in 1927. By comparing data from 1927 with measurements in 1984 it can be shown that the pH values of soils have fallen both in the upper humus layer and in the deeper layer.

To avoid large-scale acidification of surface water, soil and groundwater, the deposition of sulphur should not exceed 0.5 g S/m^2 a year. To avoid the serious consequences of nitrogen saturation of forest soil the deposition of oxidized and reduced nitrogen should not exceed 1-2 g N/m^2 a year.

It is an important task for the scientists to produce a sensitivity map of our countries and compare it with the existing amounts of deposition in them. Our modellers can then use this information together with the emission inventories to arrive at figures for the necessary emission reductions. We should not hide the uncertainties in this process but the main problems with a European plan of action no longer reside in the scientific arena.

4. THE ACID RAIN PROBLEM IS NOT UNIQUE

Acid deposition is the best known but not a unique transboundary air pollution problem. Ozone, formed by photochemical reactions in the atmosphere with nitrogen oxides and hydrocarbons as the precursers and a suspect cause of damage to millions of hectares of European forests, has a similar transboundary pattern.

Ozone occurs in geographically very extensive episodes. During such an episode ozone concentrations of over 100 parts per billion (200 $\mu g/m^3$) may be found at the same time throughout, say, northern Europe, from the south of the Federal Republic of Germany to central areas of the Nordic region. The figure of 100 ppb or more should be compared with background ozone concentrations, which usually vary between around 15 and 40 ppb (30 and 80 $\mu g/m^3$).

Ozone is a remarkable substance in that the difference between background concentrations and the concentrations that are harmful to plants and human beings is very small. Even small increases in ozone formation, therefore, have harmful effects.

One reason for the small gap between background and harmful concentrations may be that the background value has increased in recent decades.

Ozone concentrations in air have been measured in the German Democratic Republic since the 1950s and in France outside Paris since the end of the last century. These measurements indicate that the background ozone value has probably increased by a factor of two in the last 50 years.

Other substances being borne by the winds over the borders are the persistent, bioaccumulating and toxic chlorinated hydrocarbons. The threat to the seal population in the Baltic Sea comes from the use of such substances in many European countries. Babies in industrialized countries get a daily intake of dioxins from breastmilk ten times higher than the dose considered acceptable by a WHO working group. The cause is not a local source but is dioxin emissions from combustion sources in many countries. Dioxins have been measured in emissions from incinerators and motor vehicles. But it has also been shown that dioxin emissions can be significantly reduced or eliminated by efficient incineration and the use of catalytic converters.

Metals like mercury, cadmium and - evident to all - caesium are being deposited thousands of kilometres from their emission source. The deposition of caesium and other radioactive substances from Chernobyl (Figure 3) clearly illustrates that air pollution respects no boundaries. Who can question the existence of the long-range transport of air pollutants after the Chernobyl accident?

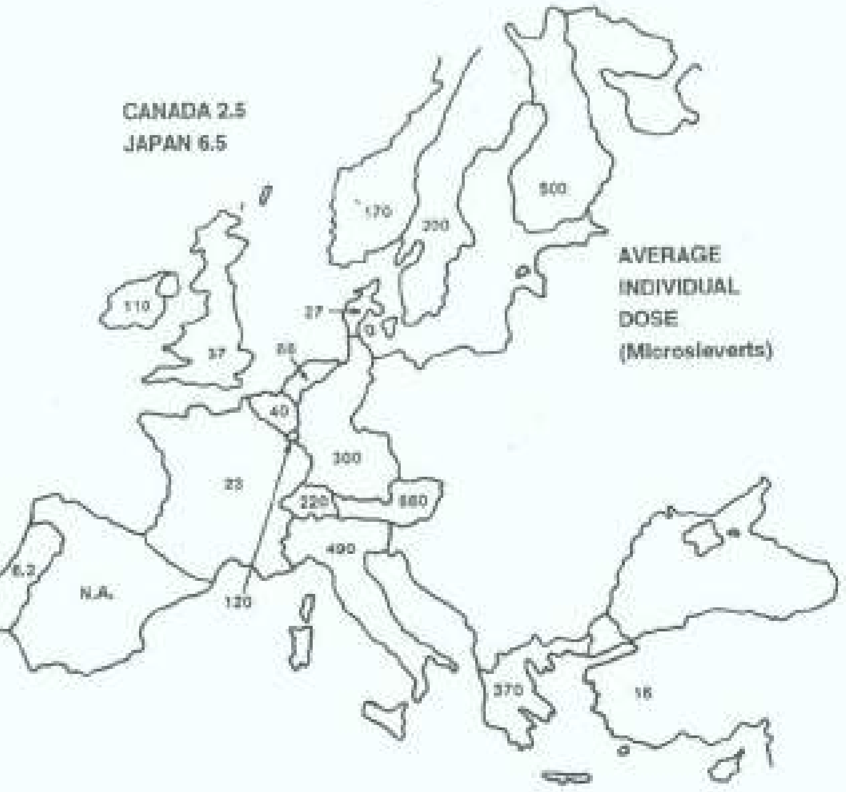

Figure 3.
Average individual dose (microsievert) in each OECD country (except the United States) resulting from the Chernobyl radioactive fallout.

The Nuclear Energy Agency (NEA) has published a detailed official evaluation of the radioactive fallout recorded in OECD countries from the Chernobyl nuclear reactor accident. The report contains a comprehensive assessment of the radiological impact of the accident based on extensive data obtained from national monitoring programmes. Competent authorities from each OECD country supplied a summary of their assessment for incorporation in this report. The information provided comprises average and peak values of total ground deposition for the principal radionuclides, estimates of individual and collective doses arising in the first year after the accident, and the countermeasures taken to reduce doses.

Individuals in the OECD countries are not likely to have been subjected to a radiation dose significantly greater than that received from one year of exposure to the natural radiation background. As a consequence, the lifetime average risk of radiation-related harm for the individual members of the public has not been changed to any noticeable extent by the accident and the number of potential health effects (cancers and genetic effects) that can be derived by calculating collective doses will not constitute a detectable addition to the natural incidence of similar effects within the population.

The long-range transport of radioactive substances from Chernobyl was the result of an accident. A similar transport of sulphur and nitrogen compounds is a daily phenomenon resulting from our deficient management of the wastes produced by fossil-fuel combustion.

5. RESEARCH AND POLITICAL ACTION

For almost 20 years now, research has been steadily providing us with ever more information on the extent and effects of acidification. It may come as a surprise to many people to hear that we have been at it so long. Certainly the first reports of lakes becoming devoid of fish in Norway and Sweden, towards the end of the sixties, did little to arouse opinion, compared with those announcing forest dieback in Central Europe in the early eighties. Of late, our knowledge of the effects on the soil has increased considerably, and the true image of acidification that is now emerging appears steadily more terrifying.

We know that acidification of the soil and water leads to changed conditions for plants and animals. The affected area is expanding, and the soil is becoming acidified to an ever greater depth, with effects on more and more of the ecosystem. Even soil scientists have been surprised at the changes in the pH of the soil during the last few decades. The acidification of forest soils leads to the conclusion that the question is not if forest growth will be affected but when.

The present forest damage of about 7 million hectares in Europe can only partially be explained by soil acidification and nutrient deficiencies. There is probably no single factor that causes the forest damage. Episodic high ozone concentrations in combination with other pollutants affect trees adversely and reduce their resistance to natural stress. Drought, frost or strong winds can then bring the trees above the tolerance limit.

It is no longer possible to evade the unpleasant truth - namely that acidification strikes hard at Europe's and North America's natural environment - by claiming that the measurements and research activities have either been inadequate in themselves or been carried out over too short a period.

This is not to say that more research is not needed. There are uncertainties about the mechanisms behind the forest damage and about how soon the lakes will recover when depositions are reduced. There are uncertainties about what happens in the laboratory in the sky that hamper our possibilities to find the most cost-effective ways to reduce ozone formation. But research should go hand in hand with political action and should not be considered a substitute for pollution control.

5.1 Convention on Long-Range Transboundary Air Pollution

Following the signing in 1975 of the Final Act of the Conference on Security and Co-operation in Europe (CSCE), a positive spirit of co-operation and détente prevailed. The Soviet Union suggested that an all- European conference on environmental protection be arranged. With the support of the other Nordic countries Norway suggested that air pollution should be the main theme of the proposed conference.

After involved negotiations, the Convention on Long-Range Transboundary Air Pollution was signed by 34 states and the European Community at the ECE Environment Ministers' Meeting in Geneva in November 1979. The Convention took the form of a framework agreement, in which the signtories recognized the problems of air pollution and their general responsibility for solving them.

The Convention came into force in March 1983, when the requisite number of states, 24, had ratified it. In the framework of the Convention extensive technical and scientific collaboration has been built up. The aim is to compile information and provide a basis for decision-making by the Executive Body for the Convention, which represents the political level.

In parallel with work relating to the Convention, several political initiatives were taken between 1979 and 1985, primarily backed by countries seeking to maintain and, if possible, increase political pressure on the work under the aegis of the Convention. Important steps in this process were taken in Stockholm (1982), Ottawa (1984) and Munich (1984).

A Protocol on Sulphur Emissions was signed at the third meeting of the Executive Body, in July 1985 in Helsinki. The meeting was held at ministerial level.

The protocol entered into force in September 1987. Its signatories undertake to reduce national emissions of sulphur dioxide - or their trans-boundary fluxes - by at least 30% by 1993 at the latest (with 1980 emissions levels as the basis for calculation).

Next on the agenda is a Protocol on Nitrogen Emissions.

National energy policies are of special importance to the solution of our problems of air pollution and acidification. In the future, environmental protection must be considered a much more important element than it is at present in the development of national energy, industry and transport policies.

ABSTRACT

LONG-RANGE TRANSPORT OF AIRBORNE POLLUTANTS

Acid deposition - better known as acid rain - is the best known but not the only transboundary air pollution problem. Ozone, formed by photochemical reactions in the atmosphere with nitrogen oxides and hydrocarbons as the precursors, has a similar transboundary pattern.

Metals like mercury, cadmium and - evident to all after the Chernobyl accident - caesium are being deposited thousands of kilometres from the emission source. Other substances being borne by the winds over borders are the persistent, bioaccumulating and toxic chlorinated hydrocarbons (DDT, PCBs, dioxin, etc.).

For almost 20 years now, research has been steadily providing us with ever more information on the extent and effects of acidification. The affected area is expanding with effects on more and more of the ecosystems (water, soil, vegetation). So far, depositions of sulphuric acid have been the main cause of the soil and water acidification. In future, depositions of nitrogen substances are likely to have a relatively greater effect.

The Convention on Long Range Transboundary Air Pollution is an important framework for internationally agreed measures to achieve a healthy environment. The Protocol on a 30 per cent reduction of sulphur emissions is an important first step.

RÉSUMÉ

TRANSPORT À LONGUE DISTANCE DES POLLUANTS ATMOSPHÉRIQUES

Les dépôts acides, mieux connus sous le nom de pluies acides, constituent le problème de pollution atmosphérique transfrontière le mieux connu, mais non le seul. L'ozone, qui est le produit de réactions photochimiques dans l'atmosphère avec des oxydes d'azote et des hydrocarbures comme précurseurs, est aussi transporté au-delà des frontières sur de grandes distances.

Certains métaux comme le mercure, le cadmium et le césium, ce dernier mieux connu depuis l'accident de Tchernobyl, sont déposés à des milliers de kilomètres de leur source d'émission. Parmi les autres matières transportées par les vents au-delà des frontières, mentionnons les hydrocarbures chlorés qui sont persistants, bioaccumulables et toxiques (DDT, PCB, dioxine, etc.).

Depuis près de 20 ans, la recherche nous renseigne de plus en plus sur l'étendue et les effets de l'acidification. Le phénomène s'étend à un territoire de plus en plus vaste et à une proportion croissante des écosystèmes (eau, sol, végétation). Jusqu'ici, des dépôts d'acide sulfurique ont été la cause première de l'acidification des sols et des eaux. Dans l'avenir, des dépôts de matières azotées auront vraisemblablement une incidence relativement plus grande.

La Convention sur la pollution atmosphérique transfrontière à longue distance est un important outil de travail par lequel les états concernés peuvent convenir de mesures pour assainir l'environnement. Le protocole par lequel il est convenu de réduire de 30 % les émissions de soufre est une première étape importante.

THE CHALLENGE OF GLOBAL CHANGE

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1. INTRODUCTION

The atmosphere may be considered in many respects an extension of the biosphere. Its composition is changing rapidly at the present time, for a variety of reasons linked ultimately to pressures exerted by an expanding population, and the aspirations of this population for an enhanced quality of life. The human species is now a force of consequence for change on a global scale. Its presence is evident from pole to pole, from the depths of the ocean to the heights of the stratosphere. We face an immediate and important challenge: to understand and predict the consequences of our actions, and to bring this knowledge to bear on policy so as to preserve the viability of the planet for ourselves and for generations yet unborn.

It is an awesome responsibility. We have just begun to appreciate the complexity of the links that regulate the environment for life on earth. On a time-scale of a few decades, the atmosphere is coupled to the biosphere, to the soils, and to the upper layers of the ocean. On longer time-scales it is coupled to the deep sea and to the sediments. It is a remarkable system that evolved over more than a billion years. The elements essential for life are in a state of constant motion. A carbon atom released to the atmosphere as a constituent of the odourless, invisible, molecule CO_2 during combustion of fossil fuel will flit back and forth between plants, soil, air and water for about 100,000 years before eventually returning to the relatively quiescent reservoir of the sediments. The average carbon atom has made the cycle from sediments some 20 times over the course of the earth's history (McElroy, 1976, 1983). Similar cycles regulate the distribution of other life-essential elements such as nitrogen, phosphorus, and sulphur.

The Greenhouse Effect on climate has received widespread attention over the past decade, not only from scientists, but also, increasingly, from policy-makers. The physics of the Greenhouse Effect is relatively straightforward. The atmosphere is bathed in two more or less distinct radiation fields. The first, originating in the sun, has the bulk of its energy in the visible and ultraviolet regions of the solar spectrum. The second, emanating from the surface and the lower atmosphere, has most of its energy in the infrared. The surface, on average, receives about 17% of its heat directly from the sun, 15% from the solar radiation scattered by clouds, and the balance, 68%, from the absorption of infrared radiation emitted from the atmosphere. The trace gases of the atmosphere, notably CO_2 and H_2O, play a major role in the transfer of infrared energy and, consequently, in the heating of the planetary surface, since the most abundant constituents of the atmosphere, N_2 and O_2, are transparent at infrared wavelengths. In the absence of gaseous species with an ability to absorb radiation in the infrared, the surface temperature would be about 40 K colder than it is today. The ocean would be frozen over and life as we know it would be impossible.

There is an important synergism between CO_2 and H_2O (Hansen et al., 1981). Carbon dioxide itself absorbs but a small fraction of the energy radiated by the surface. Water vapour is much more significant. The abundance of water vapour, however, is controlled ultimately by temperature; an increase in CO_2 would be expected to cause an increase in temperature, allowing more water vapour to enter the atmosphere, leading to a further increase in temperature. Other gases such as CH_4, N_2O, O_3 and the chlorocarbons have infrared properties similar to those of CO_2 (Wang et al., 1976). They also contribute to the Greenhouse Effect. On a molecule per molecule basis these species are even more efficient than CO_2. They absorb radiation at wavelengths where the atmosphere would be otherwise transparent.

2. CHANGES IN ATMOSPHERIC COMPOSITION AFFECTING CLIMATE

Until recently at least, interest in the Greenhouse Effect has focused mainly on CO_2. This is easy to understand. The change in CO_2 has been well documented, more or less continuously, for 30 years. The atmospheric abundance has increased steadily over this period, from about 315 parts per million (ppm) in 1958, to more than 350 ppm today (World Meteorological Organization, 1986). The increase is due largely to the release of CO_2 associated with the combustion of fossil fuel, approximately 5 billion tons of carbon in 1988. Carbon dioxide from fossil fuel is the largest single waste product of modern society. Approximately half of the carbon emitted since the industrial revolution began persists in the atmosphere today. The balance is presumed to have made its way into the ocean, or to have been incorporated in organic matter on land. The uptake of CO_2 by the ocean is limited by the supply of carbonate ions, CO_3^{2-}, in the surface waters. The bulk reaction is

$$CO_2 + CO_3^{2-} + H_2O \rightarrow 2HCO_3^- \quad (1)$$

Carbon dioxide is a weak acid; inclusion of CO_2 in the ocean leads to a reduction in its pH, switching carbon from CO_3^{2-} to HCO_3^- and dissolved neutral carbon. There is a limit, however, to this switching. The total negative charge carried by dissolved carbon compounds is fixed by the alkalinity of the ocean:

$$[Alk] = [HCO_3^-] + 2[CO_3^{2-}]. \quad (2)$$

Alkalinity can be altered only by adding salts supplied, for example, by the dissolution of calcite, $CaCO_3$, in sediments. The CO_3^{2-} content of waters at the surface is small; the sustained uptake of CO_2 requires CO_3^{2-} to be supplied continuously to the surface. Over a 100-year period the surface sees about 10% of the water in the ocean. In this case only 30% of the carbon added by burning fossil fuel can be incorporated in the sea.

A continuing rise in CO_2 is inevitable (Hansen et al., 1981). If we consider current estimates for the reserve of fossil fuel, about 4 trillion tons of carbon, and assume that half of this reserve is used up over the next 100 years, the level of CO_2 could rise above 1000 ppm. If we assume, more conservatively, that the consumption of fossil fuel will double over the next 100 years, CO_2 may be expected to grow to about 600 ppm, approximately twice its concentration in 1850. It is clearly important that we forecast as accurately as possible the associated impact on climate.

The abundance of CH_4 is increasing at an even faster rate than that of CO_2. The rate of increase is averaging between 1 and 2% per year at the present time (Rasmussen and Khalil, 1981). The concentration has risen from a pre-industrial value of about 0.7 to almost 1.6 ppm (Craig and Chou, 1982). A portion of the increase may be attributed to bacterial processes associated with ruminants, notably cattle. A further fraction is due to microbial activity in seasonally flooded soils associated with rice cultivation. There is a significant release of CH_4 to the atmosphere associated with the mining of coal and the production of natural gas. Some additional emission arises from the burning of vegetation resulting from clearing land for agriculture (Khalil and Rasmussen, 1983). It is difficult to formulate a credible budget for atmospheric CH_4. The recent trend may reflect not only changes in its source but also changes in the rate at which the gas is removed from the atmosphere.

According to present understanding, CH_4 is removed mainly by reaction with the hydroxyl radical, OH, in the troposphere. Hydroxyl radicals are formed by photochemical processes initiated by the photolysis of tropospheric O_3:

$$h\nu + O_3 \rightarrow O(^1D) + O_2 \tag{3}$$

followed by

$$O(^1D) + H_2O \rightarrow OH + OH. \tag{4}$$

They are removed by reactions with CH_4 and CO. An increase in the abundance of CO due to combustion might therefore be expected to enhance the efficiency of the atmospheric sink for OH. A reduction in the concentration of OH would extend the lifetime of CH_4. It follows that at least part of the increase in CH_4 may be attributed, albeit indirectly, to the industrial emission of CO (McElroy, 1983).

Changes in OH would have further implications for the composition of the atmosphere. Reactions with OH are important for the removal of various gases from the atmosphere (Logan et al., 1981). They represent the first step in the oxidation of an entire suite of atmospheric hydrocarbons. They are responsible for the removal of industrial halogenated gases such as $CHCl_2F$ (CFC-22), CH_3CCl_3, and CH_3Br. They regulate the removal of compounds as diverse as NO_2, NH_3, SO_2, H_2S and $(CH_3)_2S$. Reductions in OH induced by increasing concentrations of CH_4 and CO may be expected to reduce the cleansing capacity of the atmosphere. With reduced levels of OH, a relatively larger fraction of industrial chlorinated gases will penetrate into the stratosphere, leading to the enhanced loss of O_3. Concentrations of a number of gases may be expected to build up, with implications not only for atmospheric chemistry but also for climate.

The changes in composition evident in the atmosphere today may be attributed to three general influences: the emission of gases associated with the combustion of fossil fuel, the emission of gases from natural environments amended for purposes of agriculture, and the emission of gases produced by industry for which there are no natural analogues. The changes in CO_2 are largely due to the first of these effects, with an additional contribution from the second. The changes in CH_4 are due largely to the second, with a smaller contribution from the production and consumption of fossil fuels. The appearance of gases such as CCl_2F_2 (CFC-12), CCl_3F (CFC-11), $CBrClF_2$ (HALON 1211), and $CBrF_3$ (HALON 1301) attests to the ingenuity of the modern chemical industry. The growth of N_2O, comparable to that of CO_2, reflects sources from both combustion and agriculture. All of these changes can be attributed ultimately to the stress imposed by the rapid growth of the human population following the industrial revolution.

There is no way to turn the clock back. It would be unrealistic to expect society to accept voluntarily a reduced standard of living, or to expect the Third World to forego advantages enjoyed for so long by those who were privileged to grow up in the disposable society of the First World. We need a new sense of global responsibility. The clear message is that we live in a world inextricably interconnected. The atmosphere is a global resource. National prerogatives and parochial interests must be subordinated to protect the rights of all the living elements of the planet. It is essential as a first step that we develop a deeper understanding of the function of the global life-support system. Only then can we hope to make the hard choices that are essential if we are to chart a wise course to the future.

A sense of history is essential if we are to make progress. Studies of air trapped in polar ice provide an invaluable perspective. Using cores extracted from the ice sheets covering Greenland and Antarctica, it has been possible to reconstruct, partially at least, the composition of the atmosphere back to 160,000 years before the present time. We know that the CO_2 concentration was about 200 ppm during the ice ages and that it rose to about 280 ppm during the interglacials (Barnola et al., 1987). Methane was also low at times of peak glacial extent, about 0.3 ppm. It rose to about 0.7 ppm as the earth warmed up and remained at about that level until about 200 years before the present (Stauffer et al., 1988). It has increased since then by almost a factor of 3, significantly larger than the 25% increase observed for CO_2.

Viewed in this context, the pace of contemporary change is unprecedently rapid. It is this aspect of the problem that is most bothersome. One might assume that the changes in climate associated with the rising level of the Greenhouse gases would eventually cause a shift in the position of the major ecological zones of the planet. Global circulation models of the atmosphere suggest that there should be a tendency for ecological environments to shift to higher latitudes (Manabe and Wetherald, 1980). If the change in climate were too rapid, however, it might not be possible for ecosystems to adjust fast enough to keep pace. This would create an additional, perhaps impossible, requirement for human intervention to protect the integrity and diversity of the global life-support system. Wise intervention, whatever its scale, must presume a knowledge base sufficient to permit a comprehensive assessment of its impact to be made in advance; it is clear that the current state of global geoscience is wholly inadequate for such a demanding task.

There is also the hazard posed by a rising level of the ocean. Ultimately, we may have to face a potential disaster posed by an instability of the west Antarctic Ice Sheet (Hughes, 1977). If the mass of water stored in this giant reservoir were to enter the ocean, the sea-level would rise by about 20 feet. Fortunately, glaciologists believe that this scenario lies far in the future. Prudence dictates, however, that we maintain a watchful eye.

3. ANTARCTIC OZONE: EXAMPLE OF THE UNEXPECTED

It is most unlikely that the changes in the environment brought about by the changes in the composition of the atmosphere will be predictable with any measure of confidence. Recent experience with the ozone hole over Antarctica attests to our vulnerability to the vast limitations of our knowledge even in a problem area as narrowly defined as stratospheric chemistry.

The first report of the Antarctic phenomenon appeared only three years ago (Farman et al., 1985). There was previously no reason to suspect that the loss of O_3 would be especially rapid at high latitudes. Most of our attention was focused on mid-latitudes. Models suggested (World Meteorological Organization, 1986) that the loss of O_3 due to the emission of chlorocarbons would be concentrated at fairly high altitudes, near 40 km, due largely to the catalytic sequence

$$\begin{aligned} Cl + O_3 &\rightarrow ClO + O_2 \\ ClO + O &\rightarrow Cl + O_2, \end{aligned} \tag{5}$$

equivalent to

$$O + O_3 \rightarrow O_2 + O_2. \tag{6}$$

It quickly became clear that the removal mechanism for O_3 over Antarctica could not involve O; the loss of O_3 was concentrated at low altitudes over Antarctica, between about 12 and 20 km, where the abundance of O would be too low for reaction sequences such as (5) to be effective (McElroy et al., 1986). Attention was directed (Molina and Molina, 1987; McElroy et al., 1986) to catalytic sequences involving the reaction of O_3 with itself:

$$\begin{aligned} ClO + ClO + M &\rightarrow Cl_2O_2 + M \\ h\nu + Cl_2O_2 &\rightarrow Cl + ClOO \\ ClOO + M &\rightarrow Cl + O_2 + M \\ 2(Cl + O_3 &\rightarrow ClO + O_2) \end{aligned} \tag{7}$$

and

$$\begin{aligned} Cl + O_3 &\rightarrow ClO + O_2 \\ Br + O_3 &\rightarrow BrO + O_2 \\ ClO + BrO &\rightarrow ClOO + Br \\ ClOO + M &\rightarrow Cl + O_2 + M. \end{aligned} \tag{8}$$

To be effective these sequences require unusually high concentrations of halogen radicals. This would be possible only if the abundance of NO_2 were exceptionally low. It was suggested (Toon et al., 1986) that nitric acid could condense in the cold environment of the Antarctic stratosphere, and precipitate, choking off the natural source of NO_2. In addition, laboratory experiments (Molina et al., 1987; Tolbert et al., 1987, Wofsy et al., 1988; Leu, 1988) suggested that reactions on the surfaces of polar stratospheric clouds could initiate reaction sequences leading to the conversion of fairly stable chemical compounds to radicals, by reactions, such as

$$ClNO_3 + HCl(s) \rightarrow Cl_2 + HNO_3(s) \tag{9}$$
$$ClNO_3 + H_2O(s) \rightarrow HOCl + HNO_3(s) \tag{10}$$
$$h\nu + Cl_2 \rightarrow Cl + Cl \tag{11}$$

and

$$h\nu + HOCl \rightarrow OH + Cl, \tag{12}$$

where (s) denotes species present in the solid phase. The general validity of this picture was confirmed in a spectacular series of experiments performed using the ER-2 research aircraft in August and September of 1987, as described by Watson (1988). Plans are currently under way to carry out a similar series of measurements in the Arctic to explore whether the chemistry that plays such a dominant role in the Antarctic environment has an analogue in the north.

There are indications that the loss of O_3 over Antarctica in spring may affect the stability of the polar vortex, the swirling flow of air that effectively isolates the stratosphere at high latitudes from its low latitude regime during the winter and early spring. The vortex breaks up normally by mid-October, while sunlight returns to the polar region. The loss of O_3 was so extreme in 1987 that the heating of the polar stratosphere was essentially negligible. The vortex persisted until early December (Newman and Schoeberl, 1988). Ozone concentations remained low and as a consequence levels of ultraviolet radiation reaching the surface were exceptionally high.

This raises serious questions concerning the impact of enhanced ultraviolet radiation on the highly productive ecosystem of the circum-Antarctic ocean. There is an urgent need to investigate this effect, to study not only its impact on the marine food chain, but also to determine what consequence, if any, it might have for the nutrient budget of the polar ocean. There are possible implications for the release of CO_2 from the ocean. Most of the ocean's carbon is present in cold, fairly stagnant, water at depth. It returns to the atmosphere in association with a slow upwelling motion at low latitudes. While the surface waters cool and sink at high latitudes, they draw carbon from the atmosphere, roughly balancing the source at low latitudes. Falling fecal material provides an additional important means for transporting carbon from the surface to the deep. An increase in the nutrient budget of the high-latitude surface ocean would signal a decrease in the efficiency of the marine biological pump for carbon. Uncertainties are such that we cannot exclude the possibility that the Antarctic Ozone Hole might exacerbate the Greenhouse problem by enhancing the net source of atmospheric CO_2.

The Greenhouse Effect could be implicated in the Antarctic ozone phenomenon in another way. Elevated concentrations of Greenhouse gases can be responsible for an increase in surface temperature, as discussed above. They are expected, in addition, to cause a compensating decrease in the temperature of the stratosphere. Since cold temperatures are required to facilitate the formation of polar stratospheric clouds, and since these clouds are believed to play a pivotal role in removing O_3, the two problems may be interconnected. Further, since the oxidation of CH_4 is a significant source of stratospheric H_2O, there may be a double connection; higher concentrations of CH_4 could lead to higher concentrations of H_2O and consequently to an enhanced probability of condensation.

The Antarctic Ozone Hole covers approximately 10% of the Southern Hemisphere. The loss of O_3 over Antarctica could have implications not only for the local environment, but also for a significant fraction of the hemisphere. While the polar vortex breaks up, O_3-rich air from outside the vortex mixes with the depleted region within. This may be expected to lead to a more general reduction in O_3. Calculations suggest that the depletion of O_3 associated with the Antarctic phenomenon could have a significant impact on the distribution of O_3 to latitudes as low as 40°S (Ko et al., 1988).

4. NEEDS FOR A BROADLY-BASED RESEARCH PROGRAMME

We need to improve our ability to anticipate the unexpected. Geophysicists operate at a considerable disadvantage compared with other physical scientists. We are unable to carry out controlled experiments. We must rely for the most part on observations of uncontrolled natural systems, seeking to describe them in terms of the underlying physical, chemical and biological principles. Yet we are faced with the challenge of predicting the future, a current imperative to anticipate the consequence of our actions. Intensive study of the present system, in combination with appropriate laboratory and theoretical work, can help identify important processes, drawing attention to linkages previously unsuspected.

Studies of the past can help hone our skills. They are particularly important for the assessment of potential changes in climate. We can reconstruct at least a partial record of past climate using pollen stored in lakes and bogs, together with analyses of the spatial and temporal distributions of particular fossils preserved in marine sediments. In combination with information about atmospheric composition inferred from polar ice cores, this can provide a bench-mark for the assessment of the quality of climate models, and a stimulus for the orderly development and improvement of these models. Observations of the past provide a surrogate for controlled experiments; the acquisition and analysis of such records are essential elements of a sensible strategy for predicting the future.

The realistic assessment of the consequences of the changing composition of the atmosphere will require an exceptional level of detail. It is of fairly little value to predict that the global average temperature will increase by a few degrees over the next several decades. We need to know how regional climates will change. Is the drought currently devastating agriculture in the U.S. Middle West a predictable statistical anomaly, simply bad luck, or a forerunner of times to come? Should we invest now in schemes to divert water from one region of the country to another? The implications for policy are obvious and incontrovertible.

We have emphasized in this paper issues relating to changes in climate caused by increasing concentrations of the Greenhouse gases, and factors responsible for changes in stratospheric O_3. There are other matters that merit attention, acid rain for example and the possibility of large-scale enhancements in the abundance of tropospheric O_3.

5. IMPLICATIONS FOR POLICY

Of the issues discussed here, acid rain is perhaps the simplest. It is clear that emissions of SO_2 and oxides of nitrogen are the major contributors to this phenomenon in Europe and in eastern portions of North America. The chemical processes responsible for the transformation of sulphur and nitrogen in the atmosphere are fairly well understood, as is the significance of long-range transport. There is little doubt that acid precipitation, by leaching toxic metals from soils, has a negative impact on aquatic life forms in sensitive water systems, and there may be additional undesirable impacts on vegetation. Coal-fired power plants and smelting operations provide the dominant sources of anthropogenic sulphur. It is obvious that emissions from such sources should be curtailed; strategies are available that would allow rapid progress. The costs are not extreme; it requires merely the political will to come to grips with the problem.

It will be more difficult to deal with the issue of tropospheric O_3 (Logan, 1985). Elevated levels of O_3 are an important contributor to the phenomenon of urban smog. Ozone is formed in the troposphere by reactions such as

$$NO + RO_2 \rightarrow NO_2 + RO \tag{13}$$

followed by

$$h\nu + NO_2 \rightarrow NO + O \tag{14}$$

and

$$O + O_2 + M \rightarrow O_3 + M, \tag{15}$$

where RO_2 denotes a radical formed as an intermediate in the oxidation of atmospheric hydrocarbons. It has become clear in recent years that increased concentrations of tropospheric O_3 are not simply confined to the cities. High concentrations of O_3 are observed on occasion over large portions of the Eastern United States. The phenomenon, which occurs during the summer, appears to be spatially coherent over scales of thousands of kilometres. It is associated with slow-moving high-pressure systems. Individual episodes last as long as 5 days; ozone concentrations are high enough to cause damage to crops and vegetation. There are indications that a similar phenomenon in Europe may be responsible for the deterioration of forests in Germany and Eastern Europe. Anthropogenic sources of nitrogen oxides, in combination with both natural and industrial hydrocarbons, are believed to be responsible. It will be difficult to achieve major reductions in the emissions of nitrogen oxides. Their sources are more diverse than those of SO_2, and the technology for their emission control is less highly developed. It is important, though, that aggressive steps be initiated to achieve at least some reduction. Any initiative in this area can also contribute to abatement of the acid rain problem.

The policy-maker has a difficult task. His overriding objective should be to reduce the pace of change. The protection of stratospheric O_3 should be fairly easy, though even here we may have waited too long to take action. There is no doubt that industrial halocarbons are responsible for reductions in stratospheric O_3. The problem will get worse before it improves, irrespective of what we do. The long life of halocarbons in the atmosphere imposes a degree of urgency. There are reasons to believe that we passed a threshold with respect to O_3 over Antarctica in the 1970s. The Ozone Hole will persist indefinitely if we simply adhere to the original schedule of emission controls outlined in the Montréal Protocol. Fortunately the Protocol provides a mechanism for revising the initial control strategy. It should be amended as soon as possible and a schedule adopted to ensure the essentially complete, early, elimination of the emissions of industrial halocarbons implicated in removing stratospheric O_3.

The cessation of halocarbon emissions will have an additional benefit: it will slow the pace of climate change associated with the enhanced Greenhouse Effect. But elimination of halocarbons alone will not be enough. Ultimately we must strive to drastically curtail the use of fossil fuel. This will be no easy task. How can we persuade countries such as China with abundant sources of coal to limit the development and use of its most available and inexpensive source of energy? We need an international approach to the problem. The First World, responsible for so many of the problems, must lead the way. Conservation, and a vigorous search for environmentally acceptable energy source alternatives to fossil fuel, should receive urgent priority. We need to develop incentives to persuade the Third World to follow a wiser course than we. This will require, inevitably, a transfer of resources from us to them, an investment in our common future. It would seem appropriate that this should be funded by a tax on fossil fuels, the source of so many of our problems. How such a tax should be administered is, however, unclear. It would appear to require an international body with unprecedented power and antonomy. Inevitably this will require that nations delegate at least a portion of what they previously considered inalienable rights to independent deliberation and action. But there may be little choice. The question is, can we act in anticipation of the problem, or must we wait until the crisis is obvious, and the time for orderly process is past.

In the meantime, we must accelerate our efforts to understand the consequences of change. The task requires a globally cooperative program. We need to document changes while they occur. We need to improve our abilities to model the coupled atmosphere-ocean-biosphere system. We need a commitment to long-term observatories in outer space and ready access by all to the data they provide. We need long-term observatories strategically located on the surface in sensitive ecosystems to provide ground truth data for the space observations, and to allow opportunities for interactive experiments essential to improve our understanding of relevant processes. All this will require resources and political commitment. If we fail to address the scientific issues, assuredly we shall fall short on the larger challenge: our overriding responsibility to protect the global environment for posterity.

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ABSTRACT

THE CHALLENGE OF GLOBAL CHANGE

It is clear that the composition of the atmosphere is changing at a rate unprecedented in the recent geologic record. The abundance of methane has more than doubled since the industrial revolution. Carbon dioxide has increased by about 25%. There are detectable rises in nitrous oxide and there are globally distributed gases in the atmosphere for which there are no natural analogues, the chlorofluorocarbons, for example. The abundance of stratospheric ozone has declined globally over the past decade, dramatically so over Antarctica. Evidence exists for large-scale increases in the abundance of tropospheric ozone. These changes have implications for global climate, for the distribution of nutrients and for the overall integrity of the global environment.

The paper reviews the factors responsible for contemporary change. Information gleaned from studies of chemicals trapped in polar ice used to place the present environment in a larger historical context. Implications of current policy initiatives, the Montréal Protocol for example, are discussed. The paper emphasizes the interactive nature of the global atmosphere-biosphere-soil-ocean system.

RÉSUMÉ

RELATIONS ENTRE SUBSTANCES CHIMIQUES ET IMPACTS ÉCOLOGIQUES

À l'étude du passé géologique récent il est évident que la composition de l'atmosphère change à une vitesse sans précédent. La quantité de méthane a plus que doublé depuis la révolution industrielle et celle du gaz carbonique a augmenté d'environ 25%. Il y a des accroissements discernables des quantités d'oxyde nitreux et des gaz n'ayant pas d'équivalents naturels, les chlorofluorocarbones par exemple, sont répandus dans l'atmosphère à l'échelle du globe. La quantité d'ozone dans la stratosphèere a diminué au cours de la dernière décennie, et ce de manière saisissante au-dessus de l'Antarctique. Il existe des preuves d'augmentations importantes de l'abondance de l'ozone dans la troposphère. Ces changements ont des implications pour le climat mondial, pour la répartition des éléments nutritifs et pour l'intégrité générale de l'environnement mondial.

Dans la communication, les facteurs responsables de ces changements contemporains seront examinés. L'information issue d'études des substances chimiques piégées dans la glace polaire sera mise à profit afin de situer l'environnement actuel dans un contexte historique plus étendu. Les implications des initiatives politiques actuelles, comme le Protocole de Montréal par exemple, seront discutées. La communication soulignera le caractère interactif du système mondial atmosphère-biosphère-sols-océans.

OUR CHANGING ATMOSPHERE: ENERGY POLICIES, AIR POLLUTION AND GLOBAL WARMING

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1. INTRODUCTION

Climate, the long-term ensemble of daily and seasonal weather events, gives a special character to each region on earth. Climate patterns have shaped cultural evolution and influenced which foods people grow and eat. Because of favourable climate conditions the natives of North and Central America were encouraged to grow corn whereas South Asians were dependent on rice as a staple. The stability of regional climate regimes has helped shape national temperaments, giving a distinct "flavour" to each nation.

Common wisdom recognizes that local weather varies by day, week and year. Nonetheless, most individuals and governments have implicitly assumed that familiar regional climate patterns will remain stable indefinitely. This assumption may no longer be true.

Air pollution due to energy use and other industrial activities is changing the composition and behaviour of our atmosphere in new and important ways. If current trends continue, rising atmospheric concentrations of trace gases and particulates are likely to alter the planet's radiation budget, increasing the acidity of rainfall, warming the surface and exposing the inhabitants to higher levels of ultraviolet radiation. This paper focuses on the linkages between energy use, global warming due to the greenhouse effect, and ozone depletion.

2. A BRIEF INTRODUCTION TO THE GREENHOUSE PROBLEM

By absorbing and re-emitting the low-energy radiation emanating from the earth's surface, primordial concentrations of carbon dioxide and water have vapour-warmed the lower part of the earth's atmosphere (see Figure 1). This natural "greenhouse effect" has raised the surface temperature of the planet by 33°C, from about -18 to 15°C. This warming allowed water to remain on the earth's surface as a liquid and made the evolution of familiar life forms possible. Slowly varying concentrations of these naturally occurring gases have continued to warm the planet. In combination with the periodic shifts in the earth's orbit, they have ultimately produced the familiar patterns of global climate.

The most important contributors to the greenhouse effect today are water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), tropospheric ozone (O_3), and the chlorofluorocarbons (CFCs), particularly CFC-11 and CFC-12. Over the course of the last century, the atmospheric concentrations of each of these has increased, gradually turning the vitally important greenhouse effect into the increasingly troublesome greenhouse problem.

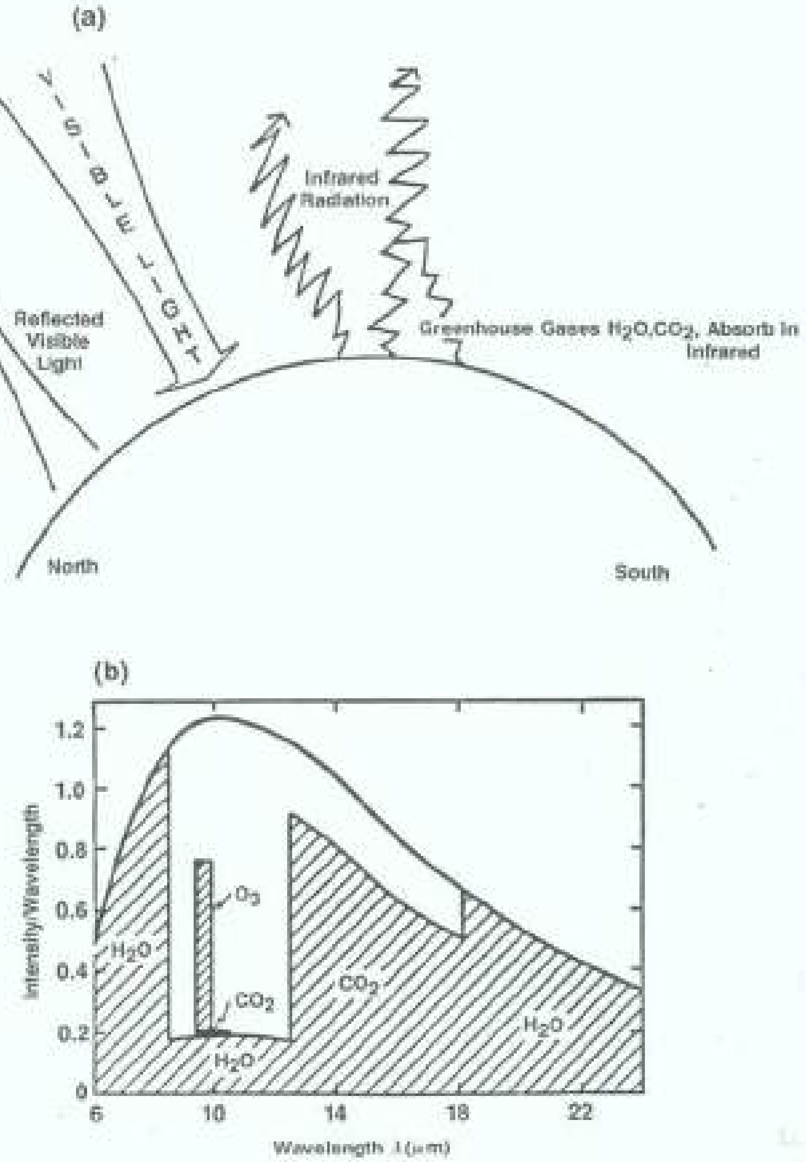

Figure 1.
(a) Earth's temperature is raised by existing greenhouse gases.
(b) Thermal emission spectrum of the earth's surface at T = 290 K. Relative values of the absorption are indicated by shaded areas. The figure illustrates why trace amounts of absorbers in the 8.5-12.5 μm region can be critically important in determining the thermal balance of the atmosphere.

A related problem with CFC emissions involves their effects on the upper atmosphere, where chemical reactions with the sun's rays have led to a depletion of the earth's protective ozone layer. This allows more ultraviolet radiation to reach the earth's surface, with potentially dire health consequences for plant and animal life alike (Miller and Mintzer, 1986).

Fossil-fuel combustion, biomass burning, the destruction of tropical forests, and other human activities have caused the atmospheric concentration of carbon dioxide to increase by about 25% since 1860, ending thousands of years of atmospheric stability. In the last several decades, the annual contribution to warming from other greenhouse gases has become approximately equal to the annual effect of the carbon dioxide buildup, partly because some of these other gases absorb infrared radiation, up to 10,000 times more efficiently per molecule than CO_2 does (see Figure 2).

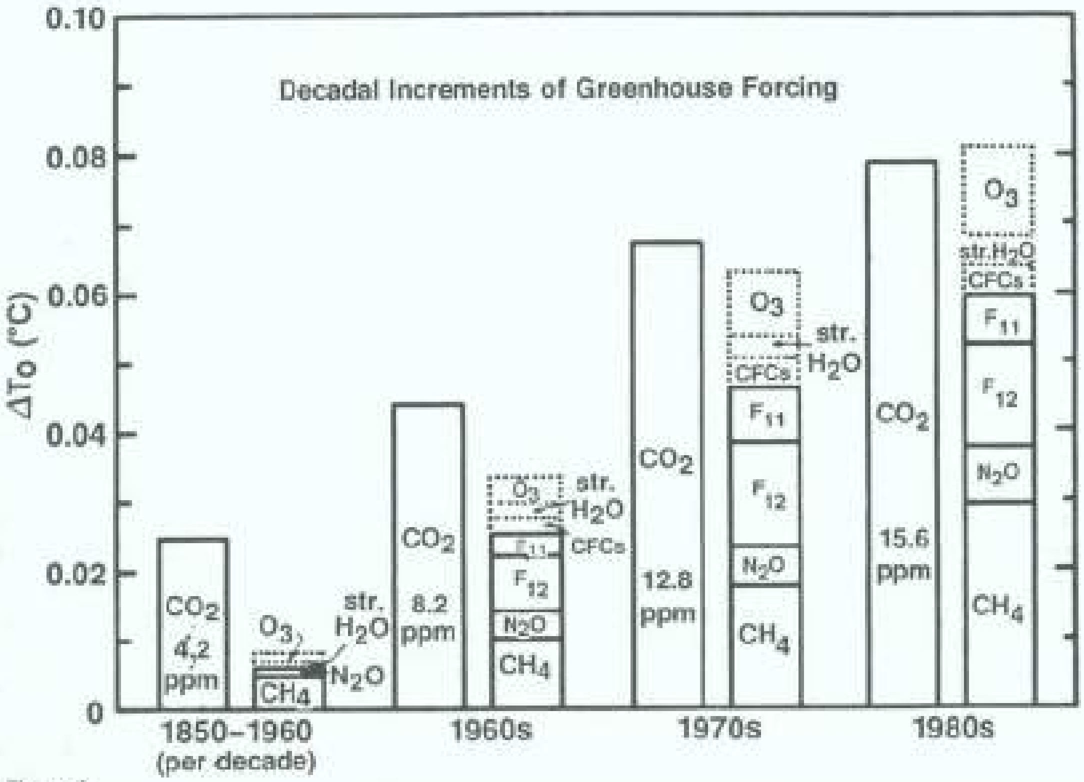

Figure 2.
Decadal additions to global mean greenhouse forcing of the climate system. ΔT_o is the computed temperature change at equilibrium for the estimated decadal increases in trace gas abundances, with no climate feedbacks included. Multiply ΔT_o by the feedback factor f to get the equilibrium surface temperature change including feedback effects. Most of the estimated trace gas increases are based on measurements. However, the O_3 and stratospheric H_2O trends (dotted bars) are based principally on the 1-D model calculations of Wuebbles et al. (1983). Source: Hansen et al. (1986).

Thus human activities are changing the composition and behaviour of the atmosphere (Bolin et al., 1986; WMO, 1986a, b). Recent analyses with advanced general circulation models of the atmosphere suggest that, if current emission trends continue, the atmospheric buildup of CO_2, N_2O, CH_4, tropospheric O_3, and CFCs could change global weather patterns significantly in the near future (Hansen, 1986; Manabe, 1986).

The best recent estimates of the warming commitment that will result from the combined effects of the increase in CO_2 and the concurrent increases in other trace gases during the last century suggest a rise of 0.7 to 2.0°C over the average global temperature of the pre-industrial period (Ramanathan et al., 1986b). Some analysts have recently suggested that the eventual warming may be as high as 1.0 to 2.5°C (Ramanathan, 1987). A global warming of even 1.5°C over pre-industrial temperatures could alter the earth's climate radically. If current emission growth rates continue until 2030, the combined effects of the six most important greenhouse gases will commit the earth to warm as much as would a doubling of the pre-industrial concentration of carbon dioxide alone (that is, an increase of 1.5 to 4.5°C above the average global temperature of the pre-industrial period).

The timing and severity of global warming could have very important consequences for natural ecosystems and human societies. Although the general direction and overall magnitude of the global impacts can be predicted today, the precise regional distribution of effects cannot. A major international scientific assessment (WMO, 1986b) sponsored by the World Meteorological Organization, the U.S. National Aeronautics and Space Administration, the Commission of the European Communities, and others reviewed current knowledge on the effects of increasing greenhouse gas emissions and concluded:

> We are conducting one giant experiment on a global scale by increasing the concentration of trace gases in the atmosphere without knowing the environmental consequences.

The effects of this atmospheric buildup will become visible sometime between tomorrow and the end of the next century. They are likely to include climate changes more extreme than any that have occurred during the past 10,000 years.

Some of the results of these climate changes will jeopardize public and private investments. Coastal developments and public water supplies would be threatened by a rise in sea-level. Agricultural output may be substantially affected by shifts in the timing and extent of rainfall. The growth of forest stands may be reduced by climatic stresses and exposure to other pollutants. Winter electric power demand might decline in the face of warmer weather, whereas summer peak loads might increase to match a higher demand for air conditioning in affluent societies. The rate of future emissions growth is likely to determine how rapidly climate changes take place and how severe the consequences will be. Energy policy decisions will substantially affect future emissions, as will private investment choices made during the next 10 years and implemented over the next few decades. If historically inefficient patterns of energy use continue, or if the amount of coal and biomass burned for energy increases, the concentration of these gases in the atmosphere will rise. As a consequence, the risks of global warming and ozone depletion would rise substantially.

3. A SKETCH OF THE IMPACTS

As indicated earlier, current theory suggests that if the concentration of CO_2 reaches twice the pre-industrial level (i.e., approximately 550 parts per million by volume or ppmv), the atmosphere will be committed to a warming of 1.5 to 4.5°C over average pre-industrial temperatures (NAS, 1983). Recent experiments with the most advanced general circulation models indicate that the warming due to such a buildup is likely to be in the upper part of this range, from 3 to 4.5°C (Dickinson, 1986).

A warming of this magnitude will directly affect many physical and biological systems (see Table 1). Sea levels will rise world-wide owing to the thermal expansion of the oceans and the melting of small, land-based glaciers. One international scientific assessment concluded that a warming of 1.5 to 4.5°C would cause a rise in global sea-level of 40 to 120 cm (WMO, 1986a). This projection is roughly in line with earlier estimates by Revelle (1983), Meier et al. (1985) and Hoffman et al. (1985).

Such a sea-level rise could cause flooding in many coastal areas, increase salt-water intrusion into aquifers, inundate vital wetlands, and destroy commercially important spawning grounds (Titus, 1986). It would also probably increase the frequency of storm damage to lagoons, estuaries and coral reefs (De Silva, 1986).

Consider, for example, the effects of a one-metre rise in sea level on lowlands in Egypt and Bangladesh. Perhaps 12 to 15% of Egypt's arable land would be inundated by such a rise (Broadus et al., 1986). The inundated area would contain approximately 8 million of Egypt's 48 million people (about 16%), and account for approximately 15% of the nation's gross domestic product in 1984-85.

In Bangladesh, a one-metre rise in relative sea-level would affect lands housing 9% of the population (Broadus et al., 1986). Approximately 8.5% of Bangladesh's agricultural output (including 11% of the country's crops) comes from the areas that would be flooded in such a situation. The loss of these lands to inundation would also reduce the fish catch, which now supplies 80% of the population's animal protein; 7.5% of the major fishing centres in Bangladesh would be flooded out (Broadus et al., 1986). Although some of these centres could be relocated, the combination of sea-level rise and decreased river flows due to the proposed construction of new dams is likely to reduce fish populations significantly by destroying key spawning areas.

The greenhouse effect will not be uniform everywhere. Warming at the poles is likely to be two to three times the global average, while warming to the tropics may be only 50 to 100% of the average (Kana et al., 1986). This increased warming at the poles will reduce the thermal gradient between the equator and the high-latitude regions, decreasing the energy available to the "heat engine" that drives the global weather machine.

As the natural thermal gradient on the planet's surface is reduced, global patterns of winds and ocean currents will change along with the timing and distribution of rainfall. Ocean currents that now moderate the climates of certain high-latitude countries may shift, causing such countries as Iceland and the United Kingdom to cool even as the rest of the world warms. The global hydrological cycle is expected to intensify by 5 to 10% if the world warms by 1.5 to 4.5°C (Clark et al., 1982). Global rainfall will probably increase slightly, whereas the timing and distribution of regional rainfall is likely to change substantially. Some areas will become wetter and others drier (Manabe and Wetherald, 1986).

These direct effects will have many important economic consequences (see Table 2). The homes and lives of millions of people living in the deltas of the Ganges, the Nile, the Mekong, the Yangtze and the Mississippi could be at risk. Hotter summers will mean increased energy and water demand in many areas. Shifting patterns of rainfall (and declines in precipitation in key regions) may turn some traditional agricultural areas to dust while new agricultural zones are opened up in other regions (Manabe and Wetherald, 1986). If these changes occur quickly, the economic and social dislocation they cause may multiply the damages substantially. Even if such changes occur over decades, the useful lives of may current and planned investments may be shortened.

4. ENERGY USE: THE KEY TO CONTROLLING ANTHROPOGENIC EMISSIONS

The global pattern of energy supply and use will substantially determine the rate of future emissions of CO_2 and N_2O. It will also affect the rate of increase in the atmospheric concentration of methane and tropospheric ozone. In the near term, efforts to make energy use more efficient by using foam insulation in buildings and in certain home appliances will affect the magnitude of future releases of CFCs. The rate of growth in emissions of all these gases will be affected by choices made in the next decade that affect the relative prices of various fuels.

Annual emissions of CO_2 from the combustion of fossil fuels are equal to approximately 5.2 billion metric tons of carbon. Emissions of CO_2 from the biota add another 1 to 2 billion tonnes of carbon to the atmosphere each year. A large portion of these biotic emissions result from the burning of biomass for energy and from the destruction of tropical forests to clear land for agriculture. As a result of the emissions from all these sources, the atmospheric concentration of CO_2 is increasing by about 0.4% per annum (see Table 3).

Not all fossil fuels contribute equally to these emissions. World-wide, coal and other solid fuels contributed approximately 44% of the total CO_2 emissions from burning fossil fuels in 1985. Combustion of liquid petroleum products contributed an additional 40%, and natural gas added about 15%.

Since 1973, global use of natural gas and coal have increased by about 36%. Oil use in 1986 is back to approximately the same global consumption level as in 1973. Over the same period, the amount of gas vented and flared has fallen by 53% (see Table 4). CO_2 emissions from the combustion of coal and natural gas have increased by about 2.4% per annum, whereas those from burning petroleum have increased by less than 0.2% per annum. For the ensemble of commercial fossil fuels, global CO_2 emissions have increased by about 17% in the last 13 years, implying an annual growth rate of 1.2%.

All nations have not contributed equally to global emissions of CO_2. The historical balance is shifting, with developing countries and centrally planned economics playing a growing role in the future. The United States, which currently consumes about 30% of the global fossil fuels used each year, produced about 25% of the fossil-fuel-derived CO_2 in 1985. The Soviet Union contributed about 20% of fossil-fuel-derived emissions in 1985, Western Europe about 15%, China about 10%, and Japan about 6%. In 1985, developing countries (excluding China) added about 15%.

This pattern has changed substantially over the last 25 years (see Table 5). The most dramatic and important shift is in the role of developing countries. In 1960, these countries contributed less than 8% of global CO_2 emissions from fossil fuel use whereas the United States produced almost 33%. At that time, the share emanating from Western Europe was 21% and the Japanese share of global emissions stood at 3%. While the levels of population and energy use increase in developing countries during the next 25 years, their share of global emissions is sure to grow. How fast emissions increase will be determined largely by the national energy strategies chosen by these countries and financed by the development assistance community.

On the biotic emissions side of the ledger, net increases of CO_2 in the atmosphere occur only when the amount of stored carbon that is burned exceeds the amount of CO_2 converted to plant matter by photosynthesis. If the quantity of material harvested and burned each year is limited to the amount of new biomass grown during the same period, CO_2 is cycled through the atmosphere but no net increase occurs. Fuel derived solely from the annual yield of agricultural crops or silvicultural plantations does not add to the atmospheric burden of CO_2.

The greater part of the nitrous oxide emissions are also due to fossil-fuel combustion. The burning of coal and residual fuel oil contributes the most. Combustion of natural gas and other petroleum products adds a smaller and somewhat uncertain amount.

All fossil-fuel combustion releases other oxides of nitrogen (NO_X) that contribute to the formation of tropospheric ozone. In addition, releases of carbon monoxide (CO) from the combustion of biomass and fossil fuels tend to increase the rate of growth of methane concentration.

4.1 Slowing the Buildup

Numerous policy options exist for reducing the rate of future emissions growth for each of the principal greenhouse gases. This section highlights some of the options related to energy strategy.

4.2 Carbon Dioxide

The three main approaches to slowing the rate of CO_2 buildup are (1) improving the efficiency of energy supply and use, (2) shifting the fuel mix away from coal toward less CO_2-intensive fuels and (3) reducing the rate of CO_2 emissions from biotic sources.

Two recent studies published by the World Resources Institute (WRI) demonstrate that an energy strategy based on increased energy efficiency can sustain economic growth in both developing and industrialized countries (Goldemberg et al., 1987a, b). Many technological opportunities now exist for improving energy efficiency (Williams et al., 1985). On the demand side, these range from the introduction of more efficient light bulbs in commercial buildings to the construction of better-insulated buildings and the manufacture of more fuel-efficient vehicles. In each area, the best technology available today requires 50% or less energy than the typical devices currently used in the United States. In most cases, these newer devices cost more to buy but have lower total life-cycle costs.

The mix of energy supply options can also be shifted away from such carbon-intensive sources as coal. Direct combustion of coal releases 26.7 million tons of carbon per exajoule. (One exajoule equals 10^{18} joules or approximately one quad of energy.) Delivering the same amount of energy from oil releases about 70% as much CO_2 whereas burning natural gas emits only about half as much CO_2 per unit of energy as coal. Burning synthetic fuels derived from coal produces even more CO_2 than burning coal directly does. If the energy is produced by nuclear reactors or by such renewable energy sources as hydropower, wind, or solar radiation, however, no CO_2 is released. To the extent that the energy supply can be shifted to these less CO_2-intensive technologies, the emissions of CO_2 can be reduced without reducing the energy supply.

Biotic sources contribute between 20 and 40% as much CO_2 to the atmosphere each year as the burning of fossil fuels does. The principal means of reducing biotic emissions are limiting tropical deforestation and making biomass use more efficient. The destruction and burning of the earth's tropical forests contribute to the buildup of atmospheric CO_2 both by reducing the stock of forests that act as a sink for CO_2 and by increasing emissions through decay and direct combustion.

Cooking with fuelwood over an open fire is the largest single end-use of energy outside of industry in many developing countries. The thermal efficiency of cooking can be improved from the current average of 10% or less to nearly 70% by substituting newer stove designs and switching to high-quality fluid fuels (Baldwin, 1987; Goldemberg et al., 1987b). If cooking is more efficient, the pressure on the forests will decrease along with the drudgery of fuelwood collection. The widespread use of such stoves could also noticeably reduce global CO_2 emissions from biotic sources.

4.3 Nitrous Oxide

Nitrous oxide is released in both bacterial processes and the combustion of fossil fuels, especially coal and fuel oil. Discouraging growth in the use of coal and coal-derived synfuels will slow the rate of N_2O emissions from fossil-fuel use. Not enough is currently known about the biotic processes leading to N_2O emissions to identify effective control policies for future emissions, but some recent research suggests that deforestation (especially clear-cutting) can increase local emissions by two orders of magnitude (Bowden and Bormann, 1986). To the extent that policies can be implemented to limit these practices, future releases of N_2O may be further reduced.

4.4 Methane

The sources and sinks of methane in the atmosphere are not completely understood today (WMO, 1986b). As a consequence, the ability of policy actions to retard the buildup of methane is limited, but a few options remain.

Losses from fossil-fuel extraction and the transport of natural gas may contribute as much as 10% of the global emissions of methane. (Natural gas is more than 98% methane by volume). About 3% of the natural gas mined in the United States is unaccounted for by gas companies. Providing incentives to improve pipeline maintenance practices and imposing strong penalties for leakage will reduce this source of emission.

Another important option is to make biomass combustion more efficient. When wood or other biomass fuel is burned in inefficient cookstoves or open fires, some of the carbon in the fuel is released as methane, rather than as carbon dioxide. Limiting tropical deforestation and introducing more efficient cookstoves could significantly reduce this source of methane. The magnitude of these effects cannot be estimated yet, but important research under way in Brazil promises to provide some valuable new data.

A third option for slowing the buildup of atmospheric methane involves preserving the natural stock of free hydroxyl (OH) radicals in the atmosphere, the principal sink for methane. Carbon monoxide itself is not a greenhouse gas. However, CO combines readily with free hydroxyl radicals in the atmosphere, depleting the natural sink for methane. By removing OH radicals, CO emissions extend the atmospheric lifetime of the methane molecules.

CO is produced primarily during the inefficient combustion of biomass and during the incomplete combustion of hydrocarbon fuels. It is released in large quantities world-wide as a component of the exhaust gases produced by cars and light trucks. Policies that encourage the introduction of more efficient cookstoves will reduce the first family of sources. The introduction of standards and performance goals for auto and truck engines will reduce the second.

4.5 Chlorofluorocarbons

Chlorofluorocarbons are manufactured molecules used as aerosol propellants, blowing agents for plastic foams, refrigerants and solvents. The most dangerous members of this family of chemicals are the fully halogenated compounds, such as CFC-11, CFC-12 and CFC-13 - extremely stable compounds with lifetimes in the atmosphere of 75 to 150 years. On a per-molecule basis, they are approximately 10,000 times as efficient as greenhouse gases as CO_2 is.

Four policy strategies can be used to slow the buildup of CFCs in the atmosphere. The incentives for each of the following options may take the form of statutory limits on the production and use of these compounds or the imposition of taxes or fees.

The first strategy involves incentives (or penalties) to improve equipment maintenance and encourage the more efficient use of CFCs in applications (such as residential refrigeration) where their special properties make substitutes impractical today. The second option involves policies that encourage recapture and recycling of these compounds rather than release and replacement. The third option is to provide incentives for the introduction of alternative, safer formulations of CFCs in such uses as building insulation. Several formulations of the new, safer CFCs (e.g., CFC-22, CFC-142b, and CFC-152a) are now available and others (e.g. CFC-134a, CFC-123, and CFC-141b) are under development. All are less dangerous than such traditional formulations as CFC-11 and CFC-12 because they have much shorter atmospheric lifetimes or they contain no chlorine. To date, they have only been produced in laboratory quantities; full-scale production processes have not yet been developed and tested. As a result, these alternative compounds are 1.5 to 5 times as expensive to produce as the more dangerous, traditional CFCs (Dupont Incorporated, 1987).

The fourth option is to encourage the use of non-CFC substitutes. One application where non-CFC substitutes could replace CFC-based products with little loss of utility is in insulated food packaging. Use of waxed paper, aluminium foil or cardboard cartons in food packaging in lieu of CFC-blown plastic foams is often less expensive, equally effective, and equally appealing to the consumer.

5. EXPLORING THE POTENTIAL OF POLICY TO LIMIT EMISSIONS

To explore the effects of various policy strategies on the timing of future global warming, a computer model - the Model of Warming Commitment (MWC) - was developed at the World Resources Institute. Combining several existing models of energy use and trace gas emissions with economic growth projections, the MWC projects future emissions of the six most significant greenhouse gases and the resulting increase in temperature (Mintzer, 1987).

The MWC tests recent suggestions that policy choices made today can affect the rate and extent of future global warming. This model can investigate the impacts on the commitment to future warming that result from policies that stimulate more efficient energy use, change the global fuel mix, slow tropical deforestation and limit the production and use of the most dangerous CFCs. The concept of "commitment" reflects the fact that changes brought about by the emission of greenhouse gases into the atmosphere - from both human and biotic sources - are largely irreversible over time spans of interest for policy-making purposes.

An analysis of four scenarios using the MWC illustrates a range of possible global warming outcomes. Each scenario incorporates both broad policy strategies and such narrow measures as taxes on particular fuels or limits on certain uses of chlorofluorocarbons. Projections from these tests indicate that present-day public policies and private practices could, if continued for several decades, significantly affect the rate and extent of global warming due to the buildup of greenhouse gases. Earlier studies, in contrast, suggested that the lack of scientific evidence severely constrains policy responses.

6. THE MODEL OF WARMING COMMITMENT

The MWC simulates the effects of global policies on the buildup of greenhouse gases in three stages. The model projects future production and emissions of the six most important gases, estimates future concentrations by calculating natural rates of gas removal, and evaluates the combined radiative effects of the gas buildup. Numerous assumptions concerning demographics, energy resources and use, and fiscal policies and other economic factors enter into the submodels used within each stage.

In stage one, the model estimates the releases of carbon dioxide and nitrous oxide during each year of the simulation period. Prompt and banked emissions of CFCs are separated, and increases in methane and tropospheric ozone concentration at exponential and linear rates, respectively, are estimated. In stage two, the processes that remove carbon dioxide, nitrous oxide and CFCs from the atmosphere are simulated; then the annual growth in the concentration of each gas is estimated. In stage three, the warming effects of greater concentrations are estimated using a simple radiative model of the atmosphere. The contributions from each gas are added together. The sum is added to the warming commitment due to emissions over the past 100 years. The model then factors in a range of values that accounts for feedback processes. The feedback results while the global warming changes the atmospheric water-vapour content, the extent of sea ice, the average extent and height of cloud cover, and the earth's surface albedo.

To estimate future CO_2 concentrations, the MWC separately accounts for emissions from two sources: fossil-fuel combustion (based upon a simulation of the market for commercial energy sources) and the use of biotic materials. The future concentration of CO_2 is estimated in a simple airborne fraction model that accounts for the effects of the global carbon cycle. An Institute for Energy Analysis (IEA) submodel is used to project long-term supply and demand for nine primary and four secondary energy forms in each of nine geopolitical regions. This submodel also provides estimates of regional energy prices. Estimated energy demand is based on data on each region's gross national product (GNP) and population. The submodel applies constant coefficients in each scenario to express changes in the efficiency of energy use and supply.

The IEA submodel projects future GNP and fuel prices, describes the future global fuel mix, and calculates the amount of CO_2 emissions related to deforestation and land-use conversion. Biotic emissions are added to the estimated CO_2 released from fossil-fuel combustion to produce an estimate of total CO_2 emissions. With an airborne fraction model, annual carbon dioxide emissions are converted to future atmospheric concentrations by introducing the rate at which carbon dioxide leaves the atmosphere.

The effects of other greenhouse gases are calculated somewhat differently. The recent growth rate in nitrous oxide concentration correlates closely with the growth in the use of fossil fuels, especially coal and fuel oil. The increase in N_2O emissions in this model follows the rate of growth in coal combustion. Applying a submodel based on work by Craig et al., (1976) and modified by Weiss (1981), the MWC computes future N_2O concentration as a function of past concentrations and future emissions.

Chlorofluorocarbons play an important but complex role in both the greenhouse and ozone-depletion problems. These compounds have not biotic sources but are produced and used solely by industry. In the MWC, an approach developed by the RAND Corporation is used to project future regional production of CFC-11 and CFC-12 (Quinn et al., 1986). The energy-economic submodel's population and GNP estimates form the basis for projecting regional CFC demand during three periods of market growth and development. Based on assumptions about alternative variations of the U.S. experience, this submodel estimates production levels for aerosol and non-aerosol applications of CFC-11 and CFC-12. The MWC then applies an approach developed by ICF, Inc., to convert estimates of future production to projections of future emissions from each of four end-uses (ICF Incorporated, 1986); the methodology of Cicerone and Dickinson (1986) is then used to convert these estimates of future emissions to projections of CFC concentration (Cicerone and Dickinson, 1986).

To estimate the eventual warming effect of a greenhouse gas buildup, an approach developed by Ramanathan et al. (1986b) is used; it takes into account the effects of changes in the concentration of each gas.

6.1 Scenarios of Future Energy Use and CO_2 Emissions

Four scenarios of future economic growth and energy use were investigated by WRI using the MWC. Each of the four takes into account a different mix of technical, economic and policy factors. Demographic factors, including regional population growth rates and the average annual increase in labour productivity, were held constant in the four scenarios. The average annual increase in the efficiency of energy use and supply, the cost and rate of change in the cost of synthetic oil and gas, the cost of solar energy, and the income elasticity of energy demand are some of the technical and economic factors affected by the policy strategies embedded in the four scenarios. Policy factors included environmental cost (calculated as a portion of the consumer price of energy) and various consumption taxes on energy use. For each scenario, the MWC creates a snapshot of data for energy supply and use at 25-year intervals, beginning in 1975. Energy use and CO_2 emissions increase in three of the four scenarios. All four scenarios support the same levels of regional GNP growth, despite the vastly different energy mixes that they assume. Table 6 summarizes the four WRI scenarios.

The Base Case projection assumes a "business-as-usual" pattern of growth and change in world energy use. The greenhouse problem does not significantly influence government policies. No efforts are directed toward reducing CO_2 releases, governments do little to help improve end-use efficiency or develop solar energy system, and electricity use increases relative to the use of other energy carriers. Rates of tropical deforestation continue to increase. Total energy use nearly quadruples over the 100-year period, partly because the price of energy includes few environmental costs. Carbon dioxide emissions from commercial fuel use almost quadruple also.

The High Emissions Case reflects aggressive promotion of energy growth with no special attention to the environmental risks of energy use. Although the price of coal doubles over the 100-year span, gas prices increase far more and coal constitutes 75% of the primary energy supply by 2075. Policies encourage the use of synthetic fuel, do not encourage solar energy use and attach minimal environmental penalties to the use of nuclear power. The increased use of coal and shale leads to an increase in carbon dioxide emission. Generally higher temperatures also result in heightened CO_2 emissions from the biota while the rate of respiration from soil bacteria rises. The biotic emissions of CO_2 increase dramatically as fuelwood demand rises, and the conversion of forests to agricultural or other development uses continues unchecked. After 50 years, CO_2 emissions from biotic sources have risen sevenfold. At the 100-year mark, tropical forest resources dwindle and biotic emissions of CO_2 decline almost to the base level.

The Modest Policies Case assumes that governments will use a mix of fiscal, tax and other incentives to spur the consumption of less CO_2-intensive fuels and to support the development of more efficient energy technologies. The use of primary energy sources, especially coal, increases more slowly than in the Base Case, but electricity use remains about the same as in that case. Utilities cut their use of solid fuels, so that CO_2 emissions from this source decrease. Natural gas and nuclear efficiency as well as end-use efficiency grow more rapidly than in the Base Case. Nations cooperate to reduce the rate of tropical deforestation and to reforest areas where trees once grew. As a result, the new annual biotic release of CO_2 decreases.

The Slow Buildup Case is based on strong global efforts to stablize the atmosphere's composition by reducing greenhouse gas emissions. Total primary energy use grows very slowly. New policies stimulate higher efficiency of energy use and the introduction of solar energy as its cost drops. Governments cooperate to limit the conversion of forests and begin sustained reforestation efforts. Coal use in 2075 is only 25% of that in 1975; the biotic contribution of CO_2 emissions in 2075 declines to 1% of the 1986 rate in this scenario. Total CO_2 emissions decrease further and faster than in any of the other WRI scenarios. The total decrease amounts to over 50%.

6.2 Greenhouse Gas Buildup, Climate Change and Modelling Uncertainty

Concentrations of greenhouse gases in the atmosphere vary by factors of two to five among the four scenarios. For CO_2, N_2O and the two CFCs, the range of concentrations projected by the MWC is more conservative than the ranges suggested by earlier studies.

The scenarios yield a range of CO_2 concentration of 420 to 820 parts per million by volume (ppmv) (see Figure 3) - which falls within the lower end of the spectrum of earlier estimates of concentration made by Nordhaus and Yohe (1983) and by Edmonds and Reilly (1983). The scenarios show a smaller range for nitrous oxide concentration, from 445 parts per billion by volume (ppbv) in the High Emissions Case to about 310 ppbv in the Slow Buildup Case. The rate of growth in coal use, which the model assumes to be the driving force in the rate of N_2O emissions growth, varies by a factor of 20 among the four scenarios (see Figure 4).

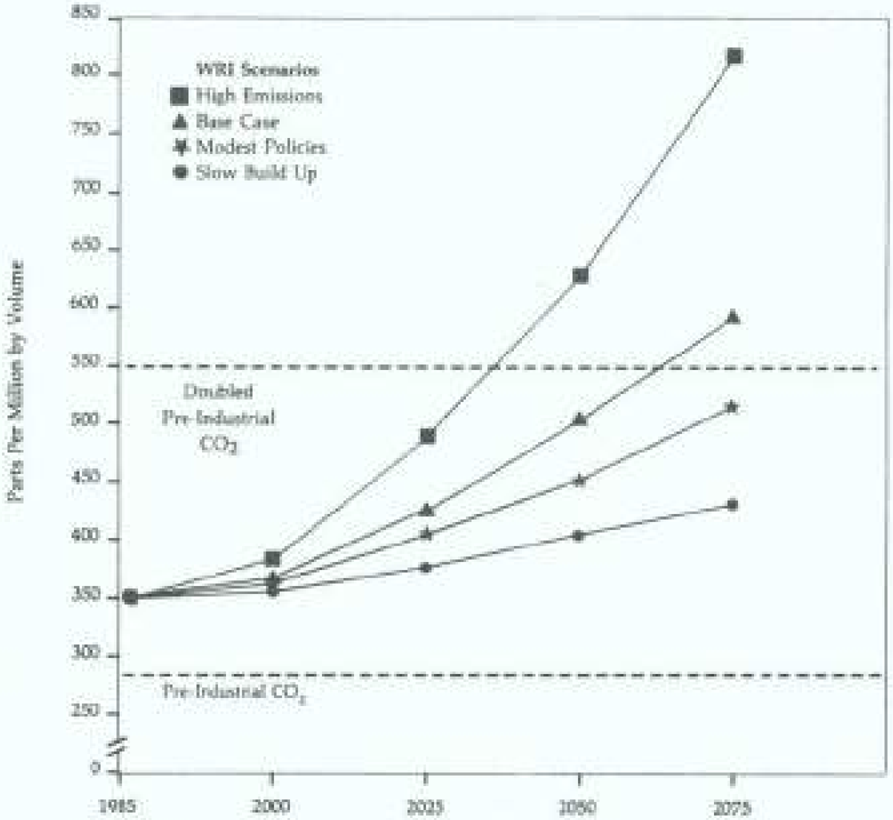

Figure 3.
Atmospheric CO_2 concentrations in the WRI scenarios (parts per million by volume).

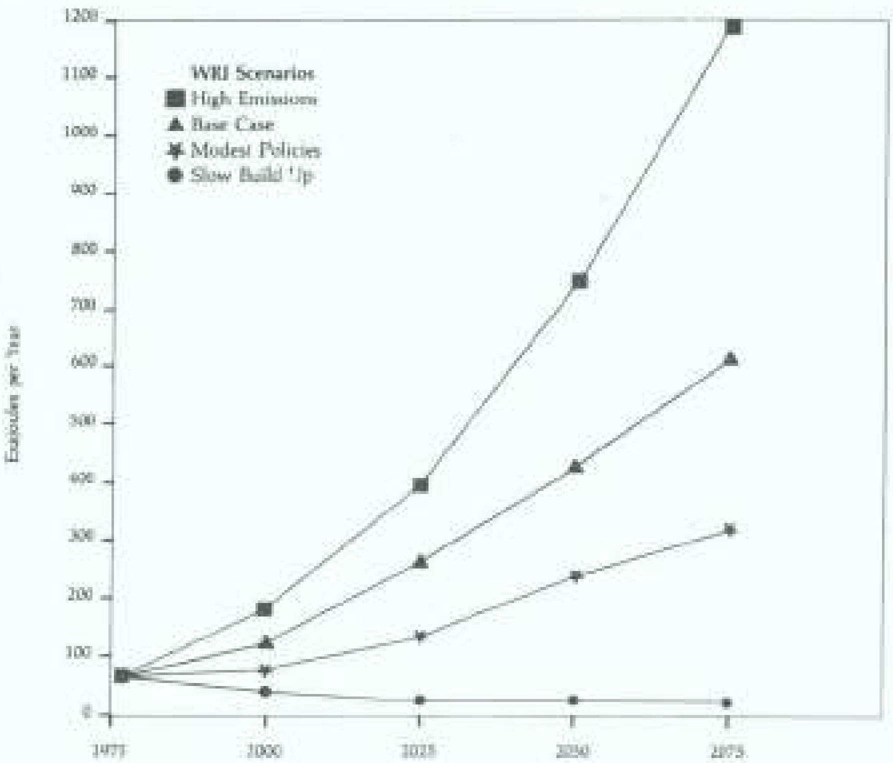

Figure 4.
Coal use in the WRI scenarios (exajoules per year).

CFC concentration will depend upon how much production and demand increase. In the High Emission Case, other regions grow at the pace followed by the United States; in the Base Case, the pace is significantly slower. The Modest Policies and Slow Buildup scenarios simulate the effects of international policies to limit global production and to control key end-uses of CFC-11 and CFC-12. Emissions of the two principal CFCs vary by factors of eight and four, respectively, between the High Emissions and Slow Buildup scenarios.

Since so little is known about the processes that control the emissions and removal of atmospheric methane, the model incorporates arbitrary assumptions about growth rates to compute future concentrations present in the High Emissions and Slow Buildup scenarios. For perspective, this range is in keeping with earlier studies, and the growth rate for tropospheric ozone compares closely with the rates projected by Ramananthan et al. (1986b).

As to the many estimates and assumptions embraced in the Model of Warming Commitment, uncertainties in the data used to project the levels of economic activity and the emissions of greenhouse gases are significant. The relationship between changing demographic patterns and primary energy demand would influence the model if they could be quantified. Economic variables, including the rates of increase in regional GNP and GNP per capita, affect projections of the production and emissions of greenhouse gases. Economists do not agree on how to pin down these rates of change.

New energy technologies may enter markets at unpredictable rates. Structural changes in the western market economies and saturation of certain key end-uses, as shown in recent analyses by Goldemberg et al. (1987a), could reduce long-run income elasticities of energy demand. Currently unquantified feedback effects between climate change and future patterns of energy use of greenhouse gas emissions may affect the future warming rate. Also uncertain are the determinants of the rates of biotic release of CO_2 and the effects of feedback between global warming and future rates of CO_2 uptake by the oceans. For example, additional research and development of coal combustion technology may break the link between coal use and historic rates of N_2O emissions. Finally, documentation of the rate of methane emissions from known sources is lacking.

The models used in this analysis also have structural limitations. The economic submodel does not disaggregate demand well; nor does it represent well the effects of policies to accelerate market penetration, or capital formation, or depreciation as a stimulus for investment. With the submodel used to estimate future N_2O production, annual emissions may be understated. Moreover, the MWC cannot adequately simulate the effects of either geographic or altitudinal variation in trace gas distribution in the atmosphere because it relies upon a one-dimensional model of the radiative effects.

7. MODELLING RESULTS AND POLICY IMPLICATIONS

The predictions of warming effects in these four scenarios provide a framework for evaluating the potential of policy to limit future global warming. Two criteria are used to evaluate the scenarios. The first is the date at which the atmosphere is committed to a warming equal to the effect of doubling the pre-industrial concentration of CO_2 alone (i.e., 1.5 to 4.5°C). The second criterion is the total warming commitment in 2075, at the end of the simulation period.

The year when emissions will irreversibly commit us to a warming of 1.5 to 4.5°C about the pre-industrial temperature varies by at least 60 years, depending upon which policies are adopted. The Slow Build-up scenario brings the planet to that point sometime after 2075; the Base Case scenario, by approximately 2030; and the High Emissions scenario, by 2015. By 2075, the range of warming commitment varies widely - from 1.4 to 4.2°C under the Slow Buildup scenario to 5.3 to 16.0°C under the High Emissions scenario (see Figure 5).

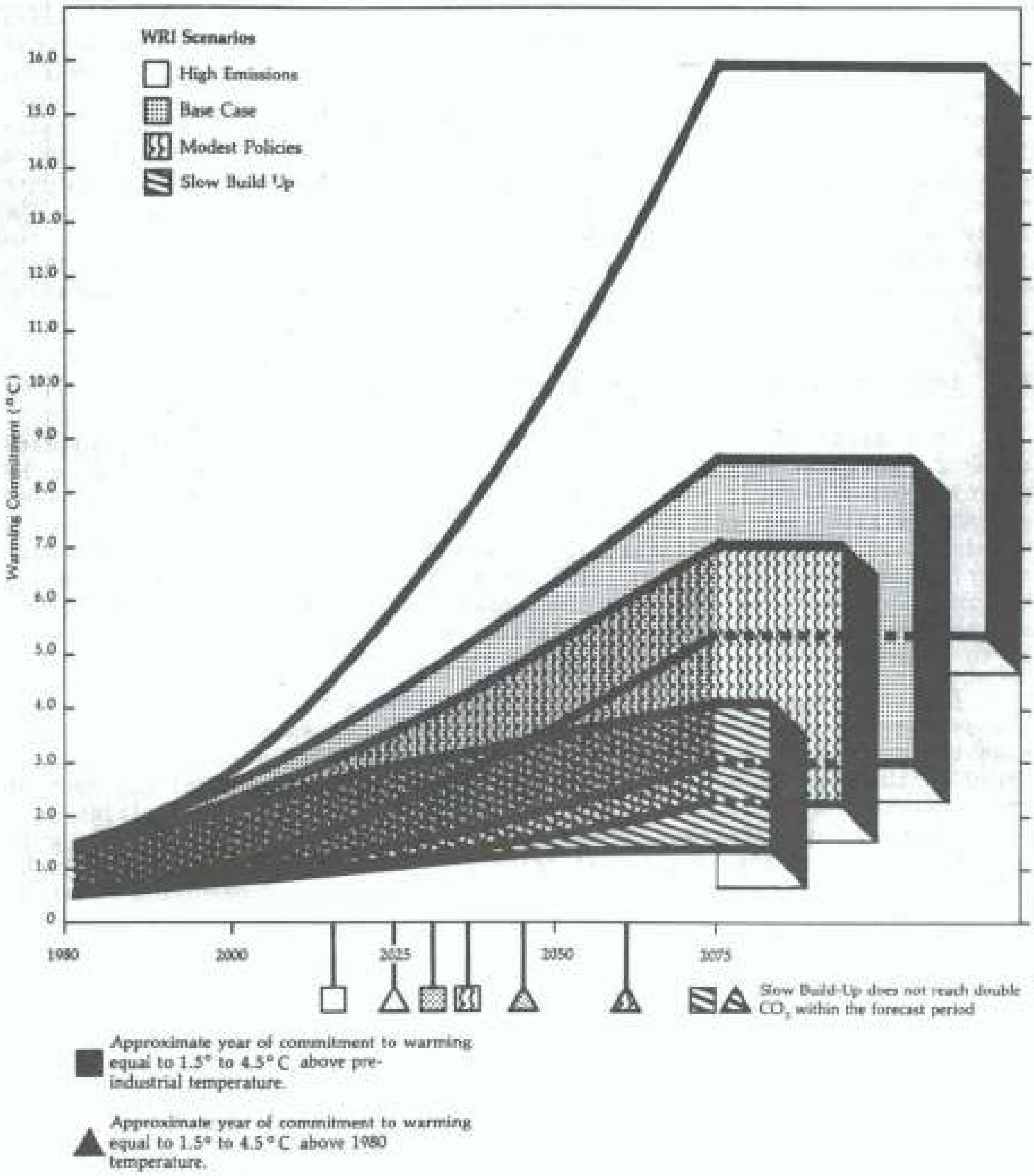

Figure 5.
Commitment to future warming in the WRI Scenarios.

Without new policies (i.e., under the Base Case scenario), the commitment to global warming by 2030 falls into the range of 1.6 to 4.7°, slightly more than would result from doubling the pre-industrial concentration of CO_2 alone. Further, an increase in emissions, such as that exemplified in the High Emissions scenario, commits the earth to warm by 1 to 3°C perhaps as early as 2000. Under either scenario, the upper estimate of warming commitment by 2075 would cause a more radical climate change than any experienced in the last one million years.

Current policies do not "lock in" the planet to the worst of these hothouse futures, but the opportunity to avoid a substantial greenhouse warming altogether is no longer ours - even under the Slow Buildup scenario. In addition, any delay in making policy choices carries significant consequences. Delaying action by, say, 30 years to remove scientific uncertainties, identify options, establish international consensus and implement appropriate policies will commit the earth to a warming 0.25 to 0.8°C higher than what would occur if a Slow Buildup scenario were implemented today. The increase that a 30-year delay would bring equals about 30 to 50% of the total warming commitment due to trace gas emissions between 1860 and 1980. Clearly, energy policy choices made today and implemented soon will substantially affect the magnitude and speed of global warming.

8.1 Implications and Challenges for Policy-Makers

The legacy of today's industrial activities will be future climate changes, and the extent of those changes will be determined largely by policy choices made in the next few decades. Atmospheric concentrations of greenhouse gases increase every day. If national governments conclude that a warming commitment greater than 1.5 to 4.5°C will cause unacceptable social risks, then remedial actions will be needed soon. The longer the delay before policy options and their implications are explored, judgments made, and choices implemented, the more extreme the policies imposed will have to be to keep temperature increases within some prudent upper bound.

The challenge facing policy-makers and managers today is to identify the policy options that will limit greenhouse gas emissions without substantially slowing economic growth over the long term. The task is complicated by the significant and persistent uncertainty in regional analyses of the impacts of climate change. Substantial methodological difficulties must be overcome to develop new analytic approaches and tools. These tools will need to have long time horizons if scientists are to evaluate adequately the policies that must be implemented over 50 or 100 years. Conventional methods of discounted cash flow analysis are clearly not adequate.

The task for policy-makers will be neither simple nor quick and the choice is not between preventing or adapting to climate change. The challenge is to find those policies that, in the circumstances peculiar to each region and nation, will slow the rate of change and allow societies to adapt to the climatic changes that cannot be avoided. This task is politically difficult because the costs of preventing or adapting to climate change are in the present and the potential benefits are both uncertain and far off. But the risk of ignoring the challenge, however seductive, is enormous.

Scientists world-wide agree that, if left uncontrolled, growth in the emissions of greenhouse gases will commit human societies, within the lifetimes of many of us alive today, to more radical and disruptive environmental changes than anything experienced during written human history. Coast-lines will be inundated, farmlands will be lost and forest yields will decline significantly. On the other hand, the benefit of meeting the challenge directly and with imagination is to sustain economic growth and preserve the health of natural ecosystems. The resulting innovations in energy use and industrial processes will reduce many forms of pollution and may just provide societies enough "breathing space" to allow a smooth transition to a new and productive climatic era.

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Table 1. Direct effects of global warming.

- Sea-level rise
- Changes in winds and ocean currents
- Changes in precipitation and water resources
- Changes in the frequencies of extreme events

Table 2. Potentially important economic impacts of global warming.

- Coastal flooding and salt-water intrusion
- Changes in availability of irrigation water
- Reduced forest and crop yields
- Increases in peak electric power demand
- Adverse impacts on human health

Table 3. Key greenhouse gases: Present concentrations in air, their rates of increase and pre-industrial era concentrations.

Gas	Concentration in Air: Pre-Industrial	Concentration in Air: 1986	Present Annual Rate of Increase	
Carbon dioxide (CO_2)	275 ppm	346 ppm	1.4 ppm	(0.4%)
Methane (CH_4)	0.75 ppm	1.65 ppm	17 ppb	(1%)
Fluorocarbon-12 (CCl_2F_2)	0.0	400 ppt	19 ppt	(5%)
Fluorocarbon-11 (CCl_3F)	0.0	230 ppt	11 ppt	(5%)
Nitrous Oxide (N_2O)	280 ppb	305 ppb	0.6 ppb	(0.2%)
Ozone, tropospheric (O_3)	15 ppb?	35 ppb	0.3 ppb? Northern Hemisphere only	(1%)
Other fluorocarbons	0.0			(5 to 15%)

ppm = parts per million ppb = parts per billion ppt = parts per trillion

Table 4. CO_2 emissions from fossil fuels, 1971-86 (millions of tons of carbon).

Year	Burning Source for CO_2 Gas fuel	Petroleum	Coal	Flaring Gas	Total CO_2 Emissions From Fossil Fuel
1971	553	1946	1594	90	4183
1972	582	2056	1612	95	4345
1973	608	2240	1622	112	4582
1974	616	2245	1620	107	4588
1975	621	2132	1715	96	4564
1976	645	2313	1754	110	4822
1977	646	2390	1812	108	4956
1978	673	2384	1828	106	4991
1979	715	2538	1899	74	5226
1980	721	2411	1922	78	5132
1981	731	2276	1930	58	4995
1982	725	2191	1986	56	4958
1983	733	2170	1992	52	4947
1984	786	2219	2080	52	5137
1985	807	2189	2181	52	5229
1986*	825	2283	2209	52	5369

* Estimated

Table 5. Historical distribution of CO_2 emissions from fossil fuels (millions of tons of carbon).

Country	Year 1960	1970	1980	1985
United States	783	1149	1249	1186
Western Europe	523	779	853	780
Japan	60	195	243	244
Soviet Union	389	613	871	958
China	214	211	395	508
Other developing countries	188	336	658	819

Table 6. Energy Policies in the WRI Scenarios.

Scenario	Related Energy Model Parameter Value	Warming Commitment (°C)
Base Case		
• "Business-As-Usual," the inertial model of growth and change in the world energy industry		1980: 0.5-1.5
• No policies to slow CO_2 emissions		2000: 0.9-2.6
• Minimal stimulus to improve end-use efficiency	(Rate of change = 0.8% per year)	2030: 1.6-4.7
• Modest stimulus for synfuels development	(Final Price = $3.15-4.25 per GJ in 2005)	2075: 2.9-8.6
• Minimal stimulus for development of solar energy systems	(Final Price = $16.50 per GJ in 2025)	
• No policy to limit tropical deforestation or to encourage reforestation		
• Minimal environmental costs included in price of energy	($0.30 per GJ for coal; $1.00 per GJ for synfuels)	
High Emissions		
• Accelerated growth in energy use is encouraged		
• No policies to slow carbon dioxide emissions		1980: 0.5-1.5
• No stimulus to improve end-use efficiency	(Rate of change = 0.2% per year)	2000: 1.0-2.9
• Modest stimulus for increased use of coal	(Rate of improvement = 0.75% per year)	2030: 2.3-7.0
• Strong stimulus for synfuels development	(Final Price = $2.75-3.50 per GJ in 1995)	2075: 5.3-16.0
• No stimulus for development of solar energy systems	(Final Price = $20.00 per GJ in 2040)	
• Rapid deforestation and conversion of marginal lands to agriculture		
• Token environmental costs included in price of energy	($0.15 per GJ for coal; $0.50 per GJ for synfields)	
Modest Policies		
• Strong stimulus for improved end-use efficiency	(Rate of change = 1.0% per year)	1980: 0.5-1.5
• Modest stimulus for solar energy	(Final Price = $15.00 per GJ in 2025)	2000: 0.8-2.5
• Substantial efforts at tropical reforestation and ecosystem protection; more intensive rather than extensive agriculture encouraged	($0.60 per GJ for coal; $1.50 per GJ for synfuels)	2030: 1.4-4.2
• Substantial environmental costs imposed on energy prices to discourage solid fuel use and to encourage fuel-switching		2075: 2.3-7.0
Slow Buildup		
• Strong emphasis placed on improving energy efficiency	(Rate of improvement = 1.5% per year)	1980: 0.5-1.5
• Rapid introduction of solar energy encouraged	(Final price = $12.00 per GJ in 2000)	2000: 0.8-2.3
• Major global commitment to reforestation and ecosystem protection		2030: 1.1-3.2
• High environmental costs imposed on energy prices to discourage solid fuel use and to encourage fuel-switching	($1.20 per GJ for coal; $3.00 per GJ for synfuels)	2075: 1.4-4.2

ABSTRACT

OUR CHANGING ATMOSPHERE: ENERGY POLICIES, AIR POLLUTION AND GLOBAL WARMING

In recent years, industrial and agricultural effluents have increased the concentration of carbon dioxide and other radiatively active trace gases in the atmosphere. These gases absorb and re-emit low-energy radiation emanating from the earth's surface, thus warming the lower atmosphere. Past emissions of these greenhouse gases have already committed the planet to a warming of 0.7 to 2.0°C. This greenhouse effect threatens to alter the earth's climate.

The timing and extent of future global warming will be strongly influenced by the rate of greenhouse gas emissions from energy mobilization and use. Recent investigations suggest that energy policy choices implemented during the next several decades could substantially accelerate or slow down the rate of buildup of carbon dioxide, nitrous oxide, ozone and methane in the troposphere. If current trends continue, the earth will be committed to a warming of 1.5-4.5°C by the early 2030s. National energy policies that encourage rapid increases in the use of coal, limited investments in technology to improve energy efficiency, and continued increases in the rate of tropical deforestation could accelerate the buildup of greenhouse gases, reaching this level before 2015. By contrast, national policies that encourage the rapid introduction of efficiency-improving technologies and renewable supplies, stimulate a shift of the fuel mix toward the increased use of less carbon-intensive fuels, and limit tropical deforestation could postpone this level of buildup until sometime after 2075.

RÉSUMÉ

L'ATMOSPHÈRE EN ÉVOLUTION: POLITIQUES ÉNERGÉTIQUES, POLLUTION ATMOSPHÉRIQUE ET RÉCHAUFFEMENT DU GLOBE

Au cours des dernières années, les effluents industriels et agricoles ont fait augmenter la concentration du gaz carbonique et d'autres gaz à l'état de trace qui agissent sur le rayonnment solaire dans l'atmosphère. Ces gaz absorbent et ré-émettent des rayonnements de faible énergie émanant de la surface de la terre, réchauffant ainsi la basse atmosphère. Les émissions passées de ces gaz à effet de serre cont dégà entraîné un réchauffement de la planète de 0,7 à 2,0°C. Cet effet de serre risque de modifier le climat de la Terre.

La répartition dans le temps et dans l'espace du réchauffement futur du globe dépendra beaucoup du taux d'émission de gaz à effet de serre provenant de la mobilisation et de l'utilisation de l'énergie. Des études récentes indiquent que les politiques énergétiques qui seront mises en vigueur au cours des prochaines décennies pourraient avoir pour effet d'augmenter ou de diminuer substantiellement le taux d'accumulation du gaz carbonique, de l'oxyde nitreux, de l'ozone et du méthane dans la troposphère. Si les tendances actuelles se poursuivent, la Terre subira un réchauffement de 1,5 à 4,5°C d'ici aux années 2030. Les politiques énergétiques nationales axées sur l'utilisation croissante du charbon, sur des investissements limités dans une technologie visant à augmenter le rendement énergétique et sur l'augmentation soutenue de la vitesse de déboisement des forêts tropicales pourraient avoir pour effet d'accentuer l'accumulation des gaz à effet de serre, de sorte que le niveau de réchauffement attendu pourrait être atteint avant l'an 2015. Par contre, les politiques nationales qui sont axées sur l'introduction rapide de techniques permettant d'augmenter le rendement énergétique et de formes d'énergie renouvelables, qui encouragent l'utilisation d'une proportion accrue de combustibles moins riches en carbone et qui limitent le déboisement des forêts tropicales pourraient retarder l'échéance de ce niveau d'accumulation de gaz jusqu'après l'an 2075.

INTERNATIONAL CO-OPERATION IN ATMOSPHERIC SCIENCES AND THE CHANGING ATMOSPHERE

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1. INTRODUCTION

It has been possible, on the basis of data exchanged world-wide, to estimate from direct instrumental measurements, the average surface temperature over the earth since the late nineteenth century. The number of observing stations providing temperature records has gradually increased over the years. From these records, it is possible to determine temperature trends. Figure 1 shows such a trend line for over 100 years. From this we see a warming trend and that last year, 1987, was the warmest year on instrumental record.

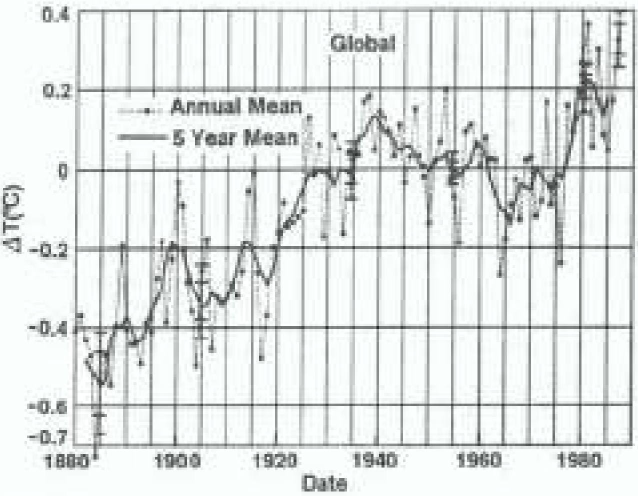

Figure 1.
Global temperature trend for the past century. The 1987 point is an estimate based on the data from 1 January to 1 November (after Hansen and Lebedeff, 1988).

At the same time, measurement networks co-ordinated by WMO* show continued, apparently inexorable, increases in greenhouse gases, carbon dioxide (CO_2), nitrous oxide (N_2O), chlorofluorocarbons (CFCs F-11 and F-12) and methane (CH_4). The warming measured by the world's observing network is entirely consistent with the output and predictions of mathematical models of the atmosphere's general circulation (or GCMs) under the stress of increasing greenhouse gas concentrations. Does this mean that we have now absolutely definitive proof that the much warmer climate predicted by the modellers is beginning to occur? Unfortunately, while the data are very suggestive, some argument still remains.

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* It should be emphasized that work attributed to WMO in this paper is work undertaken mainly by the Member countries of the Organization and co-ordinated through WMO mechanisms.

2. DETECTING GLOBAL CLIMATE CHANGE

Professional meteorologists know that in the past century departures from the climatological norm are, most often, local manifestations of transient anomalies in the atmospheric circulation, which do not constitute a significant departure from time-averaged climate. Occasionally, a significant climate fluctuation may be observed in the instrumental record to last for several years or even a decade, such as the 10-15% decrease in precipitation over Toronto during the dry "dust bowl" years around 1930. Even so, it is striking how closely the precipitation regime returned to the long-term climatological norm after 1940. However, some scientists have proposed that in certain cases, such as the 20-year-long drought in the Sahelian region of Africa, feedback mechanisms may perpetuate the atmospheric circulations that caused the drought. Thus, detecting meaningful gradual changes of the global climate in the midst of all kinds of "meteorological noise" is no small scientific problem and can only be attempted on the basis of precise environmental measurements on a scale representative of the global atmosphere and the earth's surface. The efforts of the International Meteorological Organization, now the World Meteorological Organization (WMO), spanning almost 120 years, have been successful in providing an ever-growing range of reliable, precisely calibrated measurements of atmospheric and other relevant geophysical quantities through world-wide co-operation. As a result, the atmospheric, and marine, climatological records constitute a unique resource and the main quantitative basis available to assess recent climate change and to investigate the mechanisms that may be causing current and future changes. The further development of the world meteorological observing system, the "World Weather Watch", is indeed a basic requirement for any quantitative study of climate.

In summary, the records show that (1) major changes in the chemical composition of the earth's atmosphere due to man's actions are occurring; (2) temperature changes have been recorded that are consistent with the warming predicted due to the chemical changes; (3) these changes and regional climatic anomalies, such as the long-lasting Sahelian drought and the intensification of the Antarctic winter vortex associated with intense ozone-layer depletion, are related to changes in global atmospheric circulation patterns on time-scales of seasons and decades, and to changes that are perhaps more permanent. Changes in circulation patterns are best studied by mathematical models of the atmosphere based on the data from the World Weather Watch.

3. NUMERICAL WEATHER FORECASTS AS A TOOL FOR PHYSICAL PREDICTION OF CLIMATE CHANGE

An implicit assumption under any assessment of climate change is that weather under modified climate conditions will have essentially the same kind of variability as we observe today, between winter and summer, or between different altitudes and latitudes, although with different distributions in space and time. Accordingly, our ability to estimate future climate variations cannot be better than our ability to reproduce weather and climatic events that we can observe now. In that respect, advances in understanding and predicting climate change cannot be divorced from progress in global weather forecasting, which is, naturally, a major scientific thrust in WMO.

We know in particular that the expected climatic effect of the increase in atmospheric carbon dioxide and other greenhouse gases depends very much upon a variety of "feedback processes" occurring in the atmosphere or at the surface of the earth. The foremost feedback is the controlling affect of extended clouds on the radiation balance of the earth and the temperature of the earth's surface. We know, of course, that thick clouds reflect back to space almost all of the incident solar radiation. What may not be so well appreciated is that clouds, even rather thin and invisible high cirrus, also absorb infrared radiation and contribute positively to the greenhouse effect. As a result of competing effects, the overall "feedback factor" is negative (cooling) for low stratus clouds but is positive (warming) for high clouds. It is therefore essential, for assessing the range of future anthropogenic climate change, to determine with much greater accuracy than now available, the global cloud climatology and to establish the correspondence with meteorological conditions. This is but one of many scientific tasks being undertaken by WMO, in co-operation with the International Council of Scientific Unions (ICSU), under their joint World Climate Research Programme (WCRP).

A major technological development is being planned, with the help of the world's space agencies, to launch a new generation of earth observation satellites in polar orbit by the end of the century. These satellite missions will continue systematic meteorological observations and also introduce new active sensors, using radar and laser techniques, to observe wind, cloud and rain. This is the goal of the Global Energy and Water Cycle Experiment (GEWEX) being organized within the WCRP.

4. UNDERSTANDING THE BEHAVIOUR OF THE "EARTH SYSTEM"

Substantial climate changes have occurred in the past, due to natural causes, and are a manifestation of the natural variability of the "Earth System" comprising the atmosphere, the hydrosphere (oceans and freshwater lakes and rivers), cryosphere (sea-ice, glaciers and snow), and biosphere (terrestrial vegetation and soil, marine biota). Without even going back to the last glaciation or the recent climatic optimum of the Holocene era (6000 years B.P.), we may remember that changes have occurred in the historical past, which have caused the fertile Mediterranean agricultural lands of Roman times to yield to desert under increasingly arid conditions. We know that the relatively mild conditions that prevailed at the end of the Middle Ages favoured flourishing Viking settlements in Iceland and Greenland soon to be devastated by the colder climate of the "Little Ice Age" beginning in the thirteenth century. A major task is that of discriminating between natural and man-made causes by unravelling the multiple connections between the atmosphere, the ocean and the rest of the system.

5. GEO-BIOCHEMICAL CYCLES

The examination of past climate before historical records began, does show the great influence of the greenhouse gases, especially CO_2, on the near-surface temperature of the earth's atmosphere.

A striking achievement of paleoclimatology, based on the ability to perform a precise chemical analysis of air bubbles trapped in deep Antarctic ice cores, has been the reconstruction of a 160,000-year record of the concentration of atmospheric carbon dioxide and of global temperature (Figure 2). These data show not only spectacular changes of the amount of CO_2 (180 to 300 parts per million), but also a striking relation with past climate changes. This also indicates the existence of another major feedback mechanism involving the planetary carbon cycle and especially the processes that control the partial pressure of carbon dioxide, such as change in ocean surface temperature and/or chemistry, transition to another ocean circulation regime or alteration of the photosynthetic activity of marine or terrestrial biota.

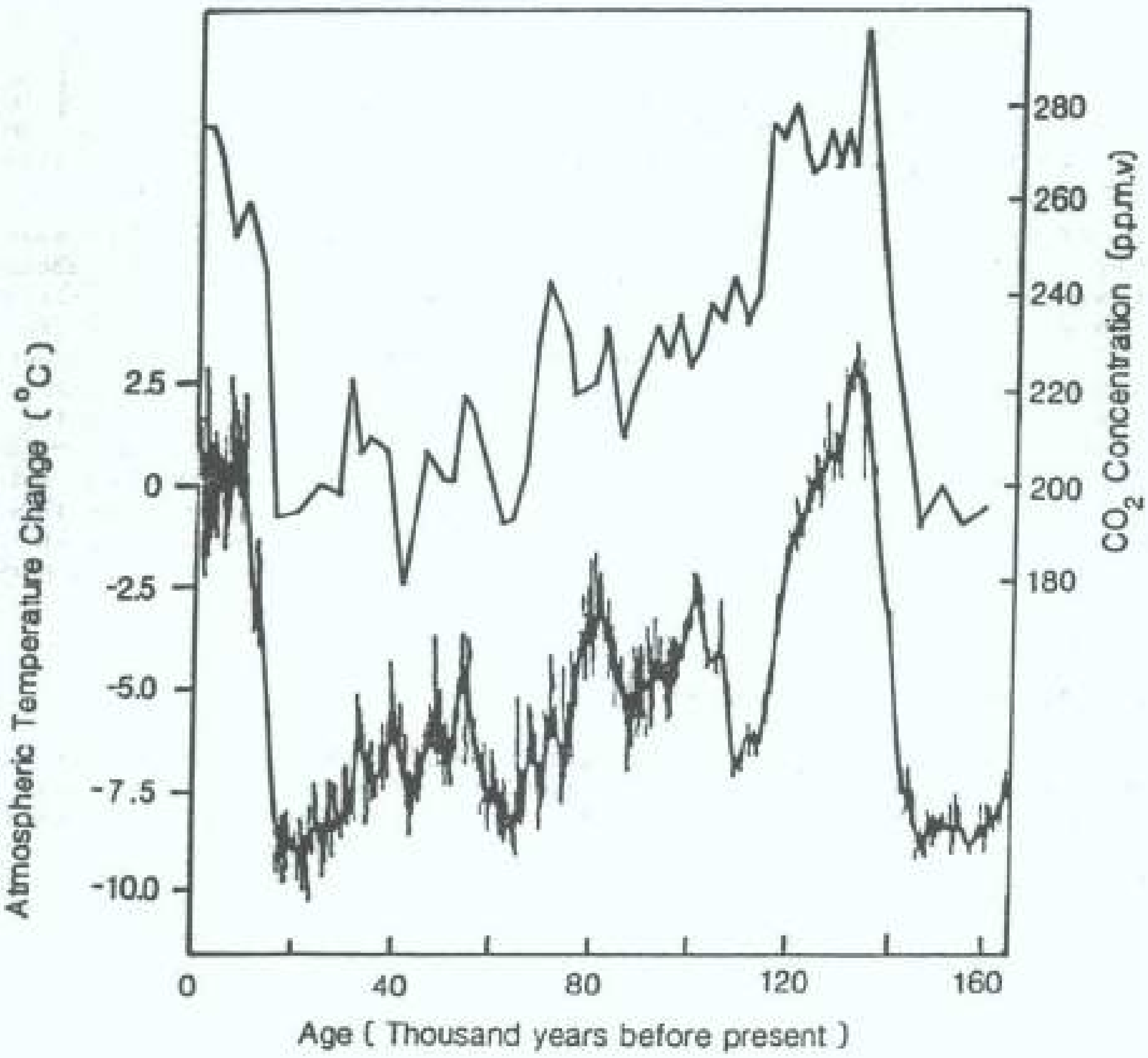

Figure 2.
CO_2 concentrations (upper curve) and atmospheric temperature change (lower curve - derived from the deuterium isotopic profile) plotted against age in the Vostok ice-core record. Source: Barnola et al. (1987).

Similarly, the concentrations of other persistent or transient radiatively active constituents of the atmosphere, such as ozone, methane and more recently, chlorofluorocarbons, involve a great many chemical reactions that depend upon atmospheric transport, temperature and the presence of water in all three forms: vapour, liquid and ice. These complex relationships between geochemistry and the physical parameters of climate need to be studied in the context of fully interactive dynamical-chemical models of the atmosphere and, ultimately, the coupled atmosphere-ocean-land system. This is the objective of the research programme on greenhouse gases, now being undertaken under the scientific leadership of the WMO/ICSU joint Scientific Committee for the WCRP.

6. MONITORING THE WORLD OCEAN

But a major key to confident prediction of future climate lies in understanding the oceans and their interaction with the atmosphere. No system equivalent to the WMO World Weather Watch exists to determine the circulation of the global ocean.

Because of the slow pace of evolution of the ocean, and enormous momentum that can build up in the deep ocean circulation, indications about impending shifts in the oceanic regime would be found in relatively subtle changes of the ocean temperature and chemical composition. To ensure that such early warnings are not missed, systematic monitoring of global ocean parameters must be undertaken, beginning with the World Ocean Circulation Experiment (WOCE) in the early 1990s. All nations are concerned with this endeavour. It is possible that only a fairly small number of nations would initially be able to carry out the necessary oceanographic observations, but all nations can and will be called upon to help, by recognizing this endeavour as an approved international oceanographic programme and, when applicable, by granting ready access to their Exclusive Economic Zones under Article 247 of the Law of the Sea.

7. THE WORLD CLIMATE PROGRAMME

The World Climate Research Programme (WCRP), which has been briefly described, is one component of the World Climate Programme (WCP). This overall Programme is co-ordinated by WMO. Two other components are managed directly by WMO. One is the World Climate Data Programme, which works to ensure that the observations, storage, analysis and retrieval of the basic data for both national use and the international compilations, such as that shown in Figure 1, are available. The second part is the World Climate Applications Programme to further develop, document and disseminate the techniques for taking maximum advantage of climatic data in national planning and economic activities. The final part of this overall World Climate Programme is the World Climate Impact Studies Programme, managed by our colleagues in UNEP, which seeks to evaluate the economic and social impacts of predicted climate change and co-ordinates the development of appropriate policy responses nationally and internationally.

While many of the uncertainties and challenges faced by the World Climate Research Programme remain before us, we must, as a responsible scientific community, put forward our best estimates of the probable future evolution of climate resulting from the changing composition of the earth's atmosphere.

8. PRESENT ASSESSMENT OF CLIMATE CHANGE

To the present, the most definitive international scientific assessment of the state of the atmosphere and the response of the climate system was that carried out at the International Conference on the Assessment of the Role of Carbon Dioxide and of Other Greenhouse Gases in Climate Variations and Associated Impacts, held in Villach, Austria, from 9 to 15 October 1985, and organized by WMO, UNEP and ICSU. The Conference statement serves notice that we will probably see a global average atmospheric temperature rise of $3 \pm 1.5°C$ by the middle of the next century. If the prediction is verified, this will be the most spectacular change in climate in magnitude and rapidity in recorded history. The overall implications are very important. This includes the possibility of a sea-level rise of between 20 and 140 centimetres, with immense consequences for low-lying island countries and coastal regions. The implications for agriculture, water resources, forestry, fisheries and other climate-dependent resources, and even for the poleward spread of tropical diseases will be of enormous importance to mankind. In order to keep the scientific assessments up to date and to consider the policy implications, WMO and UNEP are establishing an Intergovernmental Panel on Climate Change, which will have its first meeting this autumn (1988).

9. OZONE LAYER

There are other problems of the changing atmosphere for which WMO has been playing a central role by co-ordinating global monitoring and scientific effort. One such vital matter is the condition of the stratospheric ozone layer, which protects humans and other biota from excessive ultraviolet "B" radiation from the sun. WMO's Global Ozone Observing System has provided fundamental data sets for evaluating changes in the stratospheric ozone layer.

Measurements of total column ozone have been made since the 1920s using the ground-based Dobson spectrophotometer. These observations were extended greatly during the International Geophysical Year (IGY) (July 1957 to December 1958). Soon after, in 1959, the Third World Meteorological Congress defined the role of WMO in ozone monitoring and research. In 1966 (EC-XVIII), Canada agreed to archive and publish ozone data on behalf of WMO. This activity has continued without interruption ever since. The very recent (1988) important conclusion of an international panel (Ozone Trends Panel) sponsored by WMO, NASA and UNEP was based upon a careful re-analysis of the data archived by Canada's Atmospheric Environment Service. The panel concluded that in addition to the severe ozone depletion in the springtime over the Antarctic, a general ozone decline of up to 3% in the northern mid-latitudes has occurred since 1970. Observed changes in the ozone layer are attributable to the changing chemical composition of the earth's atmosphere, particularly the rapid increase since the 1930s in chlorofluorocarbon concentrations, but also to atmospheric circulation patterns. The differences between the Arctic and Antarctic ozone layer depletions (Figure 3) are primarily due to the relatively much higher persistence of the southern circumpolar vortex, which provides the conditions for the chemical processes to occur that result in the rapid deviations of the Antarctic ozone layer.

The stations in the current WMO Global Ozone Observing Network are shown in Figure 4. The network in the Antarctic is shown separately in

Figure 5. Observations of total ozone, Umkehr measurements from which the vertical ozone distribution can be inferred, and/or ballon-borne ozonesonde measurements are made at these stations.

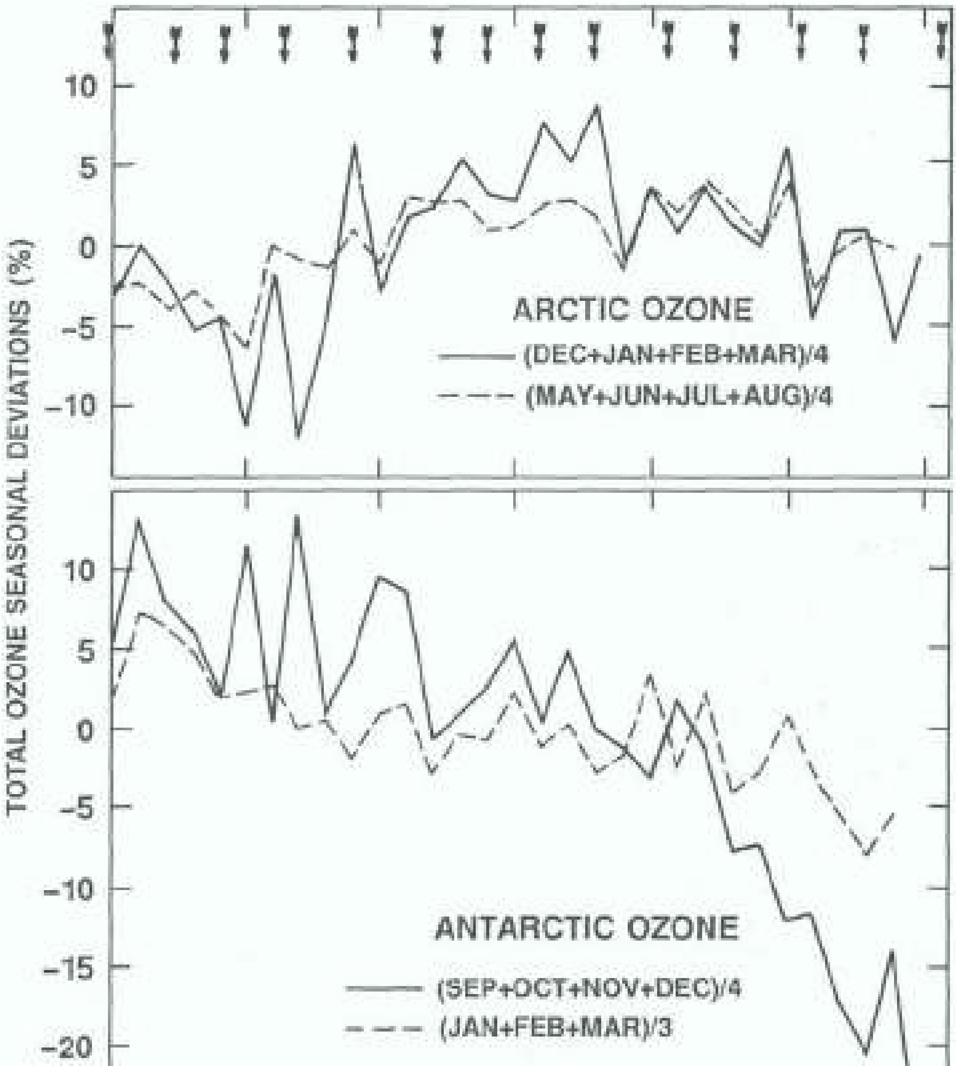

Figure 3.
Arctic and Antarctic total ozone seasonal depletions, 1957-87.

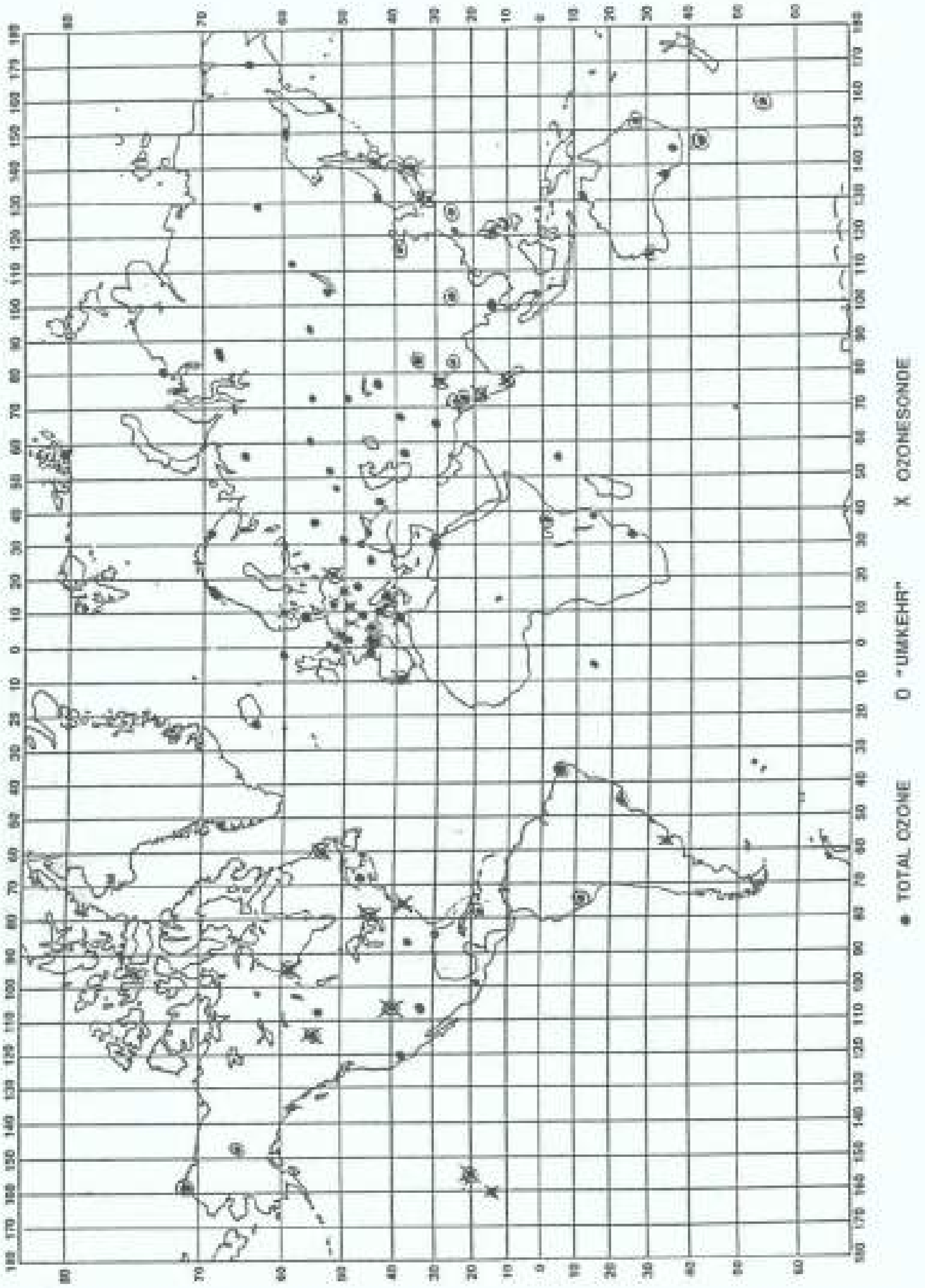

Figure 4.
WMO Global Ozone Observing Network.

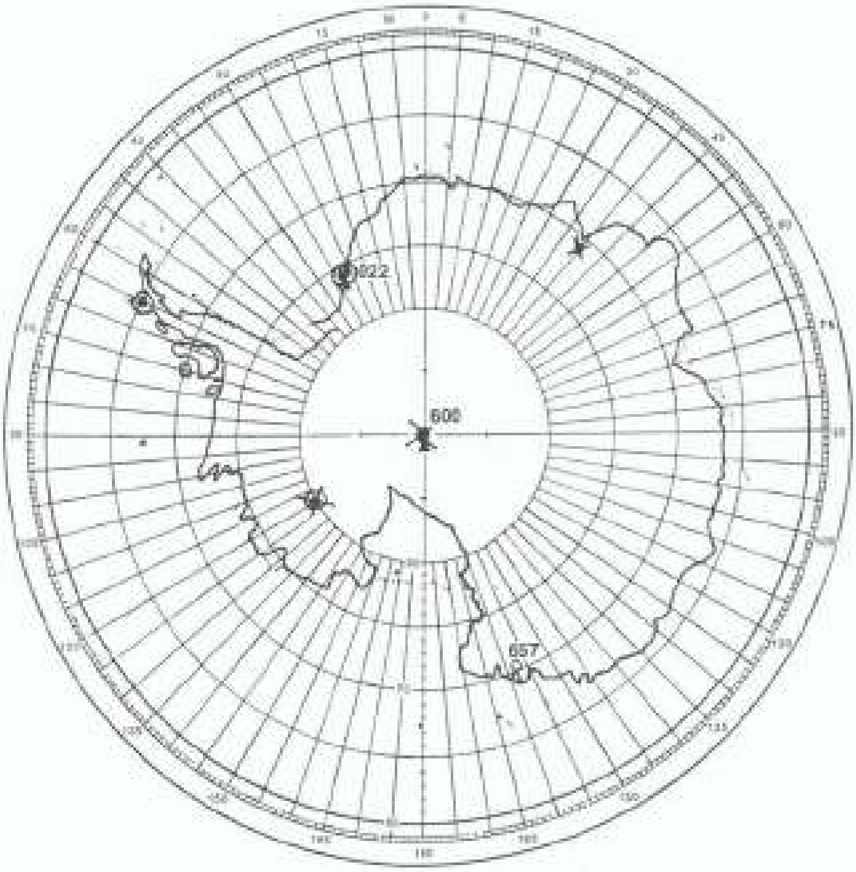

Figure 5.
WMO Antarctic Ozone Observing Network.

Data gathering, retrieval and reporting procedures are standardized by WMO; in this endeavour, much valuable help is received from the International Ozone Commission of the International Association of Meteorology and Atmospheric Physics (IAMAP). Data quality, in the case of total ozone, are insured through periodic - preferably quadrennial - recalibrations against a standard. Umkehr data retrieval is improved by concurrent lidar aerosol observations and automation at some of the stations in the WMO network.

The work of the Ozone Trends Panel has indicated the need to intensify our efforts with regard to data quality assurance, and WMO's Executive Council has just approved activities to this end.

10. BACKGROUND AIR POLLUTION MONITORING NETWORK (BAPMoN)

A further international co-operative activity that is beginning to yield major benefits in determining trends in the composition of the earth's atmosphere is the programme for background air pollution monitoring, with measurements being taken at locations away from the highly variable concentrations of pollutants in the cities.

For measurements related to climate change and environmental issues, WMO's constituent bodies approved a resolution in 1968 to establish a global network to monitor atmospheric chemical components related to climate and environment. The idea was to obtain global information through measurements

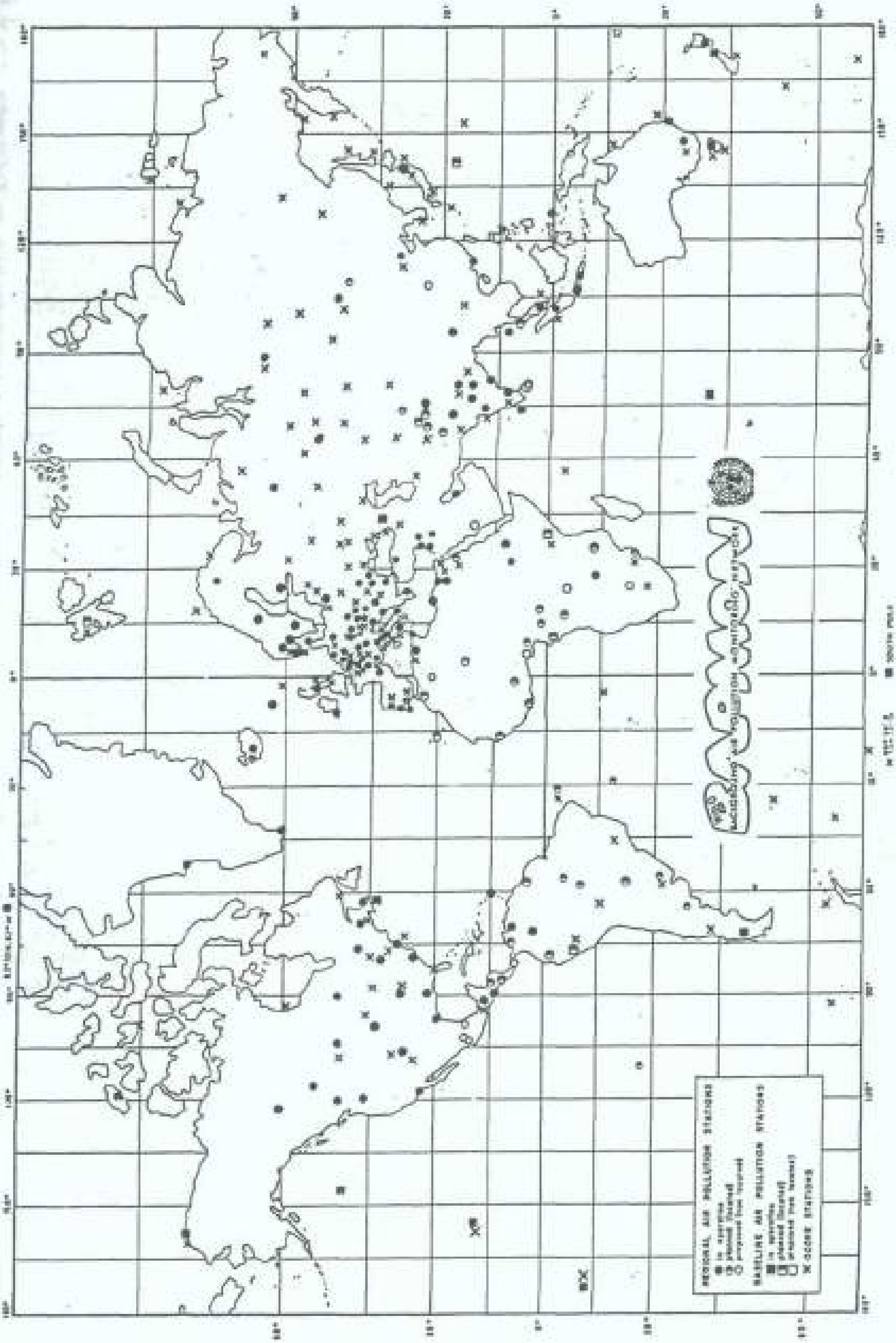

Figure 6.
Background Air Pollution Monitoring Network (BAPMoN)

made in WMO Member countries in order to determine the composition of the atmosphere and precipitation as they change owing to human activities. The monitoring programme launched at that time is now well known as the Background Air Pollution Monitoring Network (BAPMoN) comprising about 200 stations (Figure 6) of which 10% are sites designated to be of global, 15% of continental, and 75% of regional representativeness. At the minimum level, at regional stations, the parameters measured include limited precipitation chemistry, turbidity, and aerosol mass concentration. The measurement programme includes more substances for the higher categories of station representativeness. At stations with continental-scale representativeness gaseous pollutants, such as carbon dioxide (CO_2), sulphate (SO_4), nitrogen oxides (NO_X) and ozone (O_3) are also monitored. At stations with "global" representativeness many parameters are measured including halocarbons and condensation nuclei. Data generated are processed and published by a special data centre operated by the U.S.A. (National Climate Data Center, Asheville). Much effort continues to be made to ensure the best possible data quality. With respect to CO_2 measurements, very high accuracy and extremely high precision have been achieved. Work is still needed to achieve greater reliability of reported data on aerosol optical depth, and on precipitation chemistry.

The BAPMoN network has received substantial support from UNEP through its Global Environment Monitoring System (GEMS). The 80 countries participating in BAPMoN themselves spend about $100 million a year on this network.

While in some Member countries there are still technical problems in station operation, a sufficient number have now achieved a stage where the amount of data accumulated allow for the initial assessments of trends. Most of the trend evaluations, apart from establishing the global CO_2 increase very precisely, have made use of the results of the measurements of precipitation chemistry. For example, there is some good news to report. A general global downward trend from 1972 to 1984 in the sulphur content of precipitation has been observed, influenced strongly by reductions in Europe, in response to the 1985 Helsinki Convention for reduction of sulphur dioxide emissions (Figure 7). Future data analysis will emphasize relationships between pollution data and climatic variations to permit separation of natural from anthropogenic trends in the data.

No substantial achievements in the monitoring of pollution can be expected without major efforts. For instance, most developing countries still need technical and financial support, which is not available to the degree required. However, the scientific potential of BAPMoN, which is indeed the only globally harmonized background air pollution network, deserves all possible support. Probably a further geographic extension is not needed, but more emphasis should be placed on greenhouse gases other than CO_2, on radioactive substances, and on the monitoring of pollutants in media other than air, an activity known as integrated monitoring. WMO, with support from UNEP, has prepared the necessary strategies and technological information for integrated monitoring and can now advise on the state of the art in this new field. A manual on integrated monitoring was published in early 1988. Integrated monitoring can not only establish the state of pollution of the biosphere, it can also substantially contribute to the understanding of biogeochemical cycles for studies of both climate and other environmental issues.

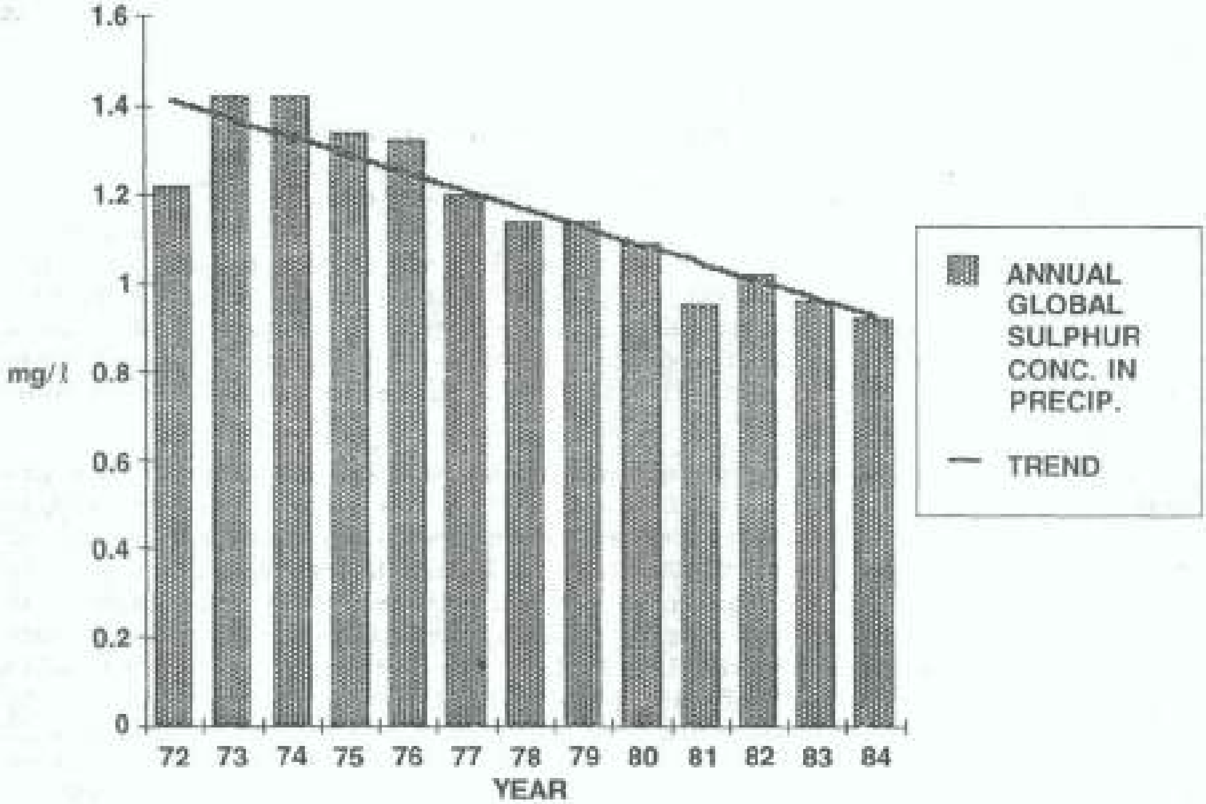

Figure 7.
Average global sulphur concentration in precipitation for 70 BAPMoN stations.

11. ATMOSPHERIC CONTRIBUTIONS TO MARINE POLLUTION

The discovery of DDT in parts of the world ocean and in organisms far from the apparent direct inputs of this pollutant stimulated a great deal of concern and prompted research dealing with the atmospheric input of pollutants into the marine environment. WMO helped to initiate international co-operation in this field in 1975 through the WMO-led Working Group on the Interchange of Pollutants Between the Atmosphere and the Oceans, established within the UN interagency Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP).

The importance of the atmospheric input of pollutants to the ocean is illustrated by recent comparisons of the atmospheric and riverine inputs to the North Sea, the Mediterranean Sea and the North Atlantic Ocean made by the Working Group. For the North Sea, the atmospheric input is roughly 10 times the river input for the polycyclic aromatic hydrocarbons, hexachlorocyclohexane, and hexachlorocyclobenzene, and 1.2 to 3.5 times that for the toxic metals, cadmium, lead, zinc and copper (Table 1). For the North Atlantic, the atmospheric input is 2 to 6 times the river input for cadmium, zinc and lead. For the Mediterranean, the atmospheric input of lead is 2-10 times the river input, and the two inputs are about equal for zinc, mercury and chromium. It is evident that for many forms of pollution of the marine environment and the world's oceans, the atmospheric contribution is as important as the river input.

Furthermore, it has been documented that physical processes are altered by pollutants in the marine atmosphere, at the atmosphere-ocean boundary, and within the sea itself. Certain of these modifications can influence marine organisms and also weather and climate on a regional or global scale.

12. RESEARCH ON ATMOSPHERIC TRANSPORT AND DISPERSION MODELLING

Some time ago, the modelling of the turbulent diffusion of air pollutants was a task of meteorologists to support urban air quality control and to set up air quality standards. The results of this work led, in some cases, to the construction of very high stacks in order to reduce high pollution concentrations near sources. A longer term consequence of such a strategy helped to create another problem, however - the long-range transport of air pollutants and their effects on lakes and terrestrial ecosystems.

Assistance to countries in developing mathematical procedures that are capable of modelling and forecasting with useful accuracy both meteorological and atmospheric chemistry processes has become another important task of WMO's Environmental Pollution Monitoring and Research Programme, not only to provide data for scientific research, but also to assist decision-makers in finding the most effective emission control strategies. The coming into existence of the Helsinki Protocol (1985) on the Reduction of Sulphur Emissions in the Economic Commission for Europe (ECE) countries was supported by WMO's collaboration in a European-North American effort, the ECE/WMO/UNEP Co-operative Programme for the Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP). In this programme WMO is responsible for co-ordinating the meteorological aspects, i.e. meteorology and diffusion modelling.

Two EMEP Meteorological Synthesizing Centres (MSCs) were established at the end of the 1970s in Oslo (MSC-West) and in Moscow (MSC-East) to make model calculations of the long-range transport and deposition of acidifying compounds over Europe that serve as the basis for air pollution control measures and international agreements. An example of inter-country budget depositions of sulphur for 1980 for some European countries is given as Table 2.

The outputs of this type of modelling show generally good agreement between calculated and observed values and the modelling capability has now reached a stage where uncertainties in the emission data are perhaps the most important factor in limiting model agreement with measurements of deposition.

13. ACCIDENTAL RELEASES OF RADIOACTIVITY AND CHEMICALS

But the development of mathematical models for assessing and predicting the measurement of pollutants is proving to be valuable not only in retrospective studies but also in urgent operational matters. The most publicized and serious of environmental accidents over the past few years was, of course, that involving the nuclear power plant at Chernobyl. When an accident of this kind involving radioactive or toxic chemical discharges to the atmosphere occurs one of the first questions asked is "Which way will the wind blow?"; or in a more sophisticated form: What is the probable transport and dispersion of the harmful substance in the atmosphere and its deposition on land or water? The mathematical models, the World Weather Watch and especially the Global Telecommunication System (GTS), are very valuable in this connection. The Chernobyl trajectories for the first 5 days are illustrated in Figure 8, and show just how transboundary in nature such incidents can be.

As a consequence of the Chernobyl accident, countries through the International Atomic Energy Agency (IAEA) have adopted two international conventions, namely:

a) The Convention on Early Notification of a Nuclear Accident

b) The Convention on Assistance in Case of a Nuclear Accident or Radiological Emergency

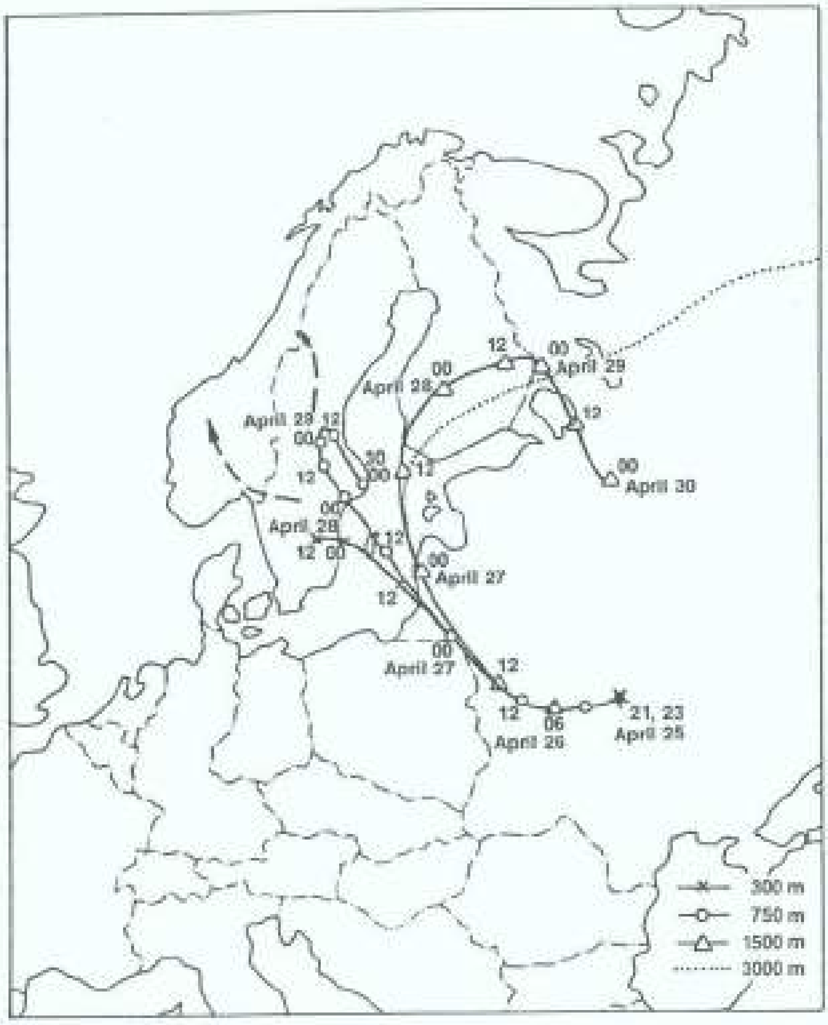

Figure 8.
The calculated transport paths and positions at various times for the radioactive cloud first emitted. For the first 9 hours, the calculations refer to 750-m altitude. Different altitudes are then indicated. After 1200 UTC on 28 April, the trajectory for 300 m turns east. Trajectory calculations made at SMHI and to some extent ECMWF have been used. The broken arrows indicate further probable transport paths for various parts of the cloud. Source: Persson et al. (1987).

Both Conventions are now in force and apply world-wide.

In response to the request of IAEA, WMO participates actively in support of the two Conventions. An agreement has been reached between WMO and IAEA on the use of the GTS for prompt exchange of information as described in Article 5.1 of the Convention on Early Notification. This information includes both meteorological data and characteristics of the release from the site of the accident. Several GTS tests have taken place and the exchange formats to be used are now widely available. The first test messages from the IAEA in Vienna were received and acknowledged in Washington and Melbourne in 3 minutes, and in Tokyo in 4.

For the purposes of taking possible countermeasures in the event of a nuclear accident, the modes of atmospheric transport, dispersion and deposition should provide the following output data to decision-makers:

- Trajectories
- Fixed-time predictions of concentration and deposition fields for each of the relevant physical and chemical forms of radionuclides
- Three-hour accumulated average wet and dry deposition fields
- Estimation of the uncertainties in the above-mentioned quantities

WMO is now working together with its Members to establish the operational meteorological centres in each Region that will have a responsibility to provide the needed predictions. Arrangements have also been made for intercomparison and validation of the various national models.

14. CONCLUSION

In these ways, and more, WMO with the support of other partners, seeks to ensure that reliable, standardized, scientific data as well as authoritative interpretations, assessments, and predictions are available on the state of health of the earth's changing atmosphere. WMO cannot, however, remain simply a neutral scientific recorder and predictor. We believe that the evidence now available indicates that nations must begin to take steps to preserve and protect this most fundamental resource, the global atmosphere. One way of doing this would be an international agreement or convention on the atmosphere. Such a convention could include a strengthening of the international collection and exchange of scientific information related to the atmosphere; it could go a long way towards maintaining a continuing watch on our planet's most important resource, currently threatened by its beneficiary, man himself.

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Table 1. Ratio of atmospheric flux to riverine flux (dissolved) for selected trace elements in coastal and oceanic areas.

Element	North Sea	North Atlantic	Mediterranean Sea	New York Bight	South Atlantic Bight
As	1.7	-		1.0	2.1
Cd	1.2-2.9	1.7	-	3.1	2.7
Cu	0.8-3.5	0.59	-	-	1.9
Fe	1.7	0.27	-	6.4	5.8
Mn	0.8	0.34	-	-	0.6
Hg	0.36-2.1	-	0.13-3.3	-	22
Ni	0.7-2.5	0.38	-	-	1.7
Pb	3.4-6.8	6.1	1.6-13	20	9.5
Zn	1.1-1.9	3.3	0.2-2.3	3.1	2.3
Cr	0.39-1.0	-	0.1-2.8	-	-
^{137}Cs	-	-	30.6	-	-
^{234}Pu	-	-	3.7	-	-

Table 2. Inter-country budget depositions of sulphur for 1980. The upper numbers are from the MSC-E model, the lower ones from the MSC-W model (units: 1000 t S).

Receiver Country	Emitter Country								
	Czechoslovakia	France	FRG	DDR	Norway	Poland	UK	USSR	Yugoslavia
Czechoslovakia	420 416	9 16	37 40	156 101	0 0	81 61	6 8	1 4	8 9
France	13 16	679 581	79 59	15 27	0 0	6 8	127 81	0 1	2 2
FRG	61 50	1031 1106	629 499	170 108	0 0	16 19	57 61	1 4	4 4
DDR	117 76	13 18	99 75	508 544	0 0	20 20	19 20	1 3	0 1
Norway	8 5	5 3	15 8	17 11	14 20	6 4	34 17	4 9	1 1
Poland	195 140	13 20	53 62	271 232	0 1	618 486	20 25	19 24	6 7
UK	10 4	26 19	20 14	23 10	0 0	7 3	1076 648	1 1	1 0
USSR	139 137	20 24	60 69	154 165	1 3	196 218	26 41	3543 3629	20 27
Yugoslavia	34 36	4 13	23 15	13 27	0 0	14 19	3 4	1 4	244 216

ABSTRACT

INTERNATIONAL CO-OPERATION IN ATMOSPHERIC SCIENCES AND THE CHANGING ATMOSPHERE

Detecting meaningful gradual changes in the global climate in the midst of all the "meteorological noise" is no small scientific problem. It can only be attempted on the basis of precise environmental measurements on a scale representative of the global atmosphere.

WMO has been helping governments sustain and augment global measurement programmes, including those for determining the world's primary climate parameters where co-ordinated efforts go back 120 years, and those for greenhouse gases, for some of which globally standardized measurements go back several decades. These data form the basis for all current assessments of changes in the earth's climate and of the causes for the changes.

WMO has been playing a central role in co-ordinating global monitoring and scientific effort. One such vital matter is the condition of the stratospheric ozone layer. WMO's Global Ozone Observing System has provided fundamental data sets for evaluating changes in the stratospheric ozone layer since 1966. Similarly, the Background Air Pollution Monitoring Network (BAPMoN) system, which started in the late 1960s, is beginning to yield valuable information on global and regional trends of acidifying sulphur and nitrogen compounds, and other pollutants.

WMO has also been closely following developments in the mathematical modelling of the atmospheric transport of pollutants, by national agencies and scientists, in many parts of the world. The modelling efforts have yielded two major benefits. They have helped to assess long-range transboundary transport of air pollutants, over long time-scales for the development of strategies to control acid rain and other pollutants. They have also allowed WMO to co-operate closely with the International Atomic Energy Agency (IAEA) and others on activities relating to the prediction of the dispersal of radioactivity, or toxic chemicals, following an accident.

In these ways, and more, WMO seeks to ensure that authoritative, standardized, scientific data as well as interpretations and predictions are available to assess the state of health of the earth's changing atmosphere. However, WMO cannot remain a neutral scientific recorder and predictor. We believe that the evidence now available indicates that nations must begin to take steps to preserve and protect this most fundamental resource, the global atmosphere. We associate ourselves vigorously with those calling for a "Law of the Atmosphere" to both protect this thin shield of air on which life itself depends, and ensure the international exchange of scientific information needed to maintain a continuing watch on our planet's most important and threatened resource.

RÉSUMÉ

COOPÉRATION INTERNATIONNALE DANS LE DOMAINE DES SCIENCES ATMOSPHÉRIQUES ET DE L'ATMOSPHÈRE EN ÉVOLUTION

Il n'est pas simple du point de vue scientifique de détecter les changements graduels significatifs du climat mondial parmi tous les "parasites météorologiques". Cette détection doit être fondée sur des mesures environnementales exactes portant sur une échelle représentative de l'atmosphère du globe.

L'OMM soutient les gouvernements pour qu'ils maintiennent et élargissent les programmes de mesures à l'échelle mondiale, y compris les programmes qui visent à déterminer les principaux paramètres du climat mondial, domaine dans lequel les efforts concertés remontent à 120 ans, et les programmes qui protent sur les gaz à effet de serre et pour certains desquels les mesures sont normalisées à l'échelle mondiale depuis plusieurs décennies. Les données ainsi recueillies constitutent le fondement de toutes les évaluations actuelles des changements du climat de la terre et des causes de ces changements.

L'OMM suit également de près les progrès de la modélisation mathématique du transport atmosphérique des pollutants qu'effectuent les organismes et les chercheurs nationaux dans de nombreuses parties du globe. Nous tirons deux grands avantages des efforts de modélisation. Ils nous permettent premièrement d'évaluer le transport transfrontière à grande distance des polluants atmosphériques, et ce sur grande échelle temporelle pour l'élaboration de stratégies contre les pluies acides et d'autres stratégies antipollution. Ils ont deuxièmement permis à l'OMM de coopérer étroitement avec l'Agence internationale de l'énergie atomique (AIEA) et avec d'autres organismes dans le domaine des activités liées à la prévision de la dispersion de la radioactivité ou des produits chimiques toxiques à la suite d'un accident.

Voilà donc des exemples de ce qui l'OMM réalise pour veiller à ce que des données scientifiques normalisées et faisant autorité ainsi que des interprétations et des prévisions soient disponibles pour que l'on puisse évaluer l'état de la santé de l'atmosphère mondiale en évolution. Toutefois, l'OMM ne peut pas se borner à enregistrer et à prévoir des données scientifiques en restant neutre. Nous pensons que les preuves dont nous disposons à présent nous indique que les nations doivent commencer à prendre des mesures afin de sauvegarder et de protéger la ressource fondamentale que constitue l'atmosphère du globe. Nous nous associons avec vigueur à ceux qui demandent que soit établi un "droit de l'atmosphère" pour protéger cet écran d'air si fin indispensable à la vie sur la planète et pour garantir l'échange international de données scientifiques qui est nécessaire au maintien d'une veille continuelle sur la ressource la plus importante de notre planète, ressource à présent menacée.

MANAGING THE CHANGING GLOBAL ATMOSPHERE THROUGH SUSTAINABLE DEVELOPMENT

Emil Salim
Minister of State for Population and Environment
Indonesia

1. INTRODUCTION

The occurrence of atmospheric change is evidence that the path of growth and development that we have pursued thus far is not one that can sustain and assure the continued well-being of humankind. It is additional proof that we must change - and the sooner the better - our development strategies; and that from now on we must pursue development that can sustain the global resource base. In brief, we must now implement sustainable development.

What is sustainable development? First of all, it implies a commitment at the level of individual nations to follow development patterns in which social benefits exceed social costs, considering a long time-frame and special consideration for the poor and vulnerable. It implies economic growth and approaches to development that promote innovation, substitution, and interdependence through trade.

This growth needs to be directed towards improvements in per capita income and quality of life, in equity and elimination of poverty, in preservation of cultural heritage and natural environments, and in maintenance of options for resource use and environmental enhancement.

No nation can be said to be fully adhering to these concepts in practice, and it has been a fundamental contention of the World Commission on Environment and Development that institutional change within countries will be required for their sustainable development strategies to be realized. In particular, all units within governments must realize and accept responsibility for the impacts of their actions.

What does sustainable development mean in terms of the problem of atmospheric change that we are now facing? An argument could be made that such a problem would not have occurred had we implemented the principles of sustainable development at the national level sooner. But such an argument is retrospective; the problem has arisen and we must learn how to deal with it. Also, how to prevent the occurrence of other similar problems.

The consideration of global atmospheric change demands new thinking, not only about national approaches to sustainable development but also about strategies for sustainable use of the global commons. We are poorly equipped for this process. Our international institutions are relatively weak and untested even to help in the detailed definition of what is needed for sustainable development at a global level, let alone to devise and implement strategies for its implementation.

Yet it was precisely the occurrence of problems of global impact such as atmospheric change that - in addition to national environmental problems - prodded us to seek the new development strategy now embodied in the concept of sustainable development. Thus we need not lose hope for the future.

2. APPROACHING THE PROBLEM OF ATMOSPHERIC CHANGE

How we can cope with the impacts of atmospheric change, and what steps we should take will depend very much on our ability to properly define the problem, its intensity, its magnitude and its anticipated impacts. Carrying out impact analyses and devising mitigating steps for known and well documented problems can often be difficult enough. Such an assignment, in the face of so many unknown variables as those in atmospheric change will be daunting indeed. Moreover, the global impact of atmospheric change means that we have to deal with impacts in a multitude of highly different geographic, demographic and social conditions. Preliminary indications are that the impacts will not be evenly distributed throughout the globe because global temperature change will in turn lead to effects on global and regional circulation patterns.

While we consider and calculate the magnitude of the problem of atmospheric change we must consider first of all the time context. This means trying to anticipate what particular level of atmospheric change would be reached at a particular time so that the impacts would not be catastrophic, making life unbearable or no longer viable in parts of the globe.

Nations and regions will have to adjust their sustainable development strategies to take into account both the positive and negative impacts of climate change likely to affect their land and water areas. Beyond this concern, they must devise measures that help to reduce their contribution to the basic causes of the problem.

Three objectives can then be met:

1. Coping with the social and physical impacts
2. Arresting or at least slowing down the rate of growth of the problem
3. Preventing similar or related problems from arising

Unfortunately we do not have very clear scenarios either for the magnitude of change, or for the time horizon in which to mount our efforts. A brief case study of my own country will illustrate the problem.

Indonesia is now preparing the Fifth Five Year Plan, incorporating sustainable development principles. We are even looking ahead into the next 25 years through our Guidelines for State Policy, which provide the broad context for the directions of development. How should problems of global atmospheric change be factored into these plans and long-term policies? Must we begin now to prepare for events perhaps 50 years ahead?

We know that over this time horizon the population of Indonesia is likely to expand from about 180 million to more than 350 million. The economy is highly dependent on fossil fuel for electricity generation and industrial growth, and upon tropical timber products for export.

We are in need of rapid domestic industrial growth to provide employment, and food self-sufficiency is an on-going concern. But our cities are rapidly expanding; most are located only a few metres above sea-level. Finally, Indonesia has a tremendous biodiversity, especially in the tropical rainforests and in the coral reefs that surround most of our 13,000 islands.

When I ask our leading climate experts, ecologists and social scientists for scenarios about the possible impacts in Indonesia from the effects of global climate change I do not receive very detailed answers because there has not been the opportunity or funds for such studies. But what I hear is quite disturbing, for they extrapolate from known climatic extremes, especially the episodic droughts. These droughts have led to massive forest fires in Kalimantan, and shortages in the reservoir water supply for major cities and for industry and irrigation, especially in the eastern part of the country. It is postulated that the drought-prone areas could expand, and the intensity of drought could increase.

In the coastal zone a rise in sea-level could be very detrimental to the large existing infrastructure of both cities and rural areas. Millions of people depend on the cultivation of shrimp and fish in brackishwater fish ponds. The large investment in drainage systems, ports and other industrial infrastructure of coastal cities could be at risk. As well, salt intrusion into urban groundwater aquifers, already a significant problem, could be exacerbated.

We are not well prepared to cope with these potential problems, and we are not certain how much investment of our limited development budget should be committed to addressing this global problem that affects us all. Our scientists do not have the same access to the sophisticated methods of simulation that are now being applied in some developed nations to examine within-country climate variation effects. Furthermore we are wary of lost export-earnings or other economic effects that might result from international action on global climate change.

Thus, in preparing scenarios of anticipated climate change impacts, an attempt should be made to differentiate the impacts on various regions of the world existing under disparate economic and social conditions. I believe that it can be assumed that impacts will be most severely experienced in poor and developing countries. At the same time, such countries would be less capable of dealing with those impacts because of their limited economic and financial capabilities, their social structure and the level of technology at their disposal.

3. SHARING RESPONSIBILITIES

The assumption that the less developed countries will suffer more from the effects of atmospheric change, and that they will also be less able to deal with such effects, has an important implication. It implies that there should be a sharing of efforts among nations in coping with such effects. At the same time, such a sharing of efforts must be considered in the light of sharing the responsibility for having caused the problems of atmospheric change in the first place.

As a principle, such a responsibility sharing is particularly important for problems of global impact that are the result of activities that can be localized. The rationale for the allocation of responsibilities is that presumably such activities produce benefits for those carrying them out, possibly to the detriment of a much larger part of the world population.

For that reason, as we try to identify the nature of global atmospheric change, we must also try to identify its causes and pin-point the location or locations where those causal factors occur. This would be the first step in allocating accountability for having caused the problem. While efforts are to be mounted to cope with, or mitigate, the adverse impacts of climate change, the share the accountable parties are to be asked to assume would be based on calculations containing at least the following components:

1. The benefits or profits obtained by the accountable party (or country) from the activities contributing to atmospheric change
2. The level of capabilities that such a country (or countries) could apply in coping with, or mitigating, undesired impacts
3. The impacts suffered by affected countries, and the probable costs and efforts required to counter or migitate those impacts
4. The level of capabilities of affected countries to mount the efforts required

I would like to reiterate that the foregoing list constitutes the minimum requirements, the most important but certainly not the only considerations, in calculating the share of responsibility for coping with the unwanted effects of environmental problems that have local causes but global impacts. What I have proposed is basically the germ of a thought that must be considerably expanded and have its feasibility tested.

In brief, the proposed approach is the application of a combination of presently available techniques. These include a form of macro-level environmental impact analysis applied ex post facto; not as a way of preventing certain impact-causing activities from happening but as a way of measuring the impacts of activities already happening. At the same time an impact analysis can also be used to halt or modify those impact-causing activities.

The second set of techniques refers to cost-benefit analysis in order to determine the share of responsibility of an impact-causing country (or countries) in the efforts to cope with such an impact in other countries. To such calculations should be added a factor quantifying the different capability of each country affected to cope with the unwanted impacts.

Approaching the problem in this way would take into account the possible disparities in benefits obtained between impact-causing countries, and also the possible disparities between countries in their abilities and ranges of options to cope with those impacts.

At this stage it can be tentatively suggested that this approach would be the most feasible for impact-causing activities that are widely dispersed (though their locations can be pin-pointed), and widely shared by a large number of countries, and have a global impact. In other words, it could be applied to the problem of global atmospheric change.

A major part of the proposal for global sustainable development is that a common sense of responsibility can be developed. The approach that I have suggested is aimed at obtaining an equitable allocation of sharing in that responsibility. Expressed differently, the approach outlined is aimed at seeking an ethically fair distribution of responsibilities in managing various aspects of such a "global commons" as the atmosphere.

The poorer nations by force of their lower state of economic development have applied the greatest restraint in their contribution to the problem of global climate change. Yet given the pattern of population increases projected into the next century, and the continued dependence of these populations on natural resources for livelihood and survival, the developing nations may well sustain the heaviest relative losses as a result of atmospheric deterioration.

4. POLITICAL IMPLICATIONS OF ATMOSPHERIC CHANGE

I have dropped the prefix geo before political because I am not sure what the phrase geopolitical connotes at the present time in the context of atmospheric change and sustainable development. Conceivably it could connote changes in the power relations between countries while these are affected by changes in the global atmosphere. Since the global commons (in this case, the global atmosphere) is a factor in the relations between nations, it will have political aspects. Also, because of atmospheric changes, food and agricultural production patterns might change and these might alter the distribution pattern of comparative advantages between nations. As a result new patterns of dependence and interdependence might arise.

But rather than focus only upon how some countries might increase their power and influence or otherwise benefit from atmospheric change, we should concentrate on how joint political action could address the dangers of atmospheric change that threaten all of us.

Based upon such a principle I would rather focus on seeking international cooperation to prevent the impacts of atmospheric change from becoming worse, and more particularly, on seeking the cooperation required to reduce the release of CO_2 into the atmosphere. In this context there are a number of options open to us:

1. Reducing the use of fossil fuels through:
    a. Increasing the efficiency of using fuels in general and increasing the efficiency of end-use energy
    b. Substituting alternative energy sources for them
    c. Reducing selectively the rate of expansion of their less essential uses, especially through price mechanism
2. Reducing the emission of CO_2 through:
    a. Increasing the use of low-CO_2-emitting fuels, reducing their use altogether and using more efficient fuel mixes
    b. Implementing better techniques for the removal or disposal of CO_2
3. Reversing the current trend of deforestation.

All of these suggested steps must be accompanied by support measures such as systems of incentives and disincentives as well as by the application of appropriate technologies.

These steps lead to priorities for action that would benefit from increased international cooperation and would include:

1. Intensification of appropriate research and of the sharing and dissemination of newly acquired knowledge and know-how through conferences and other means for transferring knowledge and technology
2. Intensification and coordination of atmospheric monitoring to improve detection of changes and the establishment of early warning systems anticipating changes
3. Intensified international consultations in support of the development of national, regional and global policies on energy, forests, trace gases, coastal zone and marine resource management, and so on
4. Development and implementation of international agreements

These are only delineations of possible categories for international cooperation. Each category should be further fleshed out and new categories could certainly be added. But even as brief a list as that outlined above is enough to make us realize that above all we must first deal with two questions. The first question is how to share in the costs and responsibiities of efforts aimed at preventing atmospheric changes. The second question is what is the adequacy of the present structures for international cooperation.

5. EQUITY IN SHARING

Earlier I submitted propositions on how nations could (or should) share in the efforts of coping with the adverse impact of atmospheric change. I believe that those thoughts would also apply to the issue of how to share in the efforts of arresting and preventing atmospheric change.

Whether in coping with, or in preventing, atmospheric change, the developing countries find themselves at a disadvantage compared with the industrialized and more advanced countries. I have already pointed to the lower level of capabilities possessed by the developing countries in terms of capital, skills and management expertise, and even in terms of the constraints resulting from social conditions. Also, developing countries may tend to be affected by atmospheric change to a greater degree.

The steps required to prevent atmospheric change will also weigh heavily upon the developing countries. The exploitation and sale of fossil fuels and hardwoods play an extremely important role in the economies of many developing countries. The utilization of wood for domestic fuel is also a dominant feature of such economies. Moreover, in these countries, rapidly growing populations and the associated growth in demands and expectations create an imperative to continue and even accelerate development, requiring the best possible use and management of our resource base.

Under such conditions additional burdens would be difficult to assume. Yet our share in the efforts to prevent global atmospheric change seem to be relatively larger compared with the shares of the developed countries.

For instance, shifting from fossil fuels to low-CO_2-emitting fuels for our infant industry and shifting from wood to other fuels for our domestic consumers would be expensive.

Reforestation, a potentially important factor in mediating global CO_2 increases, will require considerable budgetary outlays, and the establishment of tree farms will require investments. The amount of income foregone as a result of not exploiting our forests or of reducing the export of fossil fuels may also be considerable. Finally, under the presently prevailing international market and economic conditions the income that we obtain from the commodities derived from our resource base continues to shrink.

It is for these and for other reasons that I would once again urge that we step up the search for an approach that would equitably and fairly allocate our shares in the efforts to cope with, and to prevent, the adverse impacts of atmospheric change. In this context we should perhaps take another look at the existing general structures for international cooperation. This would certainly be in line with the recommendations contained in the WCED report "Our Common Future".

6. STRESSING REGIONAL AND SUBREGIONAL COOPERATION

Sustainable development requires cooperation between nations; such cooperation must be brought to a level that we have never experienced before. This in itself requires skills, management and coordinating capabilities that we do not yet sufficiently possess, judging from the performance of most of our organisations for international cooperation.

Skills, understanding and a shared sense of urgency could be more easily developed in a smaller context, in a smaller universe. This is another reason to step up efforts for improving regional or subregional cooperation among nations. Shared conditions, especially environmental conditions, provide a better potential for cooperation in the solution of problems if they are relatively similar.

Such regional cooperation should not replace global cooperation. Cooperation within regions is a first step towards cooperation between regions leading towards a renewed and possibly restructured global cooperation. Regional cooperation will also yield more immediate and efficacious results for the peoples of the cooperating countries. At the same time, it would also provide a means for articulating and aggregating regional interests to bring them to international attention. Otherwise such international attention would continue to be claimed by the more powerful countries, who would be making decisions affecting all.

7. POLITICS AND GLOBAL INTERDEPENDENCE

There will always be international politics as long as different nations pursue different interests which, moreover, are based on different perceptions regarding prevailing conditions and the appropriate means for pursuing such interests.

Furthermore the possession of different levels of skills and capabilities and of resource bases and programs to control as large as possible a resource base lies at the heart of politics. In practice this results in what may be called "the politics of dependence", with nations seeking the dependence of other nations upon them.

Yet we are now faced with the fact that the total resource base of mankind is in danger. Its limits are in sight and its quality is deteriorating. It matters little who is in control because ultimately the very existence of all will be at stake when no action is taken to halt the depletion of our common resource base.

Other developments in the world today have underscored the fact that what happens to people in one part of the world might affect the entire world. The structure of human endeavour today is such that the actions of one nation affect the entire structure. Global interdependence is an emerging fact that is not yet well appreciated. Nevertheless, there is a growing realization that only through coordinated, interdependent actions can we safeguard our common well-being. Here, obviously, is the central point and rationale for globally sustainable development strategies.

With the globe's resource base in jeopardy, in order to preserve that resource base, the "politics of dependence" must make way for the "politics of interdependence".

ABSTRACT

MANAGING THE CHANGING GLOBAL ATMOSPHERE THROUGH SUSTAINABLE DEVELOPMENT

Global atmospheric change demands new thinking, not only about national approaches to sustainable development but also about strategies for sustainable use of the global commons. How we can cope with the impacts of atmospheric change, and what steps we should take will depend very much on our ability to properly define the problem, its intensity, its magnitude and its anticipated impacts. Impact analyses must be done with full regard to the multitude of highly disparate geographic, demographic, economic and social conditions.

This paper calls for an ethically fair distribution of responsibilities in managing various aspects of such a "global commons" as the atmosphere, including sharing in the efforts of coping with the adverse impact of atmospheric change and in arresting and preventing it. Whether in coping with, or in preventing atmospheric change, poor and developing countries find themselves at a disadvantage compared with the industrialized and more advanced countries. Not only would they be more severely affected by change, they would be less capable of dealing with those impacts because of their limited economic and financial capabilities, their social structure and the level of technology at their disposal. Only through coordinated, interpendent actions can we safeguard our common well-being.

RÉSUMÉ

COMMENT GERER L'EVOLUTION DE L'ATMOSPHERE DU GLOBE GRACE À UN DEVELOPPEMENT SUPPORTABLE

L'évolution de l'atmosphère du globe nous oblige à penser autrement, non seulement en ce qui concerne la vision nationale d'un développement supportable mais également pour ce qui est des stratégies permettant une utilisation viable du patrimoine commun. La manière dont nous pourrons réagir aux incidences du changement de l'atmosphère et les mesures que nous devrons prendre dépendront beaucoup de notre capacité à définir comme il convient le problème, son intensité, son ampleur et les conséquences prévues. Les analyses des conséquences doivent être réalisées en tenant dûment compte de la pléthore de conditions géorographiques, démographiques, économiques et sociales extrêmement disparates.

Cet exposé montre la nécessité d'une répartition équitable des responsabilités en matière de gestion des divers aspects d'un "patrimoine commun" tel que l'atmosphère, y compris en ce qui concerne le partage des efforts déployés pour faire face aux conséquences néfastes de l'évolution de l'atmosphère et pour arrêter et prévenir ce phénomène. Qu'il s'agisse de réagir aux conséquences ou d'empêcher le changement de l'atmosphère, les pays pauvres et les pays en développement sont désavantagés par rapport aux pays industrialisés et plus avancés. Non seulement ce phénomène les affecterait de manière plus aiguë mais ils seraient moins en mesure de réagir aux conséquences en raison de leurs moyens économiques et financiers limités ainsi que de leur structure sociale et des techniques dont ils disposent. Seules des mesures coordonnées et prises de manière interdépendante nous permettront de préserver notre bien-être commun.

FOOD SECURITY IN THE CHANGING GLOBAL CLIMATE

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1. INTRODUCTION

Food security is defined by FAO as the physical and economic access to food for all people at all times. Swaminathan (1983) has pleaded for enlarging this concept into one of Nutritional Security, since only access to balanced nutrition and safe drinking water can ensure that every child has an opportunity for the full expression of its innate genetic potential for physical and mental development. Today, there are marketable surpluses of food grains in most developed and in some developing countries like China and India. The widespread hunger prevailing in many nations of the world is not due to the non-availability of food in the market but is due to the lack of adequate purchasing power among the rural and urban poor. Inadequate purchasing power in its turn is due to insufficient opportunities for gainful employment. The famines of jobs and of purchasing power are becoming the primary causes for the famines of food in the households of the poor.

In most developing countries, land-and-water-based occupations consisting of crop husbandry, animal husbandry, fisheries and forestry are the major sources of employment and income in rural areas. In this context, agriculture assumes a more significant role in the development of national and global food and nutrition security systems than just being the source of food. Therefore, in predominantly agricultural countries, importing food would have the additional consequence of enhancing rural unemployment, when this is done to compensate for inadequate national attention to agricultural development. Thus food security has to be viewed in the contexts of food production, job creation and income generation. An additional issue of overriding importance, if we are to ensure that today's progress is not at the expense of tomorrow's prospects, is that of conservation of the ecological base for sustained agricultural production. The various issues relating to the sustainable production of food for the growing population have been dealt with by the Panel on Food Security and Environment, of the World Commission on Environment and Development (WECD, 1987).

Although the problems we face today to promote sustainable nutrition security are staggering, we will have to be prepared to face the challenges of the future, particularly in relation to probable changes in climate. These include changes in precipitation and temperature, induced by increasing concentrations of CO_2 and other industrial gases in the atmosphere. Also, with damage to the ozone layer, the incidence of UV radiation is likely to increase. We do not know the potential impact of higher levels of UV radiation on the yield of crops. These changes will have a visible impact in about 25 years from now. Whatever the magnitude of the changes may be, it will be prudent to make the scientific investment necessary to face different climate scenarios.

We should maximize the advantages of favourable weather and minimize the adverse impact of unfavourable weather on human, animal and plant populations. Since the oceans and inland waters may not be able to provide more than 5% of the total food needs, soil-based cultivation has to be the mainstay of our food and nutrition security system. But land is a shrinking resource for agriculture and we have to produce more and more food from less and less land and water in the decades ahead.

In this paper, some of the major problems and possibilities associated with food security and the projected changes in climate are discussed. The paper deals mainly with implications for the production of cereals since these are relevant to food security. Since climate effects on agricultural production and food security are important, we have considered the relevant issues under two scenarios as follows:

i) Scenario 1: Food security in the current climate regime

ii) Scenario 2: Climate change and food security

2. SCENARIO 1: FOOD SECURITY IN THE CURRENT CLIMATE REGIME

2.1 Population Growth and Food Production

The important consideration for food security is whether the food production would remain higher than the population growth rate. Between 1970 and 1982, the world population grew at a rate of 1.8% per annum but cereal production, which constitutes 94% of the total grain production, grew at a rate of 2.3% per annum. Thus food production outstripped population growth by 0.5% on a global scale. In 1986, 1942 million tonnes of food grains were produced for a population of 4915 million. Globally, this corresponds to about 395 kg of food grains per capita. But there were regional disparities to the extent that near-famine conditions occurred in many parts of the world. Thus, hunger existed amongst plenty and food production did not provide food security to everyone.

A United Nations study has projected the population size and growth rates for the periods between 1985 and 2000 and 2000 and 2025. The growth rate is likely to decline to 1.6 and 1.2% between 1985 and 2000 and 2000 and 2025, respectively. The projected world population is 6.1 billion in 2000 and 8.2 billion in 2025 (Table 1). Sanderson (1984) estimated per capita grain consumption in A.D. 2000 based on the expected per capita consumption in the recent past. Assuming that no significant changes in per capita grain consumption occur, the food grain requirements in various regions of the world were estimated (Table 1). The global requirement of food grains in 2025 is about 3050 million tonnes, including food, feed and industrial use.

It has been pointed out in the WCED (1987) report, Food 2000, that food imports are not the answer for the increasing populations in developing countries - because importing leads to growing crops with export potential. Importing food also results in umemployment in predominantly agricultural countries. Coupled with this is the poor price of exported farm commodities in developed countries. This has resulted in the increasing indebtedness of developing countries, with several undesirable ecological and political consequences.

Assuming no significant change in food consumption patterns, the projected additional demand of food grains in 2025 over that in 1986, would be 330 Mt in Africa, 130 Mt in South America, 582 Mt in Asia, 73 Mt in Europe and 16 MT in USSR. If individual regions are to be self-sufficient in food grains, the above projections lead to the following questions.

i) What changes in productivity and cultivated areas will be needed to grow the additional food grains?

ii) Will the regions requiring additional food grains be able to produce them?

2.2 Increase in Area and Productivity

Food production in different regions must increase substantially if each region has to meet its requirements. For example, production in Africa would have to increase almost fivefold and in Latin America threefold to meet the projected demand. In Asia, the required increase would be 1.75 fold whereas in USSR and Europe increases of the order of 1.25 and 1.82 fold would be needed.

In Asia and Europe, 83 and 88%, respectively, of the potentially arable land is already being cultivated (Table 2). Therefore, yield increases would be the major or almost the exclusive means of realizing the projected food grain demands of these regions. In Africa and South America, since they have only 22 and 11% of the potentially arable land under cultivation, an increase in area could be a major means of additional food grain production. The USSR will have to combine both increases in yield and increases in the area under cultivation to meet the situation.

In regions where land is available, an appropriate strategy that balances the increases in productivity with that in land area needs to be developed. The relative emphasis on each of the two components for increasing production will differ in each region. One feasible combination of area and productivity is given in Table 3. The rates of growth of area and productivity required to attain these levels of production are given in Table 4.

Globally, the estimated arable land is 3190 million hectares, of which 1406 Mha is cultivated. Cereals account for 721 Mha, or nearly 50% of the total cultivated land. The remaining cultivated land is used for other crops. Assuming no change in this pattern, 2102 Mha would need to be cultivated by 2025, accounting for 65.8% of the arable land compared with the present 44%.

2.3 Factors Limiting Agricultural Production

2.3.1 Energy

Agricultural production operations include preparation of land, use of the appropriate crop and its cultivars, application of fertilizers and pesticides, and water management. All these operations require energy. Historically, draft animals provided a major source of energy (Pimental and Pimental, 1979). With mechanization providing a more efficient means of farm operations, draft energy was gradually replaced by fossil fuels. This has lead to a gradual decrease in farm families. As a result, today in developed countries less than 5% of the total population is engaged in agriculture. However, in developing countries agriculture continues to be the major occupation of a majority of the population (FAO, 1987).

In developed countries, the main agricultural operations and inputs have remained the same up to the early 1960s. Since then there has been a qualitative change after high yielding, short-stature cultivars replaced the conventional locally adapted cultivars. The new cultivars of wheat and rice required more fertilizer and better pest management. Since the productivity of these cultivars was higher, it made mechanization imperative. This in effect led to a situation where the commercial energy input became about equal to the equivalent energy output of edible grains (Slesser, 1986). If the energy input to the whole agricultural system was estimated, from land preparation to canned provisions in Supermarkets, then the commercial energy expended was greater than the solar energy harvested by the crops. Thus it would be virtually true to say that ultimately fossil fuels serve as food in developed countries.

In developing countries, agricultural production ranges from traditional to transitional and modern. The traditional agriculture is based on the use of local cultivars, almost no inputs of fertilizer and pesticides, poor water management, and draft energy. The transitional agriculture includes improved seeds, fertilizer, pesticides, water management, but mostly draft and human energy. The modern agriculture is mostly a replica of the Western agriculture with the exception that many practices, such as weeding and harvesting, are still manual. Therefore, in developing countries, more than 50% of the population continues to work on farms.

Thus, while projecting the need to produce food grains to meet the additional requirements in each region, it is important to consider the technological level of agriculture and the source of energy. Agricultural production systems are getting transformed in Asia and Africa. Many countries are moving from a traditional to a transitional form of agriculture. However, in all these instances draft energy continues to be the mainstay of agricultural production. Both in Africa and South America, the required additional land cannot possibly be brought under cultivation with draft energy alone. Consequently, there would be a need to introduce commercial energy into agricultural production. Sinha (1986) estimated the oil requirement for producing 2412 Mt of grain to meet the world demand in AD 2000, based on U.S. commercial energy-intensive and Indian transitional agricultural production. For each tonne of grain (wheat, rice and coarse grains) the U.S. technology uses 0.110 tons of oil whereas the Indian technology uses 0.038 tons of oil (Table 5).

The implications of this to food security has to be viewed in the context of the availability of fossil fuels. If the countries with food-grain deficits have to import grains from the United States or any other country, their cost would rise, whereas the indigenous resources of these nations may not be adequate to produce the required food grains.

2.3.2 Decreasing Fertilizer Response

Fertilizers and chemical control agents form an important component of farm inputs. FAO attributed the 55% increase in yield in developing countries between 1965 and 1976 to fertilizers. This implies that fertilizer consumption in developing countries in Africa, Asia and South America would have to rise substantially in the future. However, it is likely that the fertilizer response ratio would decrease with increasing fertilizer use in the way it has happened in the past five decades (Table 6).

2.3.3 Limitations on the Genetic Improvement of Crops

A breakthrough in the improvement of rice and wheat was responsible for the world-wide increase in agricultural production, and for the green revolution in developing countries. Therefore, scientists, administrators, planners, politicians and the public have great faith in the possibility of developing new cultivars with greater yield potentials. However, it may appear surprising, though true, that the maximum yields of rice (Paddy) and wheat in experimental trials were reached in the late sixties at the International Rice Research Institute and CYMMIT (Table 7). The rice yield was 10,130 and 7476 kg ha^{-1} in the dry and wet seasons, respectively, in 1966-67. In 1986 the best variety gave 8200 kg ha^{-1} in the dry season but only 4100 kg ha^{-1} in the wet season. The maximum yields of bread and durum wheats at CYMMIT in 1968-69 were 9313 and 8458 kg ha^{-1}, respectively. In 1984, their corresponding maximum yields were 8403 and 8882 kg ha^{-1}. The situation for other cereals is no different. A major change in rice productivity is that the yield of some recently developed cultivars is higher on a daily basis. Nonetheless, it is reasonably clear that we may have to wait for another scientific breakthrough for a major advance in the yield potentials of various cereal crops.

2.3.4 Degradation of the Resource Base

The urgent need to meet the food demands of the growing population and of industries has led to the degradation of the agricultural resource base on almost every continent. Often the poor are held responsible for environmental degradation, including the agricultural resources. The following statements at the public hearings of the World Commission on Environment and Development (WCED) sum up the situation beautifully.

Geoffrey Bruce of the Canadian International Development Agency said "Small farmers are held responsible for environmental destruction as if they had a choice of resources to depend on for their livelihood, when they really don't. In the context of basic survival, today's needs tend to overshadow consideration for the environmental future. It is poverty that is responsible for the destruction of natural resources, not the poor".

Adolfo Mascarenhas of the International Union for Conservation of Nature and Natural Resources (IUCN) highlighted the African situation succintly. "There are many contradictions in agricultural development. The blind imitation of models developed under different circumstances will have to give way to the realities and conditions existing in Africa. Large areas of virgin land have been opened up for export crops whose prices keep declining. This is not in the interest of developing countries."

"There are so many problems to be overcome that we forget that every problem is an opportunity to do something positive. This is an opportunity for us to think of conservation and environment in a broad educational context. In doing so, we will be able to capture the next generation and demonstrate the wonder and the benefits of the world around them".

The need for opening new land for cultivation, timber and fuelwood has caused extensive deforestation in different parts of the world. This, particularly in mountainous regions, has adversely influenced water conservation and led to soil erosion, silting and floods. Many river basins in India experience the impacts of deforestation. There is no conclusive evidence linking afforestation with precipitation but the loss of animal and plant genetic resources is clearly evident in many parts of the world.

2.3.5 Measures to be Adopted

Narrowing the gap between the maximum and the average national yields of crops would be the main objective of future research and development. Consequently, it would be important to analyse the contribution of different industrial inputs and environmental factors to assess the realizable potential of the genetically superior cultivars. The actual realization of this potential will be governed by the technologies adopted with respect to three factors:

a) land and water management

b) crop management

c) post-harvest management

These aspects have been discussed in sufficient detail in "Food 2000" (WECD, 1987).

3. SCENARIO 2: CLIMATE CHANGE AND FOOD SECURITY

Food production in any given year is affected most directly by the values of the critical climate elements (temperature, radiation, precipitation, etc.) during the year. The stability of available food supplies is governed by the interannual variability of these elements. Access to food supplies in different regions of the world is determined by their share of the food production, the role of cereals in the diet of the people, and the various political and market forces that act upon the global food security system. The climate anomalies that occurred during the 1970s caused fairly small fluctuations in the world cereal supply. But they occurred at a time of an increasing use of cereal as livestock feed. The food shortages were particularly severe in the Soviet Union and its large grain purchases led to dramatic fluctuations in world cereal prices. The disastrous effects these had on the world food security system are now well documented (Garcia, 1981).

Climate fluctuations of the kind witnessed in the 1970s lie within the variability of the present climate. They could have been anticipated by prudent societies if an eye had been kept on the climatic record. In addition to the normal variability of the climate, there is increasing evidence for a change in atmospheric optical properties as a result of the buildup of CO_2 and other "greenhouse gases". It is also clear that their buildup will continue. It is expected that in the long term this will result in "climate change".

Mathematical models of the potential climatic impact of such a change have been developed by various groups. Such models attempt to predict the changes in critical climate elements for a doubling of the CO_2 concentration. Although there is little agreement between various models about the specific magnitudes of the regional changes during the next 50 to 100 years, and details needed for regional planning, there is considerable agreement on the global changes, which may be summarized as follows:

1. The lower atmosphere will warm and the stratosphere will cool.
2. The annual average global warming will be 1.5 to 4°C. This is much greater than any natural climate change. The rise in temperature is, in general, greater in the Northern Hemisphere than in the Southern Hemisphere and increases (by a factor of 2 to 3) polewards.
3. The temperature rise will be greater (by about 50%) in winter than in summer. Consequently, we may expect the production of winter season crops to be more affected than that of summer crops.
4. Freeze-free periods will lengthen in higher latitudes so that larger areas may be brought under cultivation, if soil conditions

are suitable. The increase in the freeze-free period will depend on the current length of this period, e.g., a 1°C rise in temperature will lengthen an 80-day freeze-free period by about 20 days but a 120- to 130-day period by only 6 days.

5. General warming will be accompanied by a a weakening of temperature differences between the equator and the poles, which will affect the atmosphere's general circulation. This could lead to longer dry periods.

6. The global average annual precipitation will increase by about 7 to 11%, but its regional and temporal variations are uncertain.

7. Relationship between precipitation and evaporation is not likely to change in the lower latitudes. Evaporation will increase more than precipitation in the mid- to higher latitudes.

8. Soil moisture conditions will be "wetter" in some regions of the world (35°N-35°S), but "drier" in others, compared with present conditions.

9. A sea-level rise is foreseen but its magnitude and time-scale are uncertain. The effects on agriculture in coastal regions could be disastrous.

10. Agroclimatic zones will shift poleward (about 100 km per degree of warming).

11. The variability of temperature and precipitation may decrease because of the weaker circulation. The regional variations are uncertain.

12. Only changes in mean climate conditions are specified by the models. Sizeable uncertainties remain about the timing, intensity and direction of specific effects.

However, it may be noted that climate is a complex, non-linear multiple feedback system with dominant positive feedbacks. From a cybernetic systems viewpoint, a fairly rapid forced change in such a system, such as a change in the CO_2 concentration, is likely to destabilize the system. The magnitude of the destabilization tends to be proportional to the rate of change of the forcing function. Because the rate of change of CO_2 concentration is expected to be greatest between 2000 and 2060, these decades may experience chronic and severe weather variability (Markley and Hurley, 1983). One aspect of the climate change, even at the present level of CO_2 increase, is provided by a simulation study of Rowntree and Bolton (1983). They showed that, as a result of positive feedback, a hot, dry spell occurring in mid-summer in central Europe, when coupled with a weak atmospheric circulation pattern, could persist for as long as 50 days and expand into Scandinavia, Spain and North Africa. Even under conditions of moist airflow, initial hot, dry conditions maintained themselves for up to 20 days.

Thus, even though mean changes in the global climate resulting from a doubling of CO_2 concentration can be anticipated, the specific changes in the annual variability of climate are uncertain during the period when the doubling is occurring. But, keeping with the complex, non-linear and multiple feedback characteristics of the climate system, it is likely that the next 50 to 100 years will experience chronic and severe climate variability.

What are the implications of climate change for the world food security system? To answer this it is necessary to examine the effects of climate change on both the regional food production as a result of changes in mean climate, as well as the variability of the food production resulting from increased climate variability. In the ultimate analysis, the annual variability of total food production as well as the regional share of production are the determinants of food security.

3.1 Effects of Climate Change on Food Production, Increased CO_2 Concentration and Crop Yield

The climate changes envisaged in the next century are mostly attributed to the increasing concentration of CO_2 and other "greenhouse gases". Since CO_2 is an essential reactant in photosynthesis to produce organic matter, it was postulated that farmers could look forward to better harvests (Wittwer, 1986). Often these postulates were based on short-term experiments in controlled environments or glasshouses with adequate supplies of water and plant protection measures. Rosenberg (1987) made an analysis of gas exchange and concluded that climate change, at least as far as CO_2 concentration effects are concerned, may prove advantageous. However, Gifford (1987) made a more cautious assessment of CO_2 effects by including temperature change as an additional component. The following observations are relevant for assessing the effects of climate change, including CO_2 concentration, on crop yields:

1. The highest yields in C_3 crops are obtained around a mean daily temperature of 15°C and in C_4 crops around 30°C.
2. The temperature optima for vegetative growth and the reproductive phases are often different. An increase of temperature beyond a mean of 22°C causes sterility in rice resulting in reduced grain yield, though it has no effect on photosynthesis (Figure 1). In wheat, an increase in mean temperature above 16°C results in a decrease in grain weight and a poor yield (Figure 2). A higher temperature significantly reduces tillering, which is essential to building shoot population.
3. The crops having a high growth rate in the preflowering phase usually deplete soil moisture, which is necessary to normally complete the grain development phase. Consequently, high initial growth, in the absence of irrigation, results in a poor grain yield despite high dry matter accumulation.

Gifford (1987) estimated the rise in temperature that would cancel out the advantageous effects of CO_2 fertilization (Table 8). At locations ranging from 50°N in Canada to 37°S in Australia a rise of 1.5° to 2.4°C is required to cancel the advantageous effects of CO_2 on grain yield, presumably under irrigated conditions. In the absence of irrigation, crop yields may in fact be reduced.

The optimistic predictions for agricultural production made by several people in the recent past based on CO_2 fertilization effects should not lead to complacency about the question of food security. These projections have been based on a study of the individual effects of only one or two factors. It should be recognized that agricultural production is a complex process. The available evidence on CO_2 fertilization effects, when two or more factors are simultaneously considered is, at best, inconclusive.

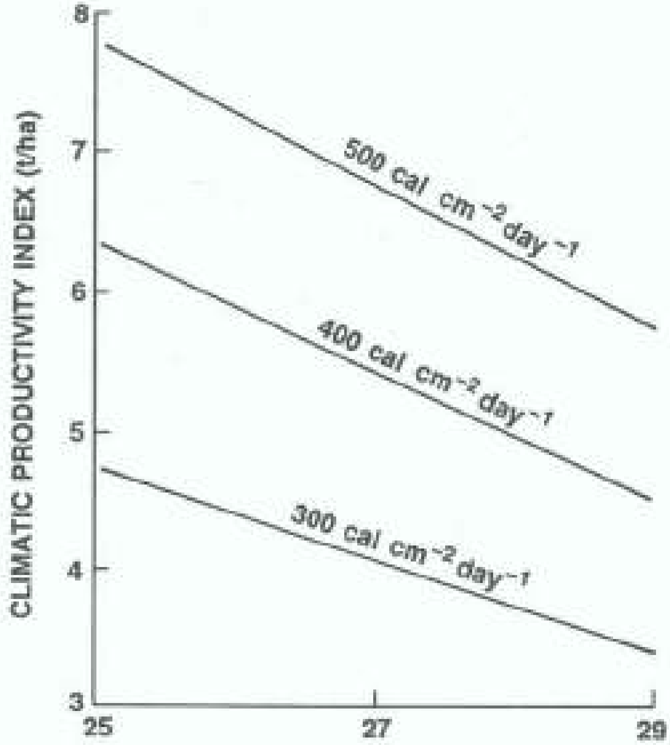

Figure 1.
Effect of increasing temperature on the productivity of rice at different rates of radiation (Yoshida, 1978).

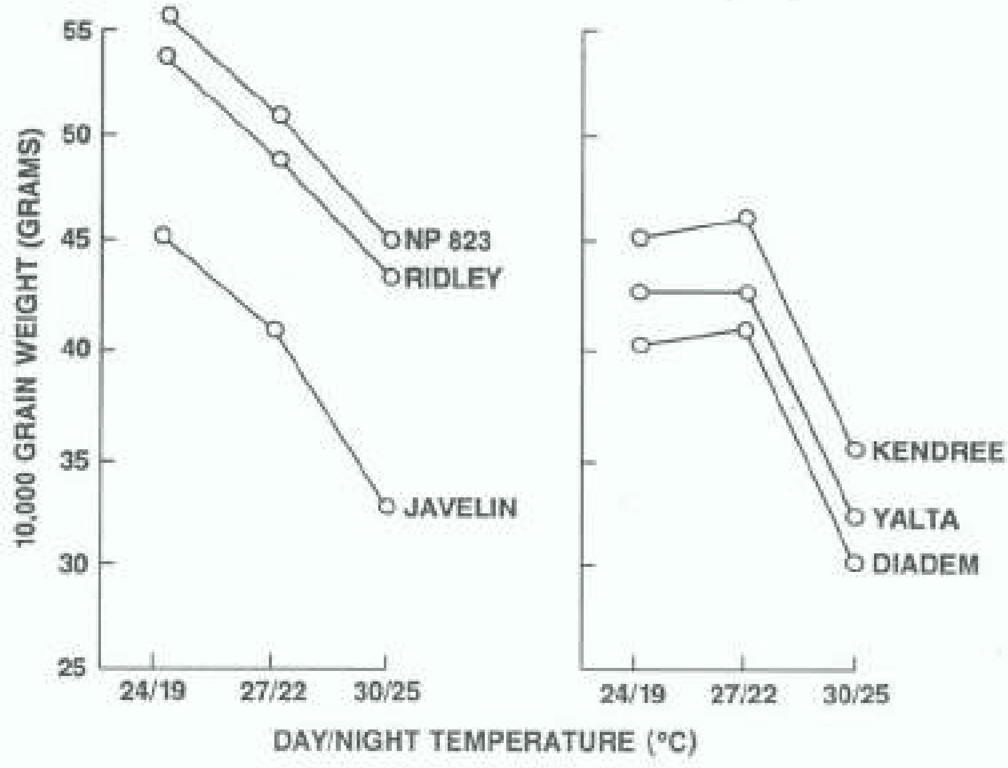

Figure 2.
Effect of increasing temperature on grain development in wheat (Asana, 1976).

3.2 Effect of Changes in Mean Temperature and Precipitation

Crop production is directly influenced by temperature and precipitation. Both are critical elements for determining the agroclimatic zones. Temperature determines the duration of a crop's growing season and controls its phenological development and water requirements. Precipitation provides the critical input for crop growth, water. The distribution of these variables during the period of crop growth is also critical. But, information on intraseasonal variations in temperature and precipitation in the 2 x CO_2 climate is not available. This discussion is, therefore, limited to anticipated changes in seasonal/annual values of the variables. The direct effects of CO_2 on crop yields are excluded since the available information is inconclusive.

In general, an increase in the average annual temperature will result in shorter freeze periods than now. As a result, larger areas can be brought under cultivation at the climatic margins. But, in the existing crop belts, the growing season duration will be reduced and productivity (crop yield) losses will result. Some crops may also be forced out of cultivation to be replaced by others. To what extent the losses in crop yield can be compensated by the increases in crop area is uncertain and will be governed to a significant extent by technology. An increase in precipitation will have beneficial effects on both productivity and crop area.

Wheat, rice and maize are the three major crops of the world accounting for about 80% of its total cereal production in 1985. The impacts of changed climate conditions on their production, when considered independently and assuming current levels of technology, are shown in Tables 9 to 11. The climate scenario considered here is based on temperature changes predicted by the GFDL model for various regions (latitude limits) for the summer and winter seasons. This model predicts the maximum increases compared with those of other commonly used models, GISS and NCAR (Rosenberg, 1987). Precipitation scenarios are considered indirectly by using the results presented by Kellogg and Schware(1981). The impacts on production are indicated as increases (+) or decreases (-) over current crop yields or areas. The results are presented for the countries/regions that accounted for significant shares of each crop's production in 1985.

Based on Tables 9-11, the following observations may be made:

1. In mid- to higher latitudes (developed countries) significant increases in area, accompanied by reductions in crop yield are expected. In the lower latitudes, because of increasing temperature, significant areas become unavailable for wheat and yields will also decline. An increase in water requirements may be anticipated in all regions in these latitudes, and irrigation management will acquire a greater significance. A net reduction in wheat production is anticipated, with the balance of production shifting further in favour of developed countries.

2. About 94% of the rice is grown in developing countries mostly during the summer monsoon. However, better yields are obtained in the dry season when temperatures are lower and pest problems are fewer. An increase in precipitation would help increase the area of this crop and its yield, but an increase in temperature promotes sterility and yields would be reduced. Almost one third of the rice is grown under upland unirrigated conditions that may benefit from increased precipitation. On a balance it would appear that devel-

oping countries will continue to be major growers of rice, and this crop will continue to be a major diet of the people in these regions.

3. The mid-latitudes account for more than 50% of the maize production. Increased precipitation may increase the share of the developing countries in the world's maize production.

Overall, the declines in the production levels of wheat are expected whereas the production of rice may remain unaffected and maize may increase, under a doubled-CO_2 climate. The existing wheat production imbalances in favour of the developed countries may be further accentuated. Similarly, the share of developing countries in rice production may also rise. Maize production may become more uniform across developed and developing countries.

The above analysis excluded the possibility of replacing one crop by another more suitable for the changed climate conditions. But this is expected to happen. For example, wheat belts may be replaced by barley, barley by maize, maize by sorghum and so on. Rice may be substituted if adequate irrigation facilities are available. But these substitutions are likely to take place only gradually since there will be problems of adaptation.

The current advantage, with respect to food security, remains with the developed countries primarily because of the rapid progress of technology or the absence of population pressure or both (see the 1985 yields of various crops in Tables 9-11). Based on currently available information it is clear that these two factors will continue to be the significant determinants of food security, whether a climate change occurs or not.

3.3 Effects of Climate Change on Pests and Diseases

Currently about 25% of food is lost as a result of pest damage. Today the high productivity of various crops in temperate regions could be attributed not only to improved technology, but also to the limited number of diseases and pests, better soil health including microflora and better response to fertilizers. The generally warmer and moist conditions in the changed climate coupled with a low general circulation and longer freeze-free periods are highly conducive to crop pests. By far, the most predictable effect of climate change is that it will cause significant increases in the pest populations. Thus, some of the advantages of existing temperate regions may be cancelled by increased temperature and uncertain precipitation.

3.4 Climate Change and Variability of Food Production

Under the current climate, the coefficient of variation (CV) of the global total cereal production for the trend in the 1970s was about 3% (Anderson et al., 1987), but is higher in some individual countries. The variability is greatest in semi-arid areas and least in humid areas. The regions of high variability also have low average crop yields. CV also tends to be less in larger countries because risk pooling is spread across regions and crops.

For individual crops at the global level, the CVs of maize, sorghum, wheat and rice around the trend are about 4, 6, 5 and 4%, respectively, but are higher in individual countries. For example, in India, the CVs of wheat, rice and sorghum are 11, 8 and 16%, respectively. In the United States, the values for maize, winter wheat and sorghum are 10, 10 and 11% respectively (Hazell, 1984). Some of the sources of inter-annual variability in national agricultural production are:

i) Variability of weather

ii) Variability of areas sown under different crops

iii) Variability of yield correlations between regions and crops

iv) Production expansion into riskier regions

v) Increased sensitivities of new technologies to weather and disease

vi) Variations in agricultural prices, policy and levels of rural infrastructure

The relative contribution of these factors to the overall variability of food production is different in different regions. It also depends on the current level of production variability in the region. For example, the variability in cereal production in India was shown to be (Hazell, 1984) a consequence of the increased adoption of high yield technology and the variability of weather, crop yields, areas cropped and prices. On the other hand, the predominant sources of production variability in the United States were crop yields and yield correlations between states.

In this context the question relevant to food security under future CO_2-induced changes of climate is whether such climate changes will lead to an increased or decreased variability of food production. Even when anticipated changes in mean climate conditions only are considered, it is clear (from the previous section) that an increased variability of production would result from sources (ii) to (v) listed above. When an increased variability of weather (i) resulting from climate change is also included, significant increases in the variability of food supplies are foreseen.

This leads to many concerns that need to be addressed by the international community. Prominent among these are: perceptions of increased risk that may discourage the adoption of new technologies and retard agricultural growth; increased instability of national and international food supplies; increased frequencies of droughts and floods over larger areas; increased destabilizing effects of agricultural prices on food production and consumption; and risk pooling across regions and crops by diversification of the crop production systems.

4. CLIMATE IMPACT ASSESSMENT

Climate fluctuations influence the lives of millions of people around the world. There are now several studies on the interaction of climate and society (Kates et al., 1985). Whether climate change induced effects could be discerned as a warning or as an attempt to mitigate adverse effects are important questions. Parry et al. (1987) have developed a methodology based on climate impact assessment in marginal areas. This is useful when the objective of such studies is to evaluate the sensitivity of ecosystems to climate changes However, food security is concerned more with stabilizing the available food supplies. Both national and global food security are dependent more on the stable and productive areas than on the marginal areas. For example, in India, seven out of 35 meteorological divisions are important determinants of food security (Sinha, 1987). This is clear from the impact of droughts of nearly equal magnitude on national food production in the two years, 1979-80 and 1982-83. There was a 17% shortfall in grain production in 1979-80 compared with the previous year's 131.4 Mt. However, in 1982-83, food grain production declined by only 3.7% relative to the previous year's 133.3 Mt. This was because, in this year, the highly productive divisions were not affected (Sinha, 1987). Therefore, for the assessment of food security, it is necessary that the impact of climate fluctuations on productive areas be studied as well. For studying global food security, it may be prudent to perform such studies on a selected group of nations.

5. CONCLUSIONS AND IMPLICATIONS FOR RESEARCH AND POLICY

5.1 Conclusions

1. The projected population growth rates and the ensuing food demands, even in the current global climate, would make it difficult to provide for human sustenance and food security in the twenty-first century.

2. Africa and South America are the most vulnerable regions in regard to food security. The food demands of these regions can be met by increasing the cultivated area. Asia is next in order of vulnerability. Significant increases in crop productivity are required in this region since it is difficult to bring additional areas under cultivation. Appropriate strategies for increasing agricultural production that balance an increase in cultivated area with an increase in crop productivity need to be designed for various regions of the world.

3. There is a near-consensus that the rising concentrations of CO_2 and other greenhouse gases in the atmosphere will lead to a climate change. This will directly affect agricultural production and food security.

4. Some recent reports on the favourable impact of climate change on agricultural production should not lead to complacency. The available evidence in support of this is inconclusive and is not based on the complex dynamics of interactions between agricultural production processes and the environment.

5. Two aspects of the effects of the changing climate on agricultural production and food security need to be considered:

   i) Changes in the mean values of the critical variables that will affect the trends of global agricultural production and the regional shares of production.

   ii) Increased instability of climate that will result in greater instabilities in food supplies.

6. In the 2 x CO_2 climate, an overall decline in production of wheat may be expected as a consequence of an increase in temperature in mid-latitudes. The production of rice may be unaffected whereas that of maize may increase as a result of the increased area and wetness in lower latitudes. Food supplies in smaller nations are likely to be affected more by the climate change compared with

those in larger nations. This is because of the advantage of risk pooling across regions and crops in large nations.

7. Even in the changed climate, the current balance of food supplies in favour of the developed nations will continue. In the future also, even more than now, technology and resource management will continue to determine this balance. The availability of energy, the decreasing marginal response of crops to fertilizers relative to that in the 1960s and 1970s, the levelling off of the production potential of major cereals and the eroding natural resource base will be the major limiting factors on the agricultural technology of the future.

5.2 Implications for Research and Policy

1. Measures to improve food security by maintaining adequate food reserves and developing efficient transportation and distribution networks require huge capital resources. The planners in many small nations are reluctant to commit the financial resources required to establish such networks. But in a changing climate, the smaller nations will also be the most vulnerable in regard to food security. Such nations may be encouraged to group and pool the resources required for stepping up food security measures. This will also provide the advantage of risk-pooling across regions and crops, and the group of nations as a whole will be less susceptible to climate effects. In the long term, the adoption of food security measures will come to be viewed in the broader context of regional development. Specific studies need to be initiated on the criteria to be adopted for forming the nation groups, the crops and production technologies required, the appropriate balance between increasing crop area and productivity, and the related aspects of infrastructural development such as transportation, distribution and marketing networks.

2. In the future, particularly in the changing climate conditions, to ensure food security will require a greater emphasis than now on land and water management, crop management and post-harvest management. The availability of energy will be a significant factor affecting production. Developments in the use of non-polluting, renewable resources of energy will play a significant role in conserving the resource base of agricultural production. Any major breakthrough in this sector, should be globally shared without reservations about political, social or economic considerations. Such a breakthrough, in addition to supporting agricultural production, would help control the "greenhouse effect" itself and will be to the benefit of mankind.

3. Considerable additional research is required on the annual, seasonal and intraseasonal variabilities of climate in individual regions. Linkages between the results of this research and agricultural production need to be established. The predictive power of GCMs has to be extended considerably before this can be done.

4. An important issue of research, in the context of food security, relates to the methodology of climate impact assessment. Current methodologies, developed for impact assessment in marginal areas, are not directly applicable. Such methodologies are useful as long

as the goal of research is to analyse and demonstrate the sensitivities of agroecological and social systems to climate change. In this case, the marginal areas provided the analytical advantage required for isolating the effects of climate variables. However, to provide food security, the major source of food is agricultural production in regions with a high potential for production. In these regions, it is difficult to isolate the climate effects from other factors. Thus, on the question of food security in a changing climate, methodological issues relating to climate impact assessment need to be critically addressed.

5. Specific research is required on the costs of not considering the effects of climate change when planning and designing agricultural production and food security systems with lifetimes of several decades. Examples are irrigation systems and agricultural expansion in coastal areas.

6. The instability of food supplies results from various sources. These include, in addition to climate variability, the uncertainties in agricultural policy. Whereas the effects of climate variability are difficult to anticipate and control, the resulting instabilities may be minimized through appropriate food policy. This requires from individual nations explicit statements about their food policy objectives (efficient growth of agriculture and related sectors, income distribution through employment, subsidies, insurance, etc.), and their specific programs and policies, not just projects. Many projects in tropical Africa achieved only a limited success because a framework for monetary, fiscal and trade policy did not exist.

7. In recent times, considerable progress has been made in drawing the attention of policy-makers to the issues related to climate change. But much more persuasion is needed before their interest gets translated into public policy and action. This requires developing the capabilities for obtaining and analysing information, developing policy alternatives and presenting them to development planners to initiate action. Simultaneously, it must be recognized that the political will to initiate action is driven by public opinion. Informed public opinion must be mobilized through the systematic communication of available research information.

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Table 1. Food grain requirement of different regions of the world in 2025.

	Population (billions)	Average per capita consumption (kg)	Food grains requirement (Mt)
Africa	1.62	257	416
South America	0.78	296	231
Asia	4.54	300	1362
North America	0.35	885	310
Europe	0.52	700	364
USSR	0.37	983	364
Oceania	0.04	578	23
World	8.22	373	3070

Table 2. Additional land requirement to meet cereal demand in 2025 (Source: WECD, 1987).

Region	Potential Arable (Mha)	Cultivated Land (Mha) 1986	Cultivated for Cereals (Mha) 1986	To be Cultivated for Cereals (Mha) 2025	Additional for Cereals (Mha)
Africa	734	158	74	277	203
Asia	627	519	307	340	33
Australia and New Zealand	153	32	16	16	-
Europe	174	154	71	78	7
North America	465	239	103	103	-
South America	681	77	39	93	54
USSR	356	227	111	146	35
World	3190	1406	721	1053	332

Table 3. Required changes in productivity of cereals and corresponding land requirements to maintain adequate supplies in different regions. (Source: WECD, 1987)

	Year			
	1986		2025	
Region	Land area (Mha)	Productivity (kg ha^{-1})	Land area (Mha)	Productivity (kg ha^{-1})
Africa	73.5	1175	277	1500
Asia	307.0	2534	340	4000
Europe	70.5	4137	77.4	4700
South America	39.0	1991	92.4	2500
USSR	111.0	1796	277.5	2500
World	721.0	2587	1053	2915

Table 4. Projected rates of growth of area, productivity and production to meet the food grains demand of different regions of the World.*

	Growth Rate (%)		
	Area	Productivity	Production
Africa	3.50	0.06	4.1
Asia	0.02	1.20	1.4
Europe	0.02	0.03	0.05
South America	2.20	0.05	2.80
USSR	2.30	0.08	1.50
World	1.00	0.003	1.30

* It is assumed that North America and Oceania would maintain the present area, productivity and production.

Table 5. World grain production and fertilizer use 1934-38 to 1979-81 (Source: WECD, 1987).

Year	World Grain Production * (Mt)	Increment (Mt)	World Fertilizer Use (Mt)	Increment (Mt)	Incremental Grain/Fertilizer Response Ratio
1934-38	651	-	10	-	-
1948-52	710	59	14	4	14.8
1959-61	848	138	26	12	11.5
1969-71	1165	317	64	38	8.3
1979-81	1451	286	113	49	5.8

* Annual Average for period

Table 6. Projected world grain requirement and the estimated oil needs for its production in A.D. 2000 (Source: Sinha, 1986).

	Grain Requirement (10^6 tons)	Oil Requirement (U.S. Technology) (10^6 tons)	Oil Requirement (Indian Technology) (10^6 tons)
Wheat	601.3	51.1	10.5
Coarse grain	1186.6	123.6	44.5
Rice	633.6	89.7	36.9
Total	2412.5	264.4	91.9

Table 7a. Maximum yield of the best varieties of Rice (Paddy) in 1966-67 and 1986.

		Yield (kg ha^{-1})	
Year	Variety	Dry Season	Wet Season
1966-67	IR 8	10,130	7,476
1986	IR 36	6,500	4,100
	IR 28	8,200	3,400

Table 7b. Maximum yield of the best variety of wheat in 1968-69 and 1983-84. (Source: Annual Reports of the International Rice Research Institute and CYMMIT).

	Yield (kg ha^{-1})	
Year	Bread Wheat	Durum Wheat
1968-69	9313	8458
1984	8403	8882

Table 8. Increase in mean temperature (ΔT) during both the spike development and grain-filling stages of semi-dwarf wheats required to annul an assumed 30% yield increase attributable to a CO_2 concentration doubling (Source: Gifford, 1987)

Location	Before Anthesis	Grain Filling	Mean Radiation ($MJ\ m^{-2}d^{-1}$)	ΔT (°C)
Swift Current Canada (50°N)	17.5	18.0	23.0	2.2
Horsham, Australia (37°S)	10.9	16.7	13.8	1.5
Dubbo, Australia (32°S)	12.0	18.0	16.3	1.7
New Delhi, India (28°N)	14.0	22.0	16.7	1.9
Clermont, Australia (23°S)	15.8	21.1	17.6	2.1
Kimberley, Australia (15°S)	23.0	24.2	19.7	2.4

Table 9. Effect of the doubling of atmospheric CO_2 on the area and productivity of wheat (total production in 1985 = 510 Mt).

Country/ Region	Share of Production (%)	Yield (t/ha)	2 X CO_2 Climate Scenario		Effects on Crop Production	
			ΔT(°C)	Soil Moisture Conditions	Area	Yield
China	17	3.0	4	Some regions wetter	+	-
India	9	1.9	3	Wetter	-	-
USSR	16	1.6	6	Drier	++	-
Canada	5	1.7	8	Drier	++	-
USA	13	2.5	5	Drier	+	-
Western Europe	16	4.6	6	Wetter	+	-
Australia	3	1.4	2	Wetter	-	-
Developed countries	60	2.3	5-8	Drier	++	-
Developing countries	40	2.1	2-4	Wetter	+	-

Table 10. Effect of the doubling of atmospheric CO_2 on the area and productivity of rice (total production in 1985=465 Mt).

Country/ Region	Share of Production (%)	Yield (t/ha)	2 X CO_2 Climate Scenario		Effects on Crop Production*	
			ΔT(°C)	Soil Moisture Conditions	Area	Yield
China	37	5.3	3	Wetter	+	+
India	20	2.2	3	Wetter	+	+
Indonesia	8	2.1	2	Drier	-	+
Bangladesh	5	4.1	3	Wetter	+	+
Developing countries	94	3.1	2-4	Wetter	+	+

* For rice, sterility effects of increasing temperature may neutralize increase in production.

Table 11. Effect of the doubling of atmospheric CO_2 on the area and productivity of maize (total production in 1986 = 490 Mt).

Country/ Region	Share of Production (%)	Yield (t/ha)	2 X CO_2 Climate Scenario		Effects on Crop Production	
			ΔT(°C)	Soil Moisture Conditions	Area	Yield
USA	46	7.4	4	Drier	+	-
Western Europe	8	5.5	4	Drier	+	-
China	13	3.5	3	Wetter	+	+
Brazil	4	1.9	3	Wetter/Drier	+	+
Developed countries	65	6.0	4	Drier	+	-
Developing countries	35	2.2	3	Wetter	+	+

ABSTRACT

FOOD SECURITY IN THE CHANGING GLOBAL CLIMATE

Food security is a cause for concern at the best of times. How future agricultural production and food systems will be affected by global climate change depends on the magnitude of the change in specific regions. But the geographical variations of the projected climate changes are uncertain. When seen in isolation, the enhanced levels of CO_2 in the atmosphere appear to promote the production of some crops if adequate input resources are available. However, most of the projections claiming advantageous effects of increased levels of CO_2 are based on studies of vegetative growth. A warming of 2°C promotes sterility in rice and hence reduces the yield by 25% or more. A similar rise in temperature could have a strong influence on wheat. A detailed regional analysis is, therefore, required to project influences on agricultural production.

Today, the agricultural production systems in developed and developing countries are significantly different. Would be developing countries, where small farms with draft energy constitute major components of agricultural production, be able to take full advantage of a favourable climate change? Would the developed countries be able to subsidize their agriculture, in view of the declining prospects of purchasing capacity by importing nations? There is no possibility of more land opening up for cultivation except in Africa and South America. Therefore, for an increasing population, most of the increase in agricultural production would have to result from increased crop yield. For most crops no major improvements in productivity have occurred in the past two decades. Therefore, sustaining a higher growth rate of food production than the population growth rate and providing for national food security would be major challenges. The international community would have to rise a great deal above regional interests to overcome problems in the global food system.

RÉSUMÉ

LE CHANGEMENT CLIMATIQUE MONDIAL ET LA SÉCURITÉ DANS LE DOMAINE DE L'ALIMENTATION

Même dans les circonstances les plus favorables, la sécurité dans le domaine alimentaire est une cause de préoccupation. Les effets du changement climatique mondial sur la production agricole et sur le réseau alimentaire futurs dépendent de l'ampleur du changement que devront subir les diverses régions. Les variations géographiques des changements climatiques prévus sont cependent incertaines. Si on l'examine seule, l'augmentation de la concentration du CO_2 dans l'atmosphère semble stimuler la production de certaines cultures dans des conditions où les ressources sont suffisantes. Toutefois, la plupart des projections qui montrent les effets avantageux de l'augmentation de la concentration du CO_2 se fondent sur des études qui portent sur la phase végétative. Un réchauffement de 2°C tend à entrainer la stérilité des plants de riz et par conséquent à réduire la récolte d'au moins 25%. Une augmentation de la température du même order pourrait avoir un effet important sur le blé. Il est par conséqeunt nécessaire d'entreprendre des analyses régionales détaillées pour prévoir les effets du réchauffement sur la production agricole.

De nos jours, les réseaux de production agricole des pays développés et des pays en développement présentent de grandes différences. Les pays en développement, où les petites exploitations non mécanisées constituent les principaux éléments de la production agricole, seront-ils capables de tirer entièrement avantage d'un changement climatique favorable? Les pays développés seront-ils capables de subventionner le domaine de l'agriculture compte tenu du déclin prévu de la capacité d'acquisition par les nations importatrices. Si ce n'est en Afrique et dans l'Amérique du Sud, il est impossible de réserver une superficie supplémentaire de terres à l'agriculture. Par conséquent, pour nourrir la population accrue, il faudra augmenter le rendement des cultures. Pour la plupart des cultures, aucune grande améloiration de productivité s'est produite au cours des deux dernières décennies. Le maintien d'une vitesse de croissance de la production alimentaire supérieure à la vitesse de croissance de la population et le maintien de la sécurité nationale dans le domaine alimentaire constituent donc des entreprises ardues. La communauté internationale devra surpasser les intérêts régionaux pour régler les problèmes qui pèsent sur le réseau alimentaire mondial.

FORESTS AND ATMOSPHERIC CHANGE

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1. INTRODUCTION

Trees and forests are an important component of the global environmental system of the planet earth. They influence the rate and nature of atmospheric change and, in turn, are themselves influenced by it. Studies on macrofossils, pollen sediments in bogs, and tree-ring analyses show that atmospheric change is not a new phenomenon. What distinguishes the current phase of atmospheric change from those of the past is the strong presence and influence of the human factor, which derives significant economic, social and environmental benefits from forests. This paper examines the dynamic relation between the anticipated atmospheric change and forests as well as the nature and role of human interventions in this interaction, particularly from socio-economic and policy perspectives (Figure 1).

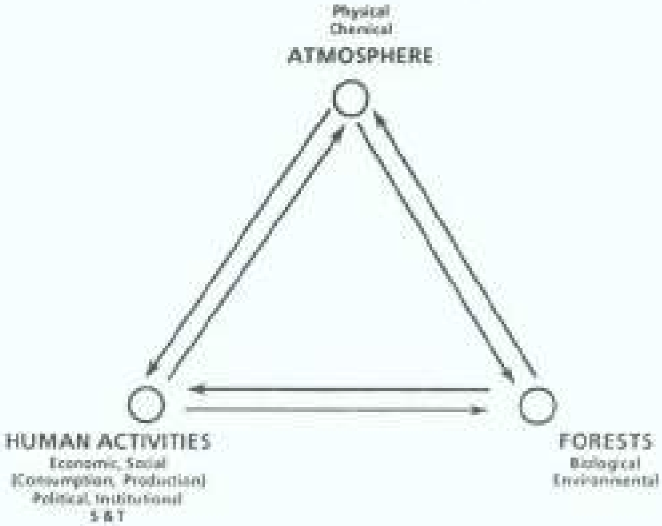


Figure 1.
Components of the three principal interacting subsystems in the forests and atmospheric change issue.

2. ATMOSPHERIC CHANGE

The ecological interaction between atmosphere, trees and forests is complex. Climate parameters influence the growth of individual trees, the zonal distribution of different forest types (e.g., tropical, temperate) and the latitudinal as well as the altitudinal tree-lines. Some aspects of the anticipated atmospheric change, considered relevant to the biology of trees and forests, are summarized below.

Atmospheric change is not a new phenomenon. Changes in the atmosphere and associated changes in plant and animal life (i.e., biota) have occurred in the geologic past (Dansereau, 1957; Davis, 1984) and have been attributed mostly to geologic events such as continental drift, glaciation and volcanic activity (Harrington, 1987). More recently, however, the emission of radiatively active gases, generated by human activities such as the production and consumption of goods, has become a significant factor in the current atmospheric change issue.

The atmospheric concentration of a number of radiatively active gases (i.e., "greenhouse gases"), particularly carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), chlorofluorocarbons (CFCs) and tropospheric ozone (O_3), has been increasing during the past few decades. There is now an increasing consensus that global warming is attributed to increased carbon dioxide emissions (50%) and to other radiatively active gases (50%). The increased concentration of these gases has led to the warming of the earth's surface as well as of the lower atmosphere, and to further changes of climate (Jaeger, 1988).

According to Stewart (1987), 95% of the CO_2 emissions originate from the Northern Hemisphere and only 5% from the Southern Hemisphere. The increase in CO_2 emission is primarily due to human activities, e.g., the escalating combustion of fossil fuels (80%) and the destruction of global forests (20%). The combined future effect of an increase in all "greenhouse gases" may be an equivalent of CO_2 doubling by the 2030s - i.e., in less than a half century (Hansen, 1987; Hare, 1988; Mintzer, 1987). Such a doubling may induce a global surface temperature increase of 1.5 to 4.5°C by the 2030s in a "business as usual" scenario, but by about 2015 in a "high emission" scenario, and by the 2075s in a "modest policies" scenario.

The warming is likely to be geographically uneven; high latitudes in both hemispheres will experience the greatest warming and the equatorial regions lesser but appreciable warming (Hare, 1988). The temperature increase will be greatest during winter months (Auclair and Pollard, 1988).

Generally the topic of weather variability has not been well researched (Auclair, 1987a). However, it should be noted that future climatic variability, whether episodic or extended over several years (Hare, 1988), will likely be biologically significant from the point of view of growth and survival of individual tree species and consequently of potential economic damage.

Soil moisture is likely to be reduced in summer over extensive mid-continental regions of both North America and Eurasia in middle and high latitudes. Over northern Canada and northern Siberia, this reduction in soil moisture is likely to result from the earlier occurrence of the snowmelt season, followed by a period of intense evaporation (Manabe and Wetherald, 1987).

The global climate has been stable over the last 100,000 years (Auclair, 1987b). The warmest time during this period was only 1°C warmer than today and a global warming of about 0.6°C has taken place during the past century.

3. IMPACT ON TREES AND FORESTS

The pattern and range of distribution of individual tree species is a result of the interaction betwen the evolutionary history of the species and the constantly changing climate. Climatic changes and consequent modifications in plant and animal life have occurred during the geological past (Dansereau, 1957; Davis and Botkin, 1985), and have resulted in the appearance and disappearance of species as well as in the shrinkage and expansion of the distribution range of individual species, forest types and biomes (e.g., forests, grasslands, tundra).

It has been estimated that, at one time, the world's forests and woodland probably covered 6 million hectares. By 1954, the increasing use of forest for agriculture, pasture and human settlements has reduced the total forest land to 4 billion hectares (IIED and WRI, 1987). An examination of the current forest areas and growing stock, by continent, shows that South America and the USSR have the major share of the world's current total, followed by North America and Asia (Figure 2). Considering the latitudinally uneven surface temperature warmings as well as the soil wetness associated with the anticipated atmospheric change, the temperate forests of middle latitudes are expected to experience the greatest perturbation. The following aspects of forests are expected to be affected by climate change.

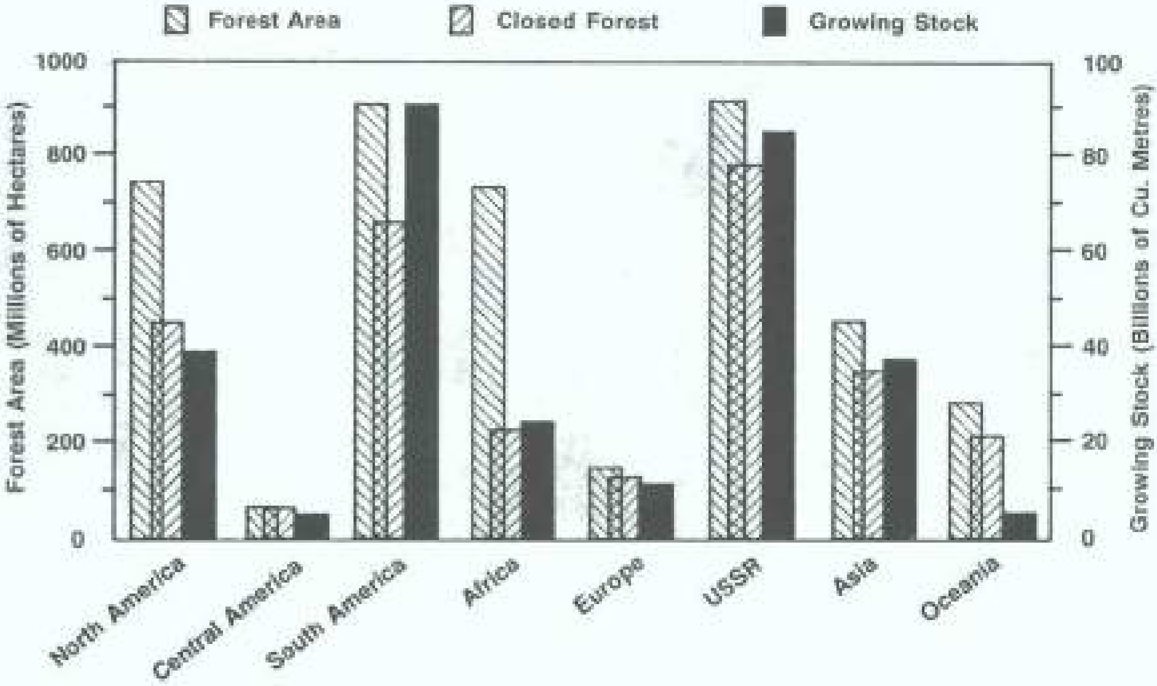


Figure 2.
Forest areas and growing stock by continent (Canadian Forestry Service, 1988).

3.1 Broad Scale Zonal Distribution of Forest Types

A simulation based on the doubling of carbon dioxide suggests that the maximum impact of the anticipated climate change is expected at high latitudes, where the simulated temperature increase is largest and the temperature intervals defining Holdridge's life zones are smallest (Emmanuel et al., 1985). Depending on average precipitation, the boreal forest zones are replaced by either Cool Temperate Forest or Cool Temperate Steppe (Figures 3 and 4). This simulation also suggests that although the anticipated changes in the tropics are smaller, Subtropical Moist Forest is replaced by Tropical Dry Forest. It is noted that this simulation is based on climate/life zone relationships and that paleoecological studies suggest that there is a time lag between climate change and spatial adjustment by vegetation (Maini, 1960 ; Davis, 1984); the latter is determined by a number of factors including the reproductive strategies and migration potential of species as well as by the rate of soil development (Shugart et al., 1986). According to

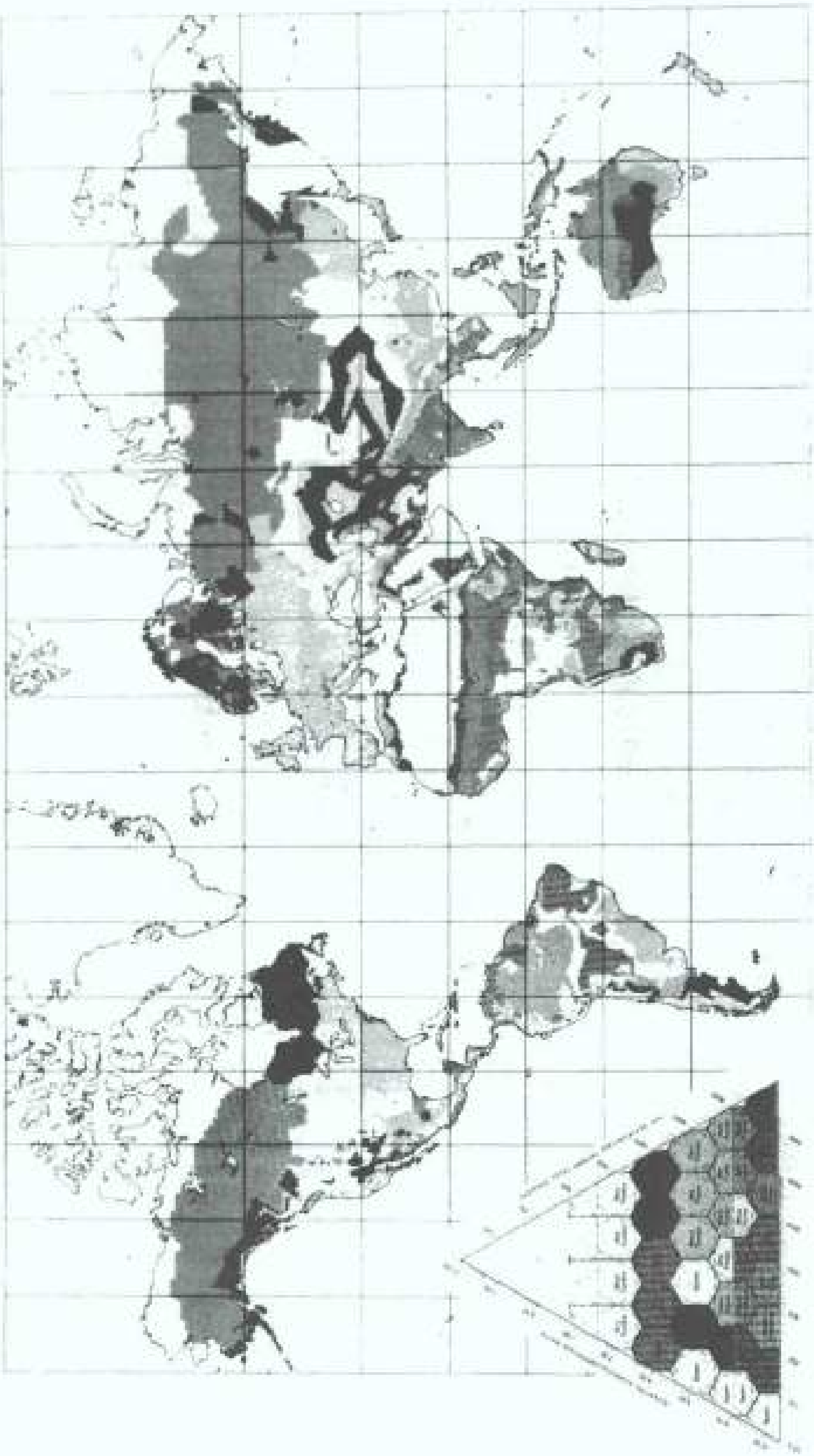


Figure 3.
Word map of the Holdridge Classification (base case). The resolution is 0.5° latitude x 0.5° longitude and the extent is from 80°N to 60°S - Greenland is not classified (Aitoff's Equal Area Projection) (from Emmanuel et al., 1985).

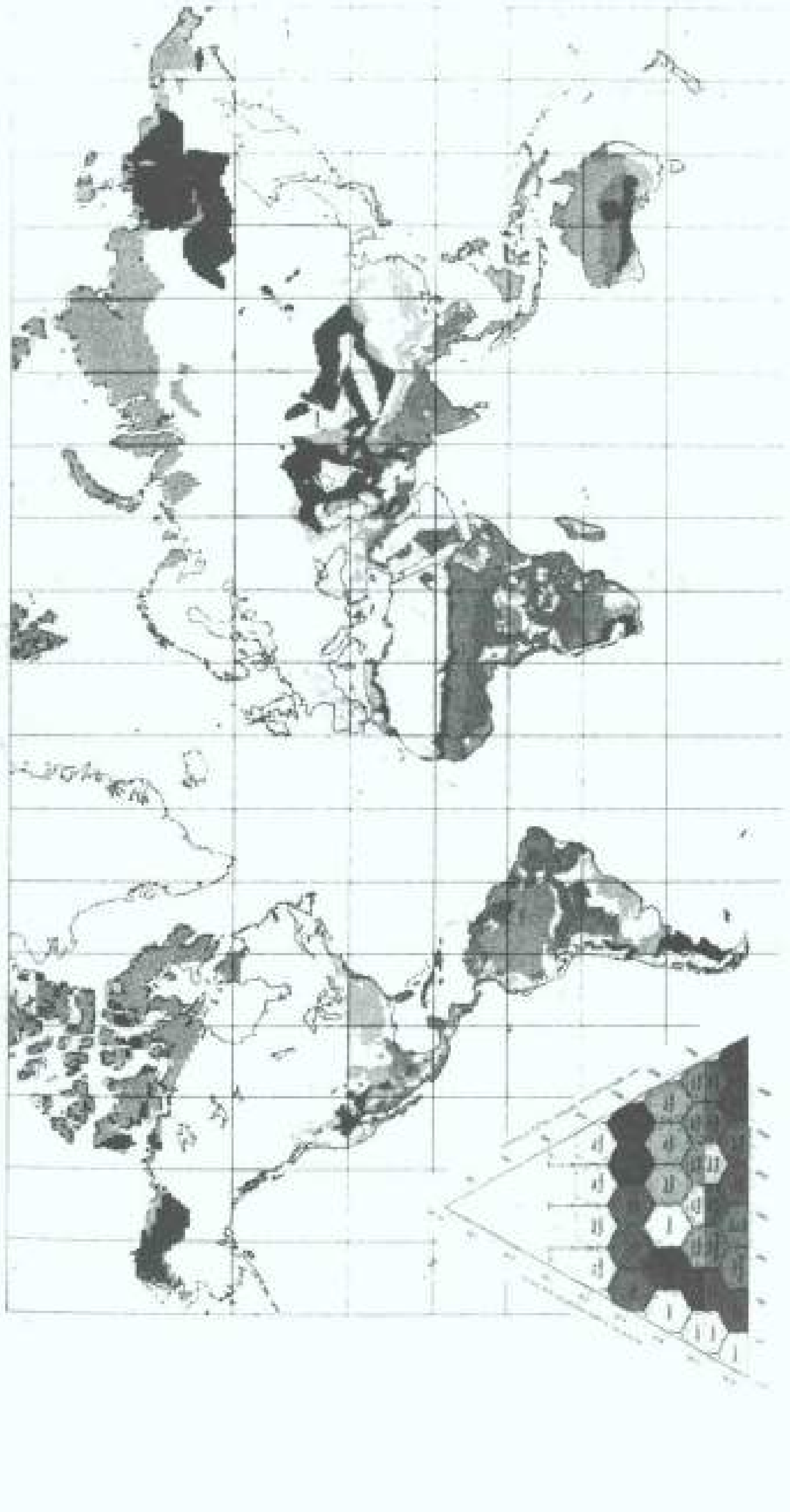
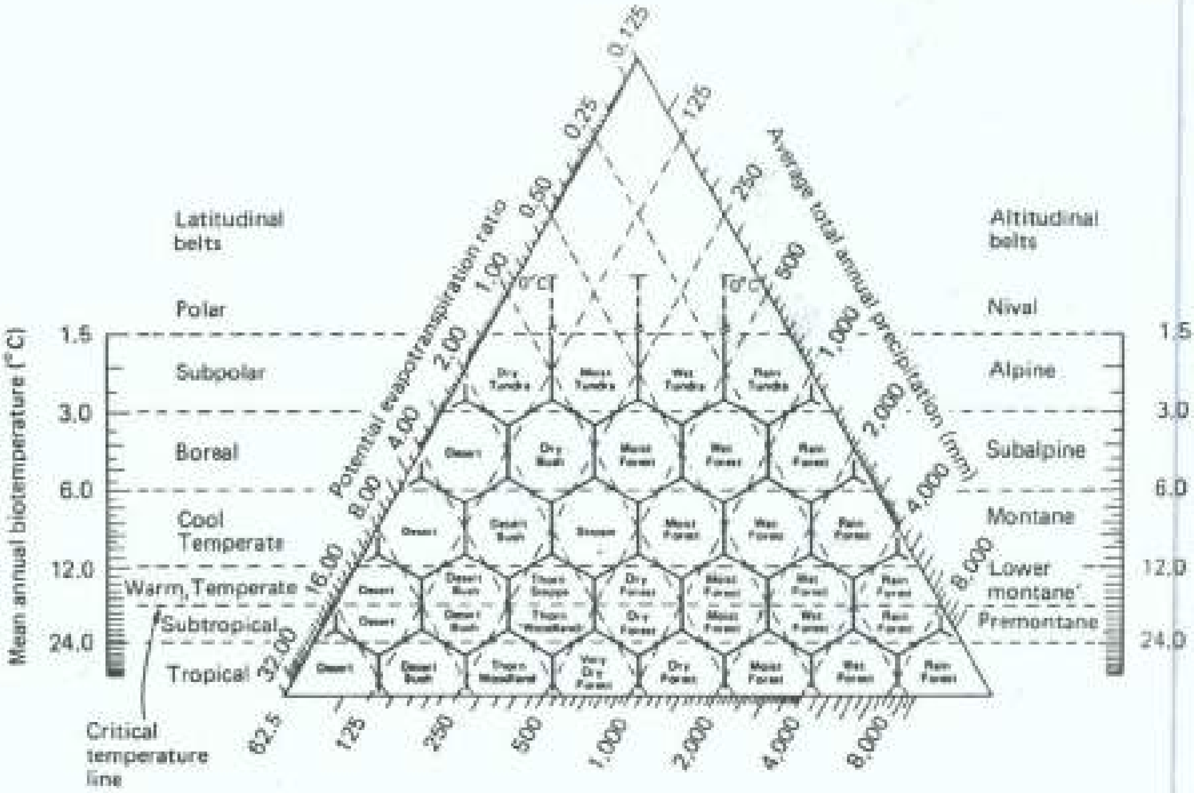


Figure 4.
World map of the Holdridge Classification with the biotemperature increased to reflect climate-simulated elevated atmospheric CO_2 concentration (Emmanuel et al., 1985).



Legend from Figures 3 and 4.

Bruce and Hengeveld (1985), the tree-line in Canada would gradually migrate about 100 km northward, for every Celsius degree of warming. Such a northward shift in vegetation zones would also likely result in the northward relocation of the zone of maximum growth of a given tree species (Maini, 1968a, Figure 5).

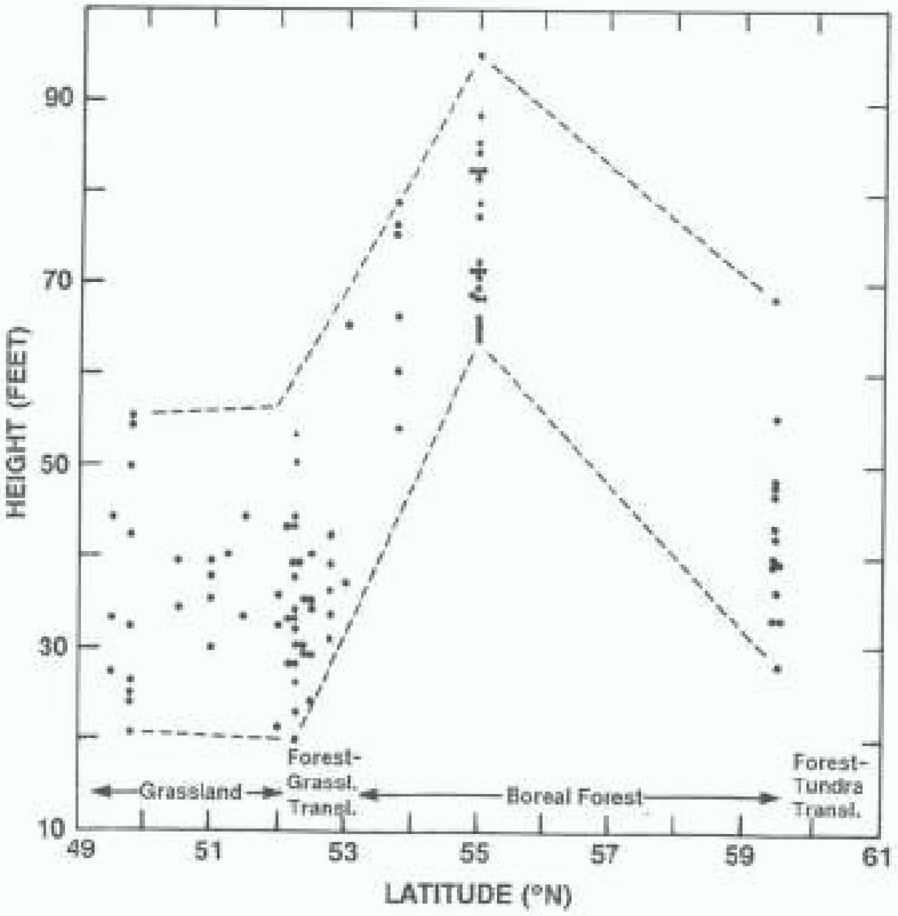


Figure 5.
Influence of a climatic gradient (as related to latitude) on height growth of P. tremuloides in Saskatchewan, Canada (Maini, 1968a).

3.2 Tree Growth

Climate affects tree growth directly. Tree growth may be enhanced by global warming in areas where temperature is now a limiting factor. Studies by Jozsa and Powell (1987) show that climate warming since the end of the little ice-age (ca. 1850) has resulted in higher biomass production in the Canadian boreal forest. According to Kauppi and Posch (1985), climate warming would yield the greatest absolute increase in growth in the warm (i.e., southern) and maritime parts of the boreal forest biome. However, potential beneficial effects of increased temperature may be more than offset by limited soil wetness, as calculated by Manabe and Wetherald (1986). Furthermore, trees growing under warmer temperatures are likely to have a higher rate of respiration (Woodwell, 1987) and possibly lower biomass production. Although Robertson et al. (1988) observed dramatic yield differences in 70-year-old Douglas-fir trees growing on a range of soil moisture regimes in British Columbia, Canada, the wood quality (expressed as average relative density) of these trees did not differ significantly. The growth of various tree species under the anticipated and altered climate regimes is inadequately understood at present.

3.3 Gene/Environmental Interaction

The life span of tree species is generally long, ranging from a few to hundreds of years. Accordingly, compared with annuals, these perennial species have evolved a greater tolerance to a wider range and variability of climatic conditions. Of particular interest is the anticipated rate of change in relation to the past evolutionary experience of trees. Temperature changes during the past 100,000 years have been smaller, both in rate and magnitude than those anticipated for the next 50 to 75 years. In the temperate zone of the middle latitudes particularly, the ability (e.g., hardiness) of individual tree species to survive under the anticipated climatic regimes (temperature, soil wetness, episodic events, etc.) has yet to be assessed. This assessment is particularly crucial in view of the billions of dollars currently being spent on reforestation programs, where the genetic characteristics of seedlings is carefully matched with the current climate of the area being reforested. In the boreal forest, for example, the seedlings being planted today, at a considerable cost, will only attain half their rotation age by the year 2030, and conceivably will be growing under a significantly different climatic regime.

3.4 Species Evolution

Climate change, species migration and exposure to new habitats create conditions for the isolation of species as well as for the evolution of new species (Argus and McNeil, 1974; Brayshaw, 1965; Maini, 1968a; Rasaneu et al., 1987; Salo, 1987). Such gene-environment perturbations associated with atmospheric change would also become an evolutionary force, and over the long term, would likely result in the evolution of new species, varieties and forms.

3.5 Forest Fires

Forest fires, an integral component of many forest ecosystems, are dependent on fuel availability and climate elements such as temperature, humidity and wind velocity. The anticipated increase in temperature and/or in frost-free season is likely to affect the intensity and frequency of forest fires and the consequent impact on economically and ecologically valuable forest land.

3.6 Forest Insects and Diseases

The climate warming would likely affect the activity, abundance and distribution of many insects and diseases. For example, the current cold climate in the northern boreal forest zone is believed to limit the northward extension of some insect species (e.g., the gypsy moth), which would otherwise cover the distribution area of their favoured hosts (deciduous trees). In a warmer climate, one might expect a northward migration of certain insects and diseases. Similarly in the Rocky Mountains area, the altitude and the associated climatic gradient determine the distribution of certain insects (e.g., bark beetles). A warmer climate in the middle latitudes is likely to extend the distribution range of some insects and diseases to higher altitudes.

3.7 Reproduction

One of the symptoms of species under stress is a loss of, or a reduction in, reproductive capacity (Rapport et al., 1985). Perpetuation of species under stress that reproduce by sexual means only (i.e., seeds) are likely to be affected more than those that have an alternate strategy for reproducing by vegetative means (Maini, 1986a, b). Under the anticipated climatic regime, the number and abundance of trees and associated ground-cover species that reproduce vegetatively is likely to increase, at least initially, thereby effecting the structure and composition of the forest types that are shifting spatially.

3.8 Competing Vegetation

While the impact of a CO_2-enriched atmosphere on tree growth is still poorly understood, it has been suggested that the ground vegetation may benefit from the anticipated atmospheric change and thereby compete more strongly with the seedlings of economically desirable species (Wheaton et al., 1988).

3.9 Forest Harvesting

Frozen ground for extended periods permits a longer forest harvesting period in the northern middle latitudes, especially when heavy machinery and equipment is used. Reduced snow cover (Manabe and Wetherald, 1986) and warmer winters would require adjustments in forest harvesting operations and technologies, from both the economic and environmental viewpoints.

3.10 Forest Hydrology

The drainage systems of many rivers around the world are covered by forests (e.g., Amazon, Ob-Irtysh, Congo, Columbia) and the tree cover plays an important role in regulating their water supply. One impact of the anticipated climate change on forest cover is likely to influence the quantity and pattern of the water flow in river systems and consequently the availability of the water supply for industrial and residential use; the altered hydrologic regimes would also influence the forest wildlife habitat.

3.11 Wildlife Habitat

Forests serve as an important habitat for many wildlife species. Under an altered climate regime and forest habitat, many wildlife species are likely to migrate. However, the impact of anticipated climate change on the growth and composition of forests and their associated ground vegetation is likely to influence the composition and population levels of wildlife species in a given area.

4. HUMAN ACTIVITIES AND SOCIO-ECONOMIC IMPLICATIONS

Human activities appear to have played a crucial role in atmospheric change from the point of view of their impact on forests. The emission of "greenhouse gases" is directly attributed to the production and consumption activities of man as well as to the large-scale deforestation during the past 8000 years. The anticipated climate change will not only impact directly on many human activities; it will also have indirect economic, social and environmental consequences through its impact on the composition and distribution of forest resources (e.g., productivity) and biological processes (i.e., reproduction and hardiness), as well as on the water supply, through altered hydrologic regimes, etc. Forest management and utilization, policy formulation and implementation, and research, are considered to be of particular interest in addressing this issue.

4.1 Forest Management and Utilization

Forests are harvested world-wide for a variety of uses, including industrial wood and fuelwood (Shugart et al., 1986). The relationship between man and forests is at least partially dependent on the level of economic development of a given society. Dependence on, and commitment to, maintaining forests usually evolves with economic development from a subsistance economy to a cash economy and then to a market economy, the latter being prevalent in the industrialized countries located in the northern middle latitudes. Consequently, in order to formulate policies and institutional arrangements that would ensure a sustainable flow of economic and other benefits from forests, it is important to understand the wide range of interactions between human activities, atmospheric change and forests within different economic contexts. Heavy financial investments, amounting to billions of dollars, have been, and are being, made in the reforestation, management and harvesting of forests and in the forest-based industries in many parts of the world. Forests are the basis for the economic activities of many communities (Pharand, 1988), countries and regions. Conseqently, qualitative, quantitative and spatial changes in the forest resource base would have far-reaching economic, social and environmental consequences on the human populations that depend on them.

4.2 Policy Formulation and Implementation

In view of the scale and scope of the anticipated atmospheric change, the following two considerations appear to be important in determining policy responses to this issue.

4.2.1 Response to Crisis

Human societies respond to crises by adopting one of at least three strategies: escape, cope or adapt. In the altered climate scenario, those engaged in the forest-based subsistance economy would have the option of employing the "escape" strategy and migrate to other areas, (cf. shifting cultivation in the tropics; "environmental refugees"). However, the formulation of response strategies should be a cause of serious concern to the policy community in governments and industry located in forest regions with a highly developed economy (e.g., the middle latitude, circumpolar boreal belt) and where heavy financial investments in capital infrastructure, forest management and human resources have been, or are, being made. Heavy financial investments, physically "anchored" at specific geographic locations, limit the policy options to coping with (short-term remedial measures) and adapting (long-term harmonization) to the altered climatic regime. Consideration of the lead-time requirement is important in formulating such policy actions.

4.2.2 International Environmental Policy Collaboration

The geographic scale and socio-economic scope of the issue is such that collective action by the global community would be required to address this issue. Determining and implementing international collective action is a particularly challenging task because of the following considerations:

- So far, the discussion of this issue has been largely confined to the national and international scientific communities; the emergence of this issue on the agenda of the international policy community such as at the Reagan-Gorbachev Summit in 1987 (Anonymous, 1988) and of the international opinion-makers, such as the InterAction Council (1988), is fairly recent.
- The environmental community has a limited experience in formulating international environmental policy and policy instruments, and in establishing the associated international institutional arrangements. To date, most of the experience with multinational collaboration on environmental issues is confined to wildlife conservation and, more recently, to the Ozone Convention; there is much to be learned from the past successes and failures of international environment policy initiatives; for example, the way the Law of the Sea Conference issue was managed from scientific and policy perspectives.
- As a global community, we have centuries of experience in international collaboration in military alliances (e.g., NATO, Warsaw Pact) for collective national security, and in trade alliances (e.g., OECD, COMCON, ASEAN) for economic security. Now we seem to be entering an era of environmental alliances for global security. It is interesting to note that it is the extra-institutional bodies such as the Palma Commission, Brandt Commission and the Brundtland Commission that have examined the global implications of various alliances and have formulated alternative visions on disarmament, on north-south dialogue and on environment and development.

Collective global action is required to reduce the emission of greenhouse gases by, for example, influencing the energy policy as well as the production and consumption patterns of individual nations. Furthermore, the proposed initiatives on massive tree planting programs (InterAction Council, 1988) to meet socio-economic and environmental objectives would also serve as a means to fix carbon and support the "modest policies" scenario to somewhat dampen the rate of atmospheric change (Woodwell, 1987).

4.3 Research

Although significant progress has been made during the past 10 years to understand the physical and chemical aspects of the "atmosphere" component of this issue (Fig. 1), there are still many uncertainties and unknowns in our understanding of the response of forests to atmospheric change and its consequent socio-economic and environmental impacts (Pollard, 1987; Wheaton et al., 1987). Nevertheless, there is a need to undertake ingenious studies that would provide glimpses of the likely future responses of the forest and human subsystems to an altered climate regime. Much is to be learned by understanding the interactions and responses of these two interacting subsystems (Wheaton et al., 1987), performing under optimum conditions as well as under stress. Insightful hindsight enhances our foresight capabilities. For example, research along the following lines may yield useful insights and lessons:

- responses of human and biological systems to El-Niño (an extended climatic perturbation that occurs periodically in Latin and Central America)
- responses of biological systems to the chinook in the Rocky Mountains region and to similar phenomena elsewhere
- re-interpretation of the results of the existing range-wide provenance trials* of species from the perspective of atmospheric change in order to determine the likely future gene-environment interactions
- macro-level growth response of trees species along latitudinal (Maini, 1968a) and altitudinal gradients to determine the likely shifts in biological productivity of given regions.

The use of techniques such as risk analysis, risk management (Maini et al., 1985), simulation modelling (Shugart et al., 1986), and the determination of the necessary lead-time required to develop "coping" and "adapting" strategies would permit the formulation of appropriate research programs and policies. For example, annuals with short breeding cycles, commonly used in agricultural crops are likely to evolve and adapt to the changing atmosphere much more rapidly than trees with longer breeding cycles. For agricultural crops, a shorter lead-time, e.g., about five years, is likely to be required to breed commerically valuable varieties to match the altered climate regimes. Most commerically valuable tree species, on the other hand, attain sexual maturity in about 10+ years and have a longer life cycle ("rotation age"); for these species, the lead-time required to develop new varieties may extend to several decades. This poses special challenges to the scientific community to design appropriate research programs, and to the policy community to provide long-term, secure funding to support this research. In view of the uncertainties surrounding this issue, there is a need to formulate robust research programs and policies that would permit a successive series of adaptive refinements.

5. CONCLUSIONS

Atmospheric change is not a new phenomenon. What is unique about the present phase of atmospheric change is the presence of the human factor. Human activities (i.e., production and consumption) have contributed to the increased emission of greenhouse gases that are associated with the anticipated climate change. Interestingly, the Northern Hemisphere, the principal emitter of the "greenhouse gases" is also the principal receptor of feedback from the system, i.e., the impact of atmospheric change is likely to be more pronounced in the middle and northern latitudes.

Heavy investments in the capital plant (machinery and equipment) infrastructure and forest management activities, as well as the significant eco-

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* Provenance trials involve growing the same genetic material under different climatic conditions.

nomic dependence of many communities, nations and regions on forest resources make this issue of profound significance to the national and international policy communities. The anticipated increase in global temperature would ultimately shift the current latitudinal and altitudinal zoning of many forest types (particularly in the middle latitudes) as well as the latitudinal and altitudinal tree-lines; cause ecological perturbations that would likely act as an evolutionary force resulting in new forms, varieties and even species; increase the incidence of fires, insects and diseases; influence growth and biomass production; and require the adaptation of current tree harvesting technologies to the altered climate regime, particularly in middle latitudes. An enriched CO_2 atmosphere may result in greater competition between ground vegetation and seedlings of economically desirable species.

The lead-time required to address new problems associated with forest insects and diseases, forest fires, vegetation competition, and adaptation of harvesting machinery and equipment to the altered climate regime, is likely to be short, i.e., less than 10 years.

Billions of dollars are currently being invested in forest management and forest industries. Tree seedlings planted today in the middle latitudes will only be half their rotation age by the year 2030 and likely growing in an altered climate regime. Robust and flexible strategies are needed to reduce the levels of risk for these massive financial investments. The anticipated atmospheric changes are beyond the recent evolutionary experience of trees and forests. Consequently, a longer lead-time is likely to be required to address the issues involving gene-environment interaction, which determines the growth and the very survival of species.

Collective international action, or an environmental alliance is required to address this issue of global environmental security. The three dynamic sub-systems (Figure 1) of the issue discussed here, operate under different time horizons. Atmospheric change extends over centuries; the investment in forest resources extends over decades (e.g., rotation age of trees); the scientific studies and experiments also extend over several decades; institutional (government departments and industry) planning usually takes 10-15 years; and the political horizon is usually about five years or less. Formulating robust research and policies and harmonizing the different time horizons of the scientific, institutional and policy communities pose serious challenges to both the national and international scientific and policy communities.

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ABSTRACT

FORESTS AND ATMOSPHERIC CHANGE

Forests play significant economic and ecological roles at the local, national, regional and global levels. The socio-economic impact on forest land of anticipated atmospheric change may be examined in terms of changes in growth, net biomass production, and wood quality; gene-environment interaction; speciation; incidence of insects, diseases and fire; reproductive behaviour of trees; and forest harvest technologies. The anticipated atmospheric changes are also likely to influence the ecologic role of forests, for example, as wildlife habitat and as drainage basins of many river systems.

The rate and scale of anticipated atmospheric changes is beyond the recent evolutionary experience of most tree species. Addressing forest management and utilization issues in this context would require an understanding of the likely lead-time needed to address a particular issue. Unlike that for agriculture, the longer life cycle (i.e., rotation age) and longer breeding cycle of many trees would generally require a longer lead-time to formulate strategies that would permit continued utilization of forest lands from both the economic and ecological viewpoints.

Considering the geographic scope, lead-time requirements and uncertainties surrounding the issue, it is important to formulate research programs and policies that are robust (i.e., flexible) and that allow successive, adaptive refinements. Furthermore, coping with, and adapting to anticipated changes at the national and international levels would require collective actions of nations at various spatial and temporal scales. However, unlike international arrangements in defence, and in trade and commerce, there is limited experience in formulating international, environmental policies and their supporting policy instruments and institutions. Harmonizing environmental, scientific, institutional (i.e., industrial, government) and political time horizons poses serious challenges to both the national and international scientific and policy communities.

RÉSUMÉ

LES FORÊTS ET CHANGEMENT ATMOSPHÉRIQUES

Les forêts jouent un important rôle économique et écologique aux échelons local, national, régional et mondial. Pour déterminer les répercussions économiques d'un changement prévu de l'atmosphère sur les forêts, on peut examiner les changements dans la croissance et la production nette de la biomasse; l'interaction des gènes et de l'environnement; l'effet des insectes, des maladies et des incendies; le comportement reproductif; et les techniques de récolte. Les changements atmosphériques prévus influeront aussi sur le rôle écologique des forêts qui constituent par exemple l'habitat de la faune et des bassins de drainage de nombreux réseaux fluviaux.

Par leur vitesse et leur ampleur, les changements atmosphériques prévus seront plus importants que la récente expérience évolutive de la plupart des espèces d'arbres. Dans ce contexte, l'étude des questions de gestion et d'utilisation des forêts exigerait d'avoir conscience du temps qu'il faudrait sans doute pour examiner une question particulière. A l'inverse de l'agriculture, l'allongement de la vie et du cycle de multiplication de nombreux arbres des forêts nécessiterait un temps plus long pour formuler des qui permettraient l'utilisation durable des terrains forestiers. Compte tenu de l'ampleur géographique, des exigences de délais et des incertitudes liées aux questions, il importe de concevoir de solides programmes et politiques de recherche, qui soient souples et qui permettent des améliorations successives et adaptatives. En outre, pour faire face et s'adapter aux changements prévus aux échelons national et international, il faudrait prendre des mesures collectives à diverses échelles spatiales et temporelles. Toutefois, contrairement à notre expérience des ententes internationales relatives au commerce, notre expérience est limitée en ce qui touche la formulation des politiques internationales d'environnement et l'appui de documents et d'établissements de régularisation. Pour harmoniser les perspectives scientifiques, institutionnelles (c'est-à-dire industrielles et gouvernementales) et politiques, les organismes scientifiques et decisionnaires devront relever de grands défis.

IMPLICATIONS OF A CHANGING ATMOSPHERE ON WATER RESOURCES

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1. INTRODUCTION

In a briefing at the end of 1987 a leading world agriculture economist analysed the possible evolution by the year 2000 of the market of agricultural commodities on a global scale, but with a particular focus on developing countries. He mentioned several possible economic alternatives, in general all of them gloomy. None did, however, take into consideration the existing observational evidence and a scientific basis for concern about the change in composition of the global atmosphere. Yet agricultural production, on the one side, and water resources development and management on the other, are obviously among the two most important humanity-sustaining activities that could be affected more by this generally called climatic variation than by commodity markets, which should, however, be taken into consideration in the offsetting of the negative impacts. The two above activities are very much linked, since the simplest way to offset the decrease of food production caused by a change consisting of less rain and more heat is to provide additional water. The latter is, however, necessary not only for agricultural production in regions that might be adversely affected, but also for other human needs, such as the water supply for population and animals, their healthy well-being, and power production both with respect to hydropower and cooling water for other power production facilities. Last but not least, the increase in the frequency of extremes of water availability, whether droughts or floods, will in all climatic regions increase the dangers to the safety of man in any society, regardless of its social and economic conditions.

The attitude of governmental policy-makers toward these problems probably follows the fundamental attitude of any government advanced at a recent high-level seminar on water resources management (Slivitzky, 1986), namely: "(1) water management problems are not different from other government problems; (2) hypothetical issues are not dealt with, because nobody is interested; (3) a certain 'pain threshold' must be reached before a change in the status quo is noted". It is indeed a pity that government decision-makers, economists and political analysts, who want to make projections leading to the year 2000, did not have the opportunity to see the spectacle of the mighty African river, Niger, in the city of Niamey not long ago, at the end of the annual flood flow, when this large river dried up, at least for all practical purposes, and the thirsty inhabitants of the city tried to capture a few drops of water by building make-shift small mud dams in the channels. For the water specialists, the problem is best illustrated by the flow hydrographs (Figure 1). Similar conditions have already prevailed for some time in the basin of Lake Chad (Figure 2). Unfortunately, meteorologists and climatologists have difficulty in providing us with even an approximate forecast of precipitation in the headwaters of the River Niger for the next year not to speak of decades, but even if they could, most statements convey the belief that not much of a permanent nature could be done to offset a change of this size. Yet water projects are formulated and initiated for the next half century and beyond, with an assumption that not much will change with the rivers and the ground water. But is it so? The following is a brief analysis

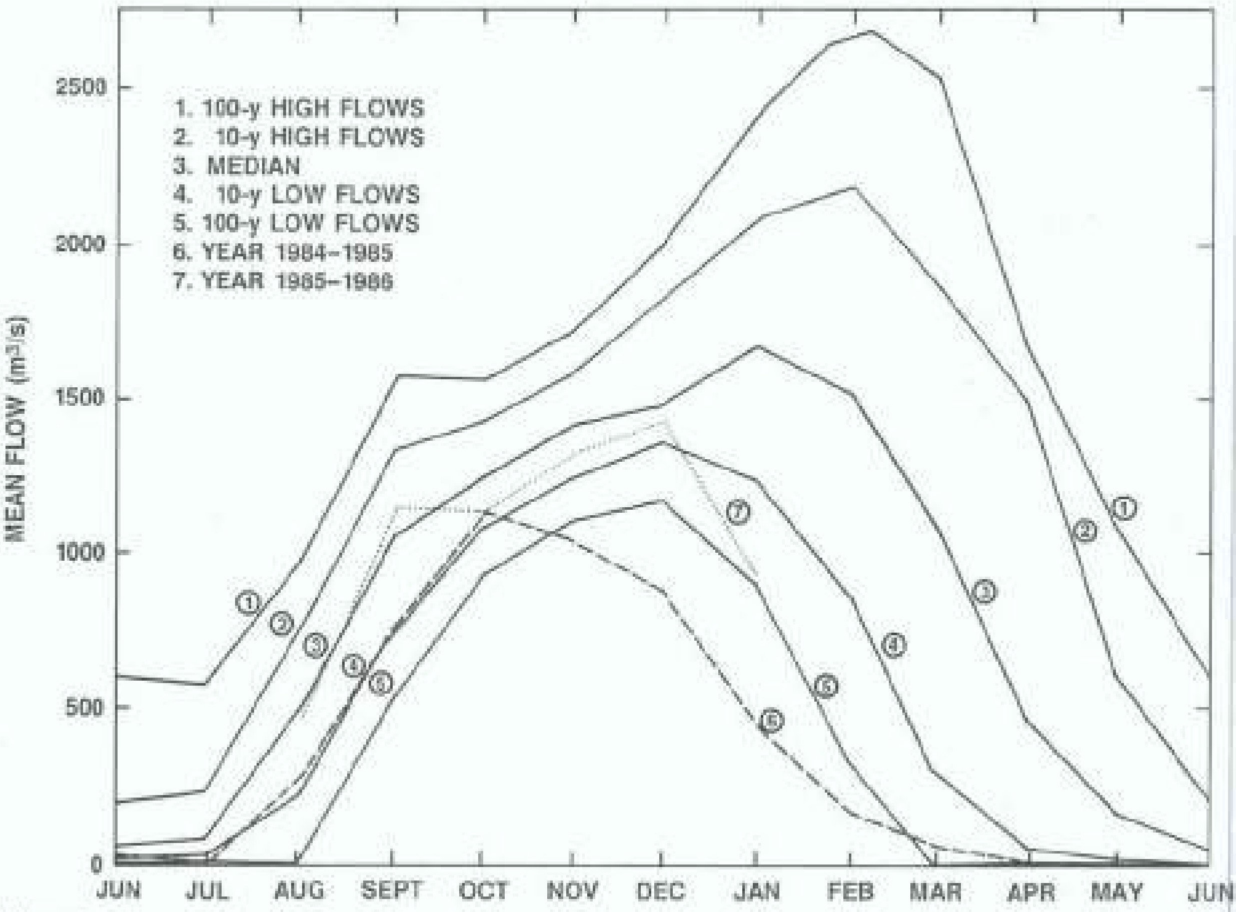

Figure 1.
Mean monthly flows (m3/s) of the Niger River at Niamey for different extremes and years compared with the median flow.

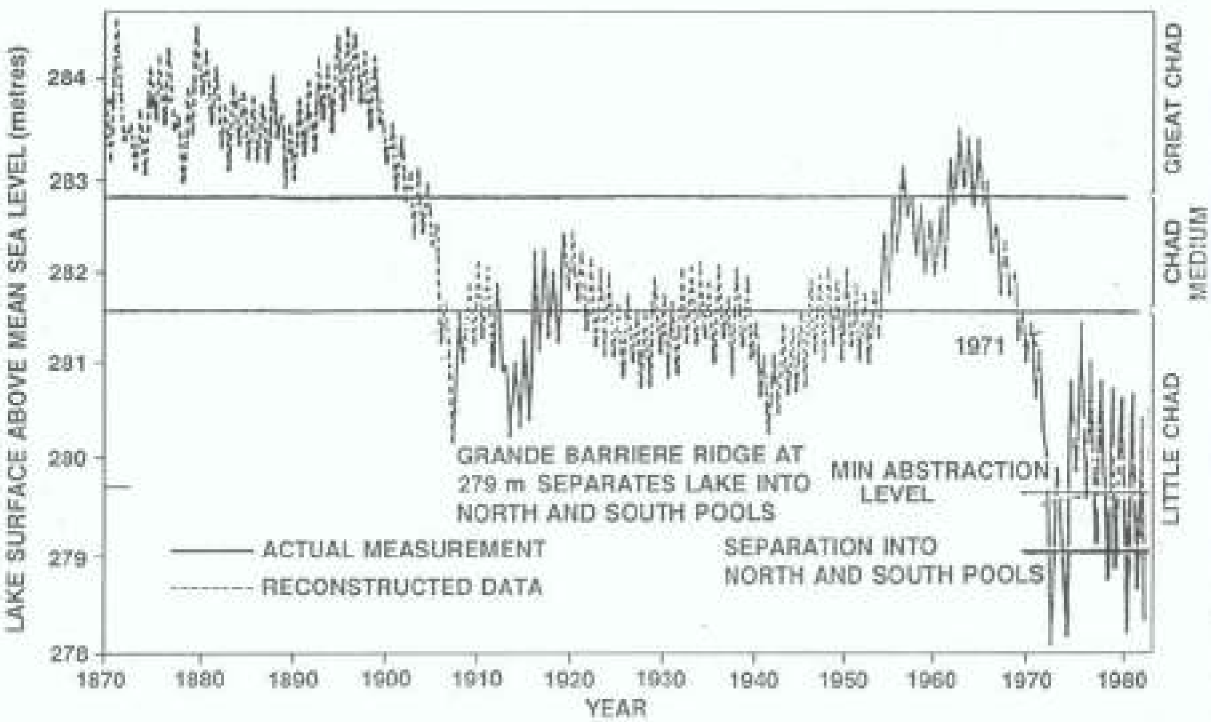

Figure 2.
Lake Chad water level record since 1870. The 1971 level was used by irrigation project consultants to make predictions. Since then the water level has dropped drastically.

of the problem of atmospheric change for regions in which this change may provoke an adverse change in the quantity and quality of water and includes an attempt to answer the above question.

2. WHERE?

Regarding predictions about the changing atmosphere, climatologists have concentrated their attention on the global means of the climate variables, and this mainly because they have little other choice. The CO_2 effect involves, in particular, changes in global mean temperature. This change will necessarily be accompanied by changes in all the climate variables, of which precipitation and evaporation are the most important for a realistic evaluation of the climate sensitivity of water resources systems. But for this latter purpose, regional and larger scale details of the future changes are needed. The capability of today's science for predicting these details is limited. The most frequent method here is to resort to the use of scenarios. Nevertheless, thanks to the particular property of the runoff component of the hydrological cycle balance, because runoff is a residual of two normally larger variables, precipitation and evaporation, it is obvious that the impact of the changes will be largest wherever this balance is already precarious under present circumstances with respect to the lower limit of the runoff variable, namely, where it presents a frequent deficit. Such areas are identifiable and, unfortunately, in many cases are located in developing countries. For such areas we can work with scenarios of the future changes.

These scenarios are not established by imagination alone; they are based on sound scientific facts as indicated by a recent meeting on water resources sensitivity to climate change (WMO, 1988). Thus they are not a hypothesis but have their probability set similarly to floods, for which prevention is readily funded.

3. HOW MUCH QUANTITATIVE CHANGE?

At this point a distinction must be made between runoff as an element of the hydrological system and water resources. Indeed, runoff availability does not make water automatically a resource. For water to be a resource, it must be at the time and place required, in a suitable quantity and quality. Thus the relevant hydrological element - surface and ground-water yield - is assessed by inputs of the meteorological variables. The availability of water is only one input in the water resources system, of which a good additional part is structural man-made conveyance and storage subsystems. Storage and conveyance of water in rivers or aquifers represent water economy variables, they influence useful water yield, flood and drought disaster risk and have secondary impacts, such as water pollution, which depends on the dilution, thus on the discharge. This relationship is represented in Figure 3. In a study of the sensitivity of the water resources system to a changing atmosphere, the input is the hydrological cycle, in addition to other parameters characteristic of the region or basin. This concept has its parallel in present studies of potential water availability for irrigation (FAO, 1987). In the latter case, for example, if there are no soils suitable for irrigation, an increase or decrease in available water for irrigation will be of little importance. This difference between the runoff as part of the hydrological cycle in a basin and the water resource to be used for an economic activity is of considerable importance in the choice of scenario for simulat-

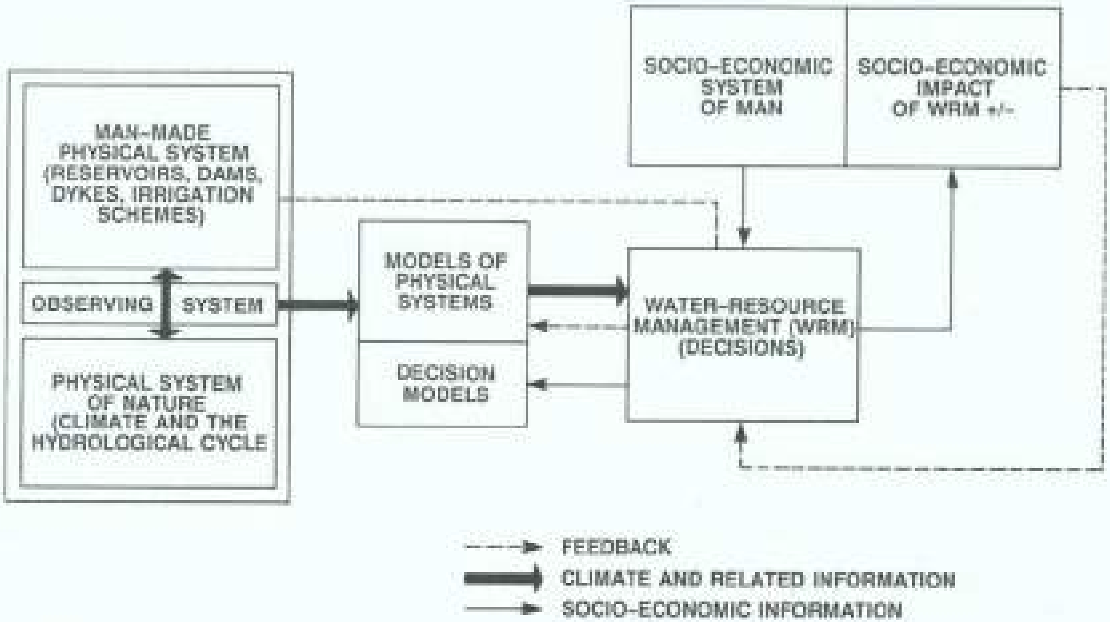

Figure 3.
Flow diagram to illustrate components in the decision-making process for water resource management.

ing the climate change impact on the hydrological cycle and on water resources. The second choice that is to be made is that of the transfer functions (models) from climate variables to hydrological ones and from the latter to water resource characteristics or water economy indices. With these boundary conditions in mind, an a priori argument was raised, at least at the time when this author started his work on this problem (Nemec and Schaake, 1982). As recalled by Glantz and Wigley (1987), it had been then and still later suggested that, in the framework of the lifetime of a water resources system, climatic change can be ignored in planning, because anticipated long-term changes in mean runoff are much less important than the intra- and interannual fluctuations that occur today and with which the water resource systems are designed to cope. However, the change of the mean is only one aspect of the climatic change problem. Climate change brings a change in variability, in frequency of extremes - floods and droughts - and in seasonality of runoff. Thus the impact of future climatic change may exceed by far any fluctuations that are occurring now or have occurred in the past and they may have important cumulative effects, for example, on storage systems, and on reservoirs of surface and groundwater, particularly if their present capacity is approaching the limits of their use. In this author's study, which was one of the very initial ones, it was ascertained that the reduction of rainfall volume by 25% produces a decrease of runoff in the dry temperate basin by about 80%, in the wet temperate basin by 60% and in the wet tropical basin by 70%. It was further ascertained that for a reduction of 25% of the rainfall in the dry basin, the yield from the storage could be maintained only by increasing the storage opportunity by 400%, which in most cases is a most difficult, if not an impossible proposition. The above results are best illustrated by Figures 4 and 5. The same methodology used by the author has since been used by several other researchers. An interesting result was obtained in Australia by Fitzgerald and Walsh (1987) who applied the same methodology. A decrease in rainfall by 20% and an increase of evapotranspiration by 15% resulted in the reduction of the irrigated area by 75%, as illustrated in Figure 6. These results are quite consistent with those obtained by

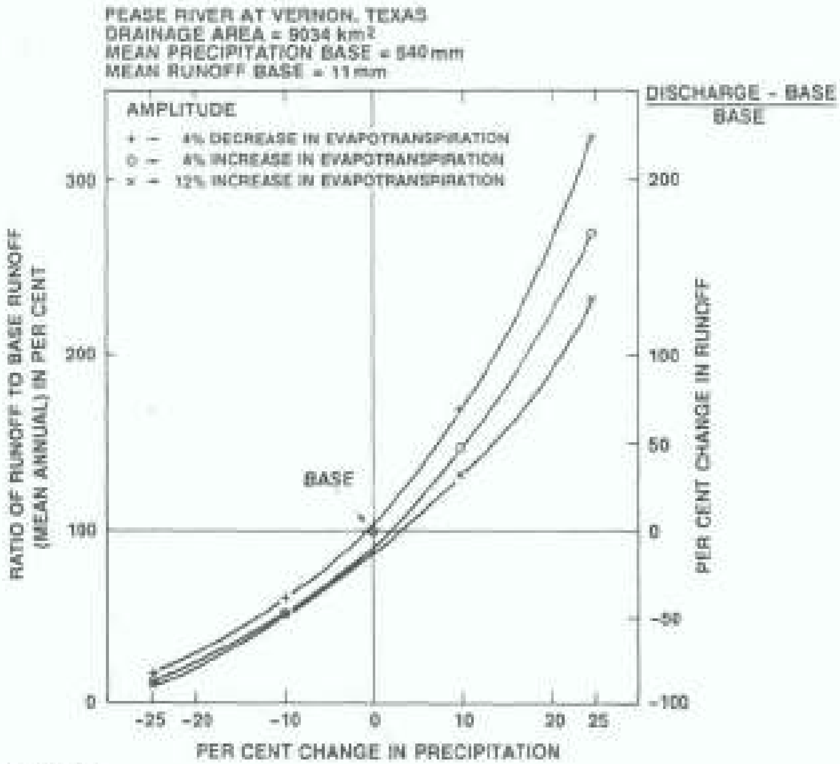

Figure 4.
Percentage change in runoff of the Pease River at Vernon, Texas, as a function of the percentage change in precipitation for three different changes in evapotranspiration.

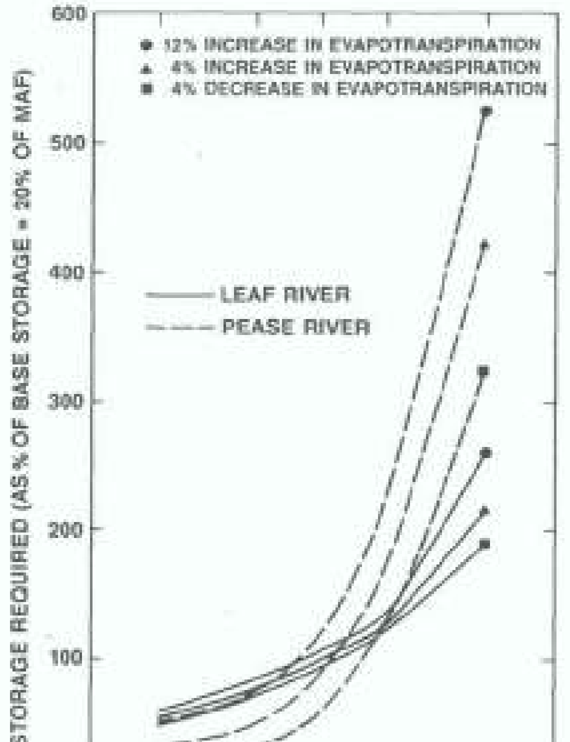

Figure 5.
Store requirements to maintain yield as a function of a change in precipitation at two temperate basins (Pease River, dry; Leaf River, wet) for three different changes in evapotranspiration.

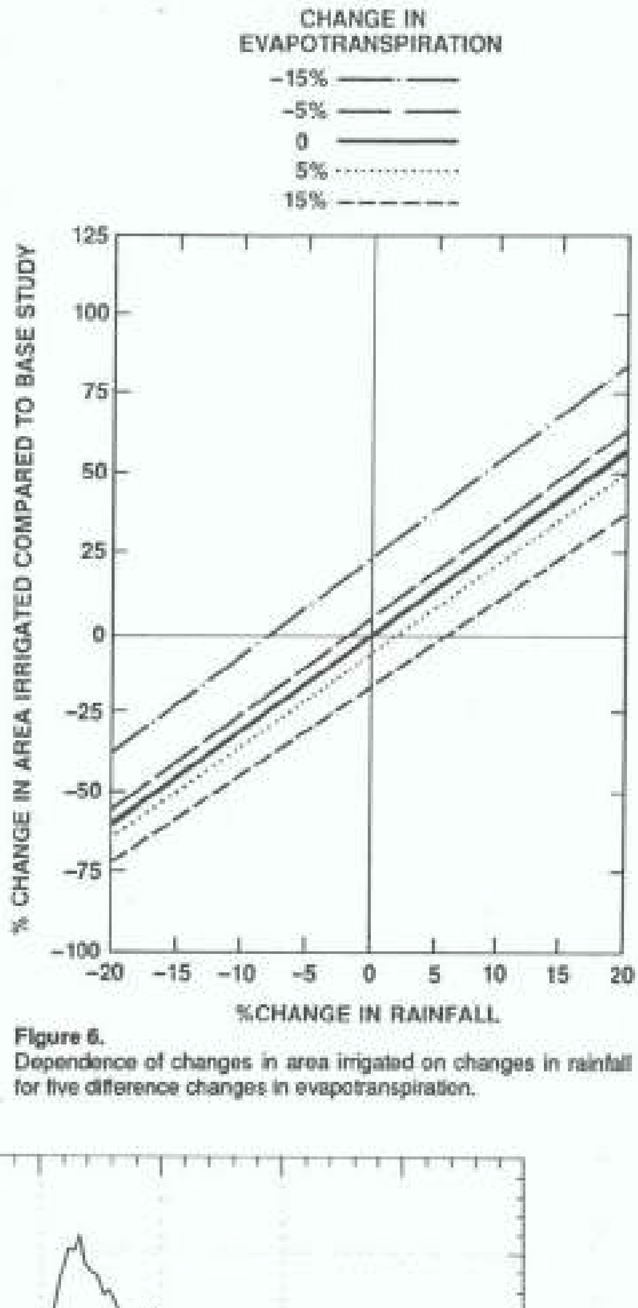

Figure 6.
Dependence of changes in area irrigated on changes in rainfall for five difference changes in evapotranspiration.

Figure 7.
Cumulated flow of the Nile to Lake Nasser at Aswan, Egypt, in billions of cubic metres. Reservoir extremes and losses are also indicated.

the author of this paper. The conclusion of Fitzgerald and Walsh is that the changing composition of the atmosphere "has the potential to significantly alter the balance between water supplies and water needs in the major irrigation valleys of New South Wales and eastern Australia generally". This view is corroborated by some observational evidence or its extrapolation particularly to the conditions for large rivers in Africa. One example is that of the High Aswan Dam in Egypt. The cumulated flow profile of the Nile's inflow to Lake Nasser together with the reservoir's storage parameters is illustrated in Figure 7. The reservoir was actually built in 1970, and thus it never spilled water, but would have done so in the period from 1887 to 1915. From 1912 to the early 1960s the Blue Nile, flowing from Ethiopia and joining the White Nile, originating from Lake Victoria, brought on average 52 billion cubic metres of water yearly to the confluence of the two Niles at Khartoum, while over the same period the White Nile provided 26 billion yearly. It should be noted that while the Blue Nile discharges represent for Lake Nasser the replenishment needed during the flood period from July to November, the White Nile discharges provide a rather steady flow over the year and sustain the river during the dry period, which is important for the Egyptian growing season in spring and summer. According to a recent study provided to the Government of Egypt by a British consulting company, the recent droughts that struck in Ethiopia reduced the contribution of the Blue Nile to Lake Nasser by 1986 to 47 billion cubic metres a year, but the increase of inflow from the White Nile to 34 million cubic metres a year compensated for the decrease of the Blue Nile. The existing forecasts of some of the Global Atmospheric Circulation Models indicate indeed that the climate change resulting from the CO_2-generated warming should increase the rainfall in the equatorial belt and decrease it in the Sahelian regions. But the compensatory flow of the White Nile has now stopped, since Lake Victoria levels have fallen and Lake Nasser is approaching its lowest levels ever, thus presenting a potential danger of a lack of water for the irrigated agriculture and even for the power supply of Egypt, whose population is rapidly increasing annually beyond the present 50 million. The British consultants consider that the Blue Nile decrease and the White Nile increase inflow were a random coincidence. In the views of this author, the substantiation of this is probably not very easy. In any case, the recent decline of the White Nile flow and of the Lake Victoria water level is difficult to explain by the rain regime over the basin only. The fact, however, is that the modelling of the behaviour of storage systems in a changing climate could be corroborated by the actual behaviour of large storage systems throughout the world, and this may be an important task for further studies. The potential danger is so large that the cost of the studies should hardly be considered in this context. These studies, however, should not and indeed do not only deal with storage.

4. WATER FOR FOOD

As accepted in some of the scenarios mentioned above, climate change will provoke latitudinal shifts of water availability for many purposes, but primarily for the irrigation of crops. In 1961 the global irrigated area was about 137 Mha (Higgins et al., 1988). Today, there are about 219.7 Mha of irrigated lands in the world of which 91% are in thirty countries, as shown in Figure 8. The predominant lands are in Asia, and nearly two thirds are in developing countries. In Asia, 30% of the farms are irrigated; in Africa, the relative share of irrigation is less than 2%, although the country with the greatest dependence on irrigation is Egypt, which is geographically situated in Africa.

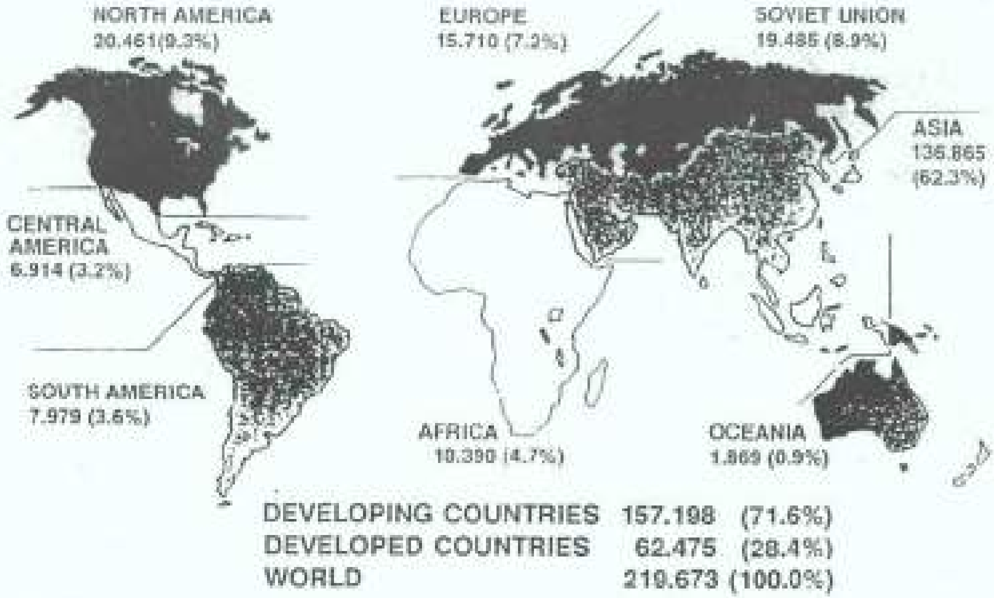

Figure 8.
Irrigated areas within various geographical regions expressed in millions of hectares and as a percentage of the world total.

The rate of expansion of irrigation has varied with time. It peaked in early 1970 and is decreasing now, because of some relaxation, if only temporary, in the additional supply of agricultural products. In these circumstances, it is probable that future investments in irrigation, particularly in developing countries, will be more sharply directed toward countries in need: those whose food supply deficits seem to be the most persistent.

The problem of climate change is therefore formulated slightly differently for the quest of water resources for irrigation: which are the countries whose food supply deficits seem to be persistent and how much climate change will alter today's picture, so that a forecast may be made to identify the highest priority countries that may have to search for irrigation water?

5. HOW MUCH CHANGE IN WATER QUALITY?

As pointed out by Bruce (1987), the term "water quality" is often thought to refer to the chemical and biological pollutants in water arising from man's activities near or far away from the water bodies. The quality of lakes, however, influencing their productivity, usefulness and harmfulness is dependent on their temperature, sediments and turbidity and penetration of light, which influence aquatic ecosystems. The transfer of energy to water bodies depends ultimately on the atmosphere. Thus any change in the energy transfer through the atmosphere may influence them, often negatively, by destroying the precarious ecological balance of the water bodies of rivers and lakes. The degradation of the soils by climatic factors causing all types of erosion is a further link between atmospheric change and the quality of water associated with sediments. According to an FAO survey in 1977, 46% of the total degradation of the earth's surface is due to different hazards related to water, of which almost 30% are due to erosion.

The temperature of the atmosphere and thus of the water is, however, also influencing the health of the population, particularly in developing countries, where the problem of drinking water and sanitation is precarious to the extent that the United Nations declared an International Drinking Water Supply and Sanitation Decade. Its goal, "the provision of adequate access to safe drinking water and sanitation for all the world's population by 1990", is today considered (Rangeley, 1986) unrealistic, since the starting point was largely overestimated. In West Africa today only about 5% of the population have sewer connections, and in the urban communities of the entire developing world only 75% of the population have access to an adequate water supply. Under these conditions a change of atmospheric temperature with its consequent impact on water bodies may result in the additional deterioration of health in the developing countries caused by water-borne diseases, since water is the principal transmission agent for 80% of all diseases in these countries. The most common of such diseases are trachome, malaria (with 800 million infections per year), schistosomiasis, elephantiasis, typhoid, cholera, infectious hepatitis, leprosy, yellow fever and perhaps worst of all, diarrhoea, since an estimated 1000 children die every hour from diarrhoeal diseases in these countries. The abundance of insects that bear disease has been shown to be closely associated with the weather and water conditions occurring in the preceding months. The distribution of schistosomiasis is clearly delineated by the mean water temperature. Similarly, yellow fever, transmitted by mosquitoes, is highly dependent on water temperature.

A change in the atmosphere is, however, not only marked by an increase in temperature and subsequent changes in the physical components of the hydrological cycle: precipitation, evaporation and runoff. The long-range transport of airborne pollutants and their deposition in water bodies are now well recognized as having serious environmental consequences not only in Europe and North America, but also in other regions of the world. While this phenomenon is known under the general term "acid rain", the pollutants, in addition to SO_2 and NO_x, comprise oxidants, heavy metals, synthetic organic compounds and other toxic substances. Thus the correct term should be "toxic rain" (Bruce, 1987). Well known is the situation in North America and the problems resulting between the good neighbours, the United States and Canada. Equally well known is the problem in Scandinavian and Central European countries, which has generated the Long-Range Transport of Air Pollutants (LRTAP) programme of the UN Economic Commission for Europe, leading to the Helsinki Protocol in 1985 to reduce SO_2 emissions by 30% in seven years. Less known is the situation in China, where acid-causing emissions already amount to 12 million tons a year, and are expected to reach 18 million tons a year by the turn of the century - as much as the emissions from all the European Economic Community countries. In India, SO_2 emissions tripled between the early 1960s and 1979 and there is serious concern for the future of the Taj Mahal, which is downwind of a major oil refinery. Japanese concern has focused on several events in which eye and skin irritations were inflicted on people exposed to acid drizzle. UNEP, through its Special Committee on Problems of the Environment, has launched a more comprehensive review of acid rain occurring outside Europe and North America.

Of increasing concern in recent years is the potential effect of acid rain on human health through the increased mobility of toxic metals (aluminium, mercury, cadmium, lead and copper) from soils, sediments and pipe systems, while the pH of the water supplies decline. Aluminium in water supplies has been tentatively linked to Alzheimer's disease, and it is recognized to have adverse effects on dialysis patients. Increased aluminium in acidified surface waters is a major contributing factor to fish decline.

Alkalinity has been declining, and acidity in water supply reservoirs and groundwater has been demonstrated to be increasing in the northeastern United States, Ontario and Scandinavia.

6. THE INTERFACE OF SALT AND FRESH WATER

The fact that the change in air temperature may result in the melting of the polar ice, thus provoking a "rapid rise" in sea-level of the order of 1-2 metres could cause very serious problems for those human activities and settlements located in the low-lying coastal areas affected by the rise. In addition, the adjacent areas with low elevations will experience impacts that may be quite severe on their hydrological and other environmental conditions (Volker, 1988). They will consist of impacts on the flood protection of low-lying coastal regions, such as deltaic areas, coastal marshes and embayments. These are threatened not only by floods, both from the rivers and the sea, but also by the intrusion of seawater into surface water and groundwater. Furthermore, these impacts will have consequences on land subsidence caused by natural and man-induced effects.

The socio-economic consequences could be particularly important in developing countries dependent on agricultural production. For example, the mangrove belt along the coasts of most tropical deltas will deteriorate or even disappear. Furthermore, since the protection that this belt provides to the populations during storm surges, such as in Bangladesh, where it extends over some 12,000 square kilometres, will not exist, this may result in large losses of human life, particularly during tropical cyclone-related surges. The necessary elevation of coastal protection works (dykes) would require enormous investments, for which funding will obviously not become immediately available. The effect of sea-water intrusion on surface water and groundwater is well known even at present. Needless to say, this effect would be considerably increased with consequences not only for water supplies but also for irrigation and drainage. In general, all of the coastal water management systems for agricultural purposes, as well as the reservoirs, would have to be adapted to the new sea levels. It should be noted that a reasonable simulation of the effect already exists in many estuaries and harbours. Thus in the Rotterdam Waterway, which allows access to the port of Rotterdam, the effect of saline intrusion moved over 35 km in some 60 years, as a result of deepening the channel by dredging. While most of these adverse effects have their technical solutions, the level of funding of the relevant investments would probably be prohibitive for many countries, the developing ones in particular.

7. IN QUEST OF WATER WITH A CHANGING ATMOSPHERE: CAN WATER BE TRANSFERRED BY RIVER OR CANAL DIVERSIONS ON A CONTINENTAL SCALE?

It was indicated above that climate change may render irrigated agriculture difficult or impossible in areas of precarious water balance. The studies made in Canada and the United States provide some answers to the question whether the water scarcity caused by a change in climate can be offset by large-scale interbasin transfers and continental water resource redistribution. The recent developments in the USSR with respect to such proposals also indicate that even in countries where the decision-making process is in general not encumbered by procedures inherent in capitalist economic and democratic political systems, a decision involving a major incision in the living body of the land and in the atmospheric phase of the hydrological cycle is not easy because of the risk of negative consequences. In Canada there are at least six proposals for interbasin transfers of water for power purposes and more than six proposals for schemes for redistributing continental water resources (Clark, pers. commun., 1986). Of these, mainly the use of diversions into the Great Lakes is considered as a viable solution, with many caveats and assumptions, such as "it should be done only where this is necessary and economic and can be demonstrated to be environmentally and ecologically acceptable". A similar experience can be cited in connection with the above-mentioned decreasing flow of the River Nile into the High Aswan Dam. The opportunity to water flow by constructing the Jonglei Canal, which should increase the yearly inflow of water by some 3.8 billion cubic metres, the amount that the canal should save from evaporation in the Sadd swamps, has been wrecked in the middle of its construction by many difficulties. A technically viable solution to store water in the African equatorial lakes is still subject to political problems, of which the solution may not be possible even on the time-scale of the "greenhouse effect". Whereas changes in the timing and regional distribution of the flow in streams are well within the capacities of the engineer, and man-made reservoirs or artificial control systems in natural lakes have been used by engineers for several millenia, moving the water from a region of "surplus" to another of "greater need" creates serious tensions and conflict. The first, and obviously more acceptable step in offsetting a water shortage, particularly for agricultural purposes, is to encourage local re-allocation of available supplies, more efficient water use, which in irrigation on a world-wide scale apparently does not average more than 40%, and reduction of pollution. We agree with Clark (1987) that these steps are to be preferred to entertaining prohibitively expensive proposals for increasing the water supply through large interbasin diversions that would likely have, as indicated in the USSR, irreversible, detrimental effects on the environment. In any case, a scientifically based forecast of a scenario in climate change and the available water resources resulting from it would allow decisions about the above problem to be made more easily and safely.

8. WHAT NEXT?

The view is prevailing in the water specialists' community, which is aware of the possible impact of climate change on water resources, that the need to bring their concern to a larger circle of managers and decision-makers responsible for water-related economic activities (often called the water industry) is an absolute top priority. Thus, once the realization of the problem takes root in these circles, it is obvious that future activities would have to be directed towards the need of the user and may vary with the requirements of different types of water resource management and development systems.

To be able to satisfy these needs, scientists and water resource specialists will have to be ready to answer two questions (WMO, 1988):

i) What specific aspects of climate change are most relevant to specific water resource systems?

ii) What problems can be solved on the basis of present knowledge?

There is no doubt that the international scientific community, involved in the studies of the impact of climate change on economic activities and society, has made considerable progress in assessment and projections; the question, however, remains as to what extent the results of these studies are sufficiently accepted by decision-makers as trustworthy, particularly in developing countries. It is the opinion of this author that agricultural practices and water resource management are two aspects of the life-sustaining activities in the developing countries of the world, as indicated in this paper, which may be substantially altered by a changing atmosphere.

What is the role of international organizations such as FAO? In the view of this author it is to try to bring the possible consequences to the attention of those decision-makers in its member states in order to stimulate their awareness and obtain the reaction needed for a preparedness commensurate with the risk at hand. Senator Chaffee of the US Senate summarized the problem very concisely:

> "We lose so very little by trying, we may lose everything by doing nothing."

As a scientist and international civil servant, this author believes that for the developing countries this very terse statement is even more valid and could be paraphrased as follows: <u>The risk is too large not to look for possible alternatives and means of mitigation, even if the search is based on predictions with a large margin of error. Forecasting is a dangerous game. Blind and passive waiting for a possible disaster is even more dangerous</u>.

Recommendations for actual mitigating actions should follow a responsible, objective and realistic evaluation of each region or country involved. This is the point where the international community starts to become involved and that is why international organizations, such as FAO, get ready to give assistance, if this is requested and needed.

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ABSTRACT

IMPLICATIONS OF A CHANGING ATMOSPHERE ON WATER RESOURCES

The most immediate impact of a possible change in climate on society - a changing atmosphere - is considered to occur through changes in food production. It is proposed that in some respects the impact on the availability and demand of water resources is of an equal, if not a greater, importance. The analysis of the impact on availability starts with the investigation of changes in the hydrological parameters, in particular, average yield and the frequency distribution of extremes during both droughts and floods.

The most vulnerable societies are no doubt those that exist in areas with small excess rainfall and those that are sustained by man-made water resource systems. Examples of such cases are presented and discussed.

The needs of applied and basic research in both of the above directions are analysed and tentative priorities are assessed. The role of the international community is discussed.

RÉSUMÉ

RÉPERCUSSIONS DE L'ÉVOLUTION DE L'ATMOSPHÈRE SUR LES RESSOURCES EN EAU

On estime qu'une éventuelle modification du climat aurait, comme première conséquence immédiate pour la société, une modification de la production alimentaire. On suggère qu'à certains égards, l'incidence sur la disponibilité des ressources en eau et sur la demande de ces ressources sera tout aussi importante, sinon plus; l'analyse commence par l'étude des variations des paramètres hydrologiques, en particulier par l'étude du rendement moyen et de la distribution de fréquence des extrêmes, à la fois durant les périodes de sécheresse et les périodes d'inondation.

Sans aucun doute, les sociétés les plus vulnérables sont celles qui vivent dans des secteurs situés à la limite d'un équilibre hydrologique naturel vis-à-vis du régime pluviométrique, et celles dont l'existence dépend d'un réseau artificiel de ressources en eau. On expose et détaille des exemples de tels cas.

On évalue les besoins en matière de recherche fondamentale et appliquée dans les deux situations susmentionnées, ainsi que les priorités établies provisoirement. On commente le rôle de la communauté internationale.

NATURAL DISASTERS AND THE HUMAN COSTS IN URBAN AREAS OF LATIN AMERICA

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1. INTRODUCTION

Throughout history, earthquakes, floods, landslides, avalanches, droughts, "huaicos" and hurricanes have had a devastating impact on the lives, economic activities and social development of many Latin American nations. This is especially so in cities and other settlements of all kinds and sizes where people and activities are highly concentrated. Generally it is the lower income groups who have been the worst hit by natural disasters. Each time a disaster is recorded in the newspapers, most of those who have had to be evacuated and lodged in transitory shelters and who have had to be fed and nursed are the lower income groups. In different ways such situations reflect the very large and growing numbers of urban poor in Latin America but also the high risk areas where many are forced to live as a result of their poverty and lack of other alternatives. What this paper will outline is how poorer groups living in urban areas often have no alternative but to live and work in areas subject to floods, earthquakes, landslides or other natural disasters, and how societies have done little or nothing to lessen their dangers or to offer them safer alternatives.

A natural disaster brings to the surface the poverty that frames the daily life of many. After counting the dead and moving the injured, the evaluation of the impact of a disaster reveals the vulnerability of the lives of thousands or millions of households. Take the case of those who had organized the construction of their own housing in squatter settlements or illegal subdivisions, which remains the most common way in which lower income groups acquire houses of their own in most Latin American cities. They have lost their homes and belongings because the design and technology used in constructing their houses cannot resist an earth tremor or because the site where the people built their shelters was flooded or destroyed by a landslide. They lose their source of income because after being moved to a different (and safer) place, usually under the direction of some public or international agency, the new location is too distant from their jobs or from the location where they earned their income. They lose most or all of their "capital"; the physical improvements they introduced in their houses and in the infrastructure within their settlement by their savings and work, such as improvements in the water system or in the collection of garbage, a nursery, a health centre or sidewalks are also destroyed. And in some cases, they are forced to move to a new site where the social networks of the past (family, friends and contacts important to finding paid work) are lost. Once again they have to start to build shelters on their own, and acquire some furniture and clothing. There seems to be no end to these individual and collective tragedies whose number continually increases.

Until five or six decades ago, the population of a Latin American city was still small, distances were short and most people could live within the original site of each city, presumably on safe ground. As cities began to grow many poor groups were pushed to their peripheries giving place to spontaneous developments. Inevitably, these people invaded lands that were unsafe. These were the only land sites close to the cities where they had some chance of avoiding eviction, because the dangers of (for instance) floods or landslides made the site ill suited to commercial development. At that time, their difficulties in getting to and from their places of work could only be overcome by living close by since public transportation was poor. The need to be close to employment outweighed the dangers inherent in the sites selected. Thus began, many decades ago, the massive use of sites on the hills in Rio de Janeiro, La Paz, Caracas and Quito, the swamps of Guayaquil, the areas subject to floods in Asunción, Santa Cruz, Buenos Aires and Santa Fe. Meanwhile, the western coast of Latin America and some areas in the interior, threatened by periodic earthquakes - where Mexico City, Gautemala City, San Salvador, Managua, Quito, Trujillo, Lima, Santiago and many more cities are located - continue concentrating increasing numbers of people and services and productive investments.

To understand the reason why so many contemporary Latin American cities are situated in locations where a high proportion of their population live on dangerous sites, one needs to examine why these sites were originally chosen. The present settlement pattern in each Latin American nation has colonial origins. Most of today's capital cities and cities with over 500,000 inhabitants were founded by the Spaniards and Portuguese during the sixteenth century in territories occupied by indigenous civilizations and, occasionally, as in Brazil, Uruguay and the River Plate basin, in areas where the impact of prehispanic cultures on the landscape was weakest or almost invisible. For political, strategic and economic reasons the Spaniards selected for their early foundations the sites of existing cities and smaller settlements and areas with higher population densities.

Indigenous civilizations had a great deal of experience about the ecological advantages and disadvantages of different locations for constructing their cities, which they balanced with the defensive, commercial and productive conveniences of different sites. The constant floods that threatened the capital of the Aztecs, Tenochtitlan, which they tried to control with a dam and irrigation channels, was not enough to persuade the Aztec kings to move the city to a different location.[1] Terraces were built in the environs of many settlements - large and small - in the Andean cultural area, to enhance agricultural production but also to control erosion. They carefully avoided the use of good agricultural lands or lands that could be more easily irrigated, for the construction of large as well as small settlements. Most cities on the coast of Peru were built in sites safe from the dangerous "huaicos", which have become in recent decades a permanent threat to human lives and expensive infrastructure investments.

The sites of many early colonial foundations were selected with haste. Although Spanish conquerors received rather general royal instructions to select safe locations for their foundations, the immensity and diversity of the space they were conquering forced them to make frequent erroneous decisions. Many settlements destroyed by landslides, earthquakes and floods were relocated one, two or even more times.[2] The history of Guatemala City is revealing. Originally founded in 1524 over an indigenous settlement, it was moved shortly afterwards to a not very distant site (present Pueblo Viejo), which was destroyed by a landslide in 1541. Then it was moved to another location (present Antigua), which was destroyed by an earthquake in 1773. A new site, considered safe, was chosen for present Guatemala City but as its more recent history reveals, central Guatemala is liable to receive the full impact of some of the worst earthquakes in the region.[3] The hostility of the indigenous cultures was, perhaps, the main cause for relocating a Spanish settlement but among the causes recorded were also the impact of floods and droughts, landslides, eruptions of volcanoes, hurricanes, poor climate, shortages of water, soil erosion, invasions of ants and mosquitoes and the death of Indian tributaries due to ill treatment.

Integrated into the networks of settlements established by the Spaniards and Portuguese four centuries ago or more, thousands of new settlements were hastily founded after the 1850s in the now independent nations, to be used as new provincial and local administrative centres or as development centres for mining, forestry and agriculture, or as river and sea ports, railway stations, tourist resorts, industrial sites and other commercial establishments.

It is essential to remember that at the turn of the century there was not a single city in Latin America with one million people and by 1930 there were only four: Buenos Aires, Rio de Janeiro, Sao Paulo and Mexico City.

Urban growth rates began to increase very fast after World War II reaching unprecedented levels during the 1950s and 1960s. To build and manage urban agglomerations that have been growing by 500,000 people or more a year for more than a decade would defy the present technical knowledge, administrative skills and financial mechanisms of even the more developed nations, especially when growth takes place over the dry beds of lakes and sandy deserts, in deep ravines, in areas subjected to periodic floods and tides, on the slopes of mountains and, in many cases, in areas subject to periodic earthquakes, landslides and even volcanic eruptions.

2. CITY FORMS SHAPED BY POVERTY

We are witnessing in Latin America, the formation of a different type of city-region that combines the worst impacts of rapid demographic and uncontrolled physical growth with a chronic shortage of investments in the construction of a basic infrastructure and social services. The misuse of already very scarce public investments is replicated by the extraordinary ingenuity of low-income groups to solve their own collective and individual problems.

The multiplicity of popular innovations and decisions permits the city region to function while providing sources of livelihood to millions. But there is a limit to what these groups can do.

The traditional city-region has almost collapsed. The new type of city-region shows a decline in the quality and quantity of most, if not all, social services, and decreasing per capita investments by the public sector and the official private sector. It is increasingly the city of the poor, the malnourished and those with no regular paid work who are forced to live in unsuitable and even dangerous urban and suburban environments.

Poor households evaluate carefully the advantages and disadvantages of their individual or collective decisions. Proximity of the sources of employment and, more often, to the sources of informal incomes, and access to public transportation weigh more heavily in their decisions than an environmentally safe terrain. Participating in the massive land invasion of unsafe lands is a better guarantee that they will not be evicted, and might even obtain legal tenancy of their plots, than a similar move, by a few families would have. Invaders are aware of the legal status of the land. There is an "invasion technique"; I have met people - both men and women - who have participated in three or more land invasions. They know where to find political allies and technical and legal advisors. But the crucial problem remains.

Which land sites to occupy? Which is the legally and environmentally safest land that provides the necessary degree of access to jobs, sources of income and services that low income households need more than any other social group? Even the availability of environmentally unsafe but accessible lands is very limited in any metropolitan area.

Governments cannot on moral, social and political grounds, evict hundreds of thousands or millions of people who in only one metropolitan area might live in totally unsuitable environments on unsafe terrain without providing them with better alternatives. In the meantime they should find solutions to their most pressing problems. The impact of such environments on health - especially on children's health - is devastating. Diarrhoeal diseases are regarded by the residents of the squatter settlements as their first problem. These are linked to the quality and cost of water. Unsafe and highly priced water is the greatest threat to a resident of the barrios. There are other situations, equally distressing. A poor family which has patiently built their own shelter on a dangerous site, using time they could have used to earn more income and saving every peso or cruzeiro to buy bricks, a corrugated sheet or some wood, can witness years of efforts destroyed in a few minutes. It requires unusual energy to overcome the sense of frustration and impotence caused by such a disaster.

The key question is then: Is it possible to reconcile, even partially, these situations? Let us start by asking: Do all these households have comparative economic advantages in living in such sites? And then, do they have other viable alternatives? The information about these households is, as a whole, very poor or non-existent. Quick surveys, periodically updated, of the most serious situations could be of immense help, not only because squatter areas are constantly growing but also because it is possible to predict - and then minimize to some degree - the impact of certain natural disasters in areas that quite possibly would be soon invaded.

For decades, urban population sectors have tried to organize themselves to solve their immediate problems and to demand answers to their requests. Large areas in all Latin American cities have been built over the years through these endless negotiations, but there is a limit to the possibilities of building basically adequate environments for low-income groups in this way. Community and non-governmental organizations, with or without public support, can provide answers to some problems but even their combined efforts cannot find solutions to others that require comprehensive responses from national and local governments.

3. THE IMPACT OF EARTHQUAKES

Managua*

On 23 December 1972, central Nicaragua was shaken by three successive earthquakes that reached an intensity of 5.0-5.6 on the Richter scale followed by several earth tremors. Central Nicaragua is vulnerable to earthquakes. Between 1884 and 1972, twelve earthquakes were recorded in central, western Nicaragua in the area that surrounds Managua, the national capital.

The 1972 earthquake flattened 13 square kilometres in the centre of Managua, a city of 300,000 inhabitants, which concentrated 40% of the nation's export industries and 60% of its commercial activities, and badly damaged 27 square kilometres. 8,000 people were killed, 20,000 were injured and 53,000 dwellings were destroyed or badly damaged. In addition, 95% of the city's workshops and industrial buildings and 140,000 square metres of offices, businesses, hospitals and warehouses were destroyed. The cost of the damage was estimated at $845 million US dollars or 60% of the city's fixed investments; this would amount to more than $2 billion in today's US dollars.

This earthquake had other serious side effects. Since it destroyed 95% of Managua's central district, community life in the old barrios (neighbourhoods) was totally disrupted, and poor people lost their houses or their sources of livelihood. The destruction of public buildings and private offices meant a great disorganization in administration. In contrast, the largest and mid-size enterprises located in the suburbs suffered less damage.

Between 1975 and 1979 Managua received massive in-migrations of people. During those four years Managua grew at an annual rate of 9.8%, the highest recorded in its history. Managua now has over 700,000 inhabitants and the central district is still largely vacant with only a housing project and several public buildings occupying here and there, the old street pattern. In 1972, Somoza's dictatorship was used to taking decisions in a centralized way. Inevitably the reconstruction was organized in the same way, stimulating speculation and corruption. The speculation with rents, land and building materials was rampant. The building boom that followed, largely financed with foreign resources, benefited Somoza and his family and cronies. Still in 1975, three years after the earthquake, a high percentage of the urbanized area supplied with public utilities remained unbuilt; its owners were waiting for a further increase in land values. The cost of new buildings was beyond the purchasing power of the poor. Because of way credit was applied, the poor were left out of the market system and, as before the earthquake, they sought rooms in the "cuarterias" (rented rooms in slums) or purchased plots in an illegal subdivision.[5] The earthquake also pushed the growth of Managua in different and safer directions. Development of the central district was frozen while new, high-cost shopping and office centres and residential suburbs sprang up without public control. Fifteen years afterwards, a vast area in the central district remains vacant and the present administration is trying to control the occupation of the areas more vulnerable to earthquakes within the fast-growing metropolitan area.

Guatemala City[6]

On 4 February 1976 at 3:03 a.m., an earthquake with an intensity of 7.5 on the Richter scale hit 16 departments of central and eastern Guatemala, covering an area of 60,00 square kilometres where over 4 million people lived. 25,000 people were killed and 78,000 were injured. One sixth of the population lost their houses and enormous damage to the physical and social infrastructure was recorded. Most houses destroyed were built with mud and "bahareque". The total loss was estimated at 1,021 million Quetzales (Q), which represented 15% of the country's total capital.[7] Of this, 65% were houses, 21% was social infrastructure, 8% economic infrastructure and 7% investments in manufacturing sectors. Guatemala City was cut off from Puerto Barrios, the country's only seaport, where the destruction of the docks slowed down commercial exports for a long time.

Post-earthquake reconstruction faced some immediate problems. When the removal of 4.5 million cubic metres of rubble was being planned, the equipment needed was found to be very limited. When emergency and more permanent shelters were planned, wood and metal sheets were found to be very scarce. When people were asked to move to temporary shelters, they resisted because they felt that they were going to be evicted from the sites where they lived (which had often been occupied as a result of a land invasion). New construction was constrained by a shortage of qualified labour, shortages in the supply of building materials and an increase in prices resulting from speculation. There was an anarchic distribution of building materials and widespread corruption.

Furthermore, in a country with scarce accumulated capital, social problems, now aggravated by the impact of the earthquake, received a low priority. The emergency caused by the disaster could have provided the opportunity to rethink the land tenure system in urban and suburban areas in order to provide house-site ownership to the poor and to develop imaginative credit systems. But the opportunity was ignored; indeed the socio-economic system was not even moderately changed. Although housing credits continued to serve groups which had purchasing power and which could present collateral for credit, the situation of the poor remained unchanged. In many instances, housing credits were used by the wealthier groups, who obtained them to start small productive enterprises or to buy consumer goods.

In late 1987 the housing and living conditions of the poor were even worse than before the earthquake. By then, there was an increasing number of squatter settlements in the suburban areas and of low-income tenants who had lost their houses and had no access to credit. Lack of employment and low incomes in the urban areas remain a very serious social problem. In attempting to overcome this situation, the government tried to implement a credit programme to establish productive activities in rural areas in order to slow down migration from the rural areas and small hamlets affected by the earthquake, but the programme had little impact.

Life in the rural areas is as precarious as ever. People who lost their houses in urban areas tried to use new building materials - cement blocks instead of adobe, wood instead of iron, asbestos and metal corrugated sheets instead of tiles, for instance. But since there were no changes in the patterns of land ownership and tenure, they built their own homes within the narrow limits of previous plots and with no changes in the overall design of the houses and in the use of their inner spaces.

4. THE IMPACT OF FLOODS*

Several cities in Paraguay and Argentina that now have large populations, such as Asunción, the capital of Paraguay, Formosa, Corrientes, Resistencia and Sante Fe, were established along the shores of the Parana and Paraguay rivers by the Spaniards or after independence. There are also important subregional centres like Concepcion in northern Paraguay, Goya, Bella Vista and La Paz in Argentina, and many smaller settlements.

The rivers have annual cycles of growth and decline but every few years unusual floods have been registered. For instance, in Asunción, these were recorded between 1902 and 1906, 1918 and 1923, 1956 and 1962 and 1979 and 1983. Unusual peaks were registered in Resistencia in 1905, 1912, 1966 and 1982-1983 with minor peaks in 1922 and 1933.[3] The 1983 flood was the result of unusually heavy rains in the interior of the hinterland of each city at the moment when the annual cycle of maximum growth of both rivers (in late summer and early fall) reaches its peak. But large sections of both cities are flooded every two or three years. Losses in the Argentine section of the Paraguay-Parana basin alone, as a result of the 1982-1983 floods, amounted to the equivalent of $1.5 billion US dollars. There were very few deaths but about 350,000 people had to be evacuated.

About 50% of the urbanized area of Resistencia and 70% of its population were directly or indirectly affected by the floods. In the province of Chaco, 258 schools representing 27% of all the schools were flooded; 72 additional schools built on safe sites were used for emergency housing. As a result, 46% of the children enrolled in schools had to abandon school temporarily. It is difficult to evaluate the social and economic impact of such a disaster in a province that has one of the lowest per capita incomes in Argentina. In April 1983 only 6.5% of the provincial labour force was registered as unemployed but 23.3% had no stable incomes, meaning they gain their livelihood in the informal sector. As a result of the floods, some 15,000 people lost their homes. Most were low-income families which dedicate a very high percentage (sometimes over 80%) of the family income to the purchase of food. As entire households had to be evacuated and housed in distant places (in army barracks, schools, improvised tents, for instance) they lost their informal sources of income, which are located in the central district of the city.[10]

Even more complex is the evaluation of the social dislocations produced by such events. Many families left the rural areas that had been flooded and moved to urban areas in the province or outside the province; many rural families had also lost their houses, cattle and crops. The 1982-83 flood in Resistencia was also unusual because it continued for 13 months. Local people, especially the low-income groups, were not prepared to live in a state of emergency for such a long period. Low-income households are aware that they have built their settlements in suburban and urban areas that are still unprotected by flood defences. They had illegally occupied such land since this was the only possibility they had for obtaining land on which a house could be built; safer sites were beyond their means.

The flood also showed the carelessness of several public agencies and the greed of many private sector firms. A simple list showed that defences were incomplete; that a 1,000-unit housing project built by the national housing ministry was flooded; that public agencies had neither the organization nor the necessary surpluses of food, medicine, clothing and general equipment nor indeed the knowledge to cope with such an emergency. The flood waters were halted just short of the drinking water plant and the power station.

5. DROUGHTS

Droughts inevitably affect regions that are among the least developed in the world and within each country. With very few exceptions, each drought increasingly deteriorates the natural and living environments, which are already fragile. Although natural disasters always interrupt development, droughts increase underdevelopment, undermining even further the precarious situation of regions that are overpopulated relative to available land and water resources that are very scarce.

The drought that hit the highlands of Bolivia (and also the southern highlands of Peru) in 1982-83 arrived at a particularly critical moment for the economy of one of the poorest countries in Latin America. In 1982, the gross national product of Bolivia had declined for the third consecutive year showing all the signs of an hyperinflation that reached unprecedented rates, even for Bolivia, in 1984.

The 1982-83 drought affected an area of 380,000 square kilometres or 35% of Bolivia's territory, mostly in the highlands, and over 1.6 million inhabitants. The worst hit departments were Potosi, Cochabamba and Oruro, a traditional mining area settled from ancient times by peasant communities living in small and mid-size settlements, with the city of Potosi as its principal centre.

The impact of droughts on cities and settlements in general has not been a subject of research for Latin American social scientists until very recently.[11] But it has attracted the attention of novelists and essayists for a long time.[12] Droughts have been recorded for the highlands of Bolivia since precolumbian times, and fifteen great droughts have been registered for northeastern Brazil between 1605 and 1844-45, an average of one every sixteen years.

A drought affects a city in many ways. One of the first visible impacts is the exodus of peasants from the rural areas. After consuming their scarce grain reserves - even seeds for the next crop - and killing the few animals they have, peasants from the Potosi region moved to the city of Potosi, and many migrated to La Paz or to Argentina and Chile. Some heads of households remained behind with the hope of saving their herds. The results of such migrations on the education and health of children is easy to understand. I visited Potosi in 1984 and saw jobless migrants everywhere in the city.

Another impact in Potosi was the rapid decline in the already poor water supply for human consumption and industrial use. In 1984 water still had to be carried from long distances by truck and railway to a city built at over 4,000 metres altitude and connected with the rest of the country by a very primitive road system. The consumption of scarce and non-potable water favoured the spread of diarrhoeas, typhus, scabies and gastroenteritis. The children's death rate increased from 208 per thousand in 1982 to 333 per thousand in 1983. Mining production declined by 15% to 20% as a result of the lack of water, and the key factories in the city, for such commodities as beer, flour, and dairy and food products slowed down and even suspended their activities for some time, with an obvious impact in labour.

The fall in the region's agricultural production, especially of potatoes, sweet potatoes, corn and vegetables, led to a sharp increase in prices, in Potosi and all over Bolivia, despite the importing of 170 million dollars worth of those foods that are the staple of the low-income groups.

As its main objectives the government's rehabilitation plan considered returning to the already low pre-drought levels of agricultural production and occupation, to avoid further migrations, and to decrease food imports. But many years will be needed for the land productivity to return to the pre-1983-84 levels, and there is no clear indication about how long the tens of thousands of households that migrated to the cities will have to remain in Potosi, La Paz and other urban centres that are not prepared to absorb further population increases. Eventually some will return to their small landholdings, but the more dynamic age groups will remain in the Bolivian cities or abroad.

The 1982-83 drought brought emergency relief from the Bolivian government and the international community in four main areas: food, seed stock, opening new agricultural areas for colonization, and the agrarian recovery.

But once the worst impact of the drought became another milestone in a centuries-old history, life above the 3,000-metre altitude in the highlands of Bolivia remained almost as usual, only more threatening for those who decided to return to their small farms.

6. THE IMPACT OF LANDSLIDES

Landslides of stone and mud killed 250 people, injured 500 and left 20,000 without shelters in Rio de Janeiro, during the weekend of 20 and 21 February 1988, while the city was celebrating Carnival. The worst impact of the landslides was felt in three "favelas" - San Carlos, Catumbi and Santa Teresa - built in the hills of Rio de Janeiro; but not a hillside in Rio was safe. The overflow of the Maracana River and of smaller streams covered most of the city streets with mud and water and partially destroyed a hospital. After two sunny days, an epidemic (leptospirosis) transmitted by the urine of rats had caused 14 deaths and close to 200 infections - all located in the districts worst affected by the floods and landslides.

The closing parade of the Carnival was suspended. Foreign supplies were immediately airlifted. A national solidarity campaign was launched. Key singers, like Gal Costa, Maria Bethania, Simone, Caetano Veloso and others organized a festival whose revenue will be given to those who lost their shelters and belongings. One journalist wrote that it was as if a giant had stepped over the entire city.

A few days before, similar landslides caused deaths and much harm to thousands of families in Petropolis, not far to the west of Rio de Janeiro and floods had left many families cut off in Duque de Caxias. On the day of the landslides it rained 120 mm in a few hours in Rio de Janeiro. For the inhabitants of the favelas to suffer such rains are not uncommon, but since they cannot predict when and where landslides will occur they wait and hope for the best. Favelas are frequently located on steep slopes of the hills that are part of the city, where the quality of the clay soils is very poor. Clay turns into mud and moving mud is, of course, more dangerous than moving water.

7. "HUAICOS", TIDES, TORNADOES AND OTHER NATURAL PHENOMENA[13]

There are also other situations, perhaps of lesser continental impact, but causing much damage at the microregional and local levels that should be mentioned: "huaicos", sea tides, hurricanes, tornadoes and heat waves.

The desert coast of Peru is cut by some 45 rivers that flow from the Andes to the Pacific Ocean, creating valleys that have been made fertile through irrigation schemes. In these coastal valleys the Spaniards founded some of today's largest cities in Peru, such as Lima, Trujillo, Piura, Tumbes and Ica. Every year, especially between December and April, when rains fall in the Andes, the rivers carry mud and stones producing sudden currents that cause much destruction in the urban areas as well as to the crops, damaging irrigation systems and soils. They are called "huaicos" in Peru.

Each year, the "huaicos" (6 in 1980; 37 in 1981; 1 in 1982 and 37 in 1983) in the Rimac Valley, where Lima is located, partially interrupt the water supply and the sewer and energy systems of Lima and of the smaller settlements, and breaks the railway and highway links that connect the capital of Peru with Huancayo, a key commercial centre high in the mountains.

"Huaicos" impact almost exclusively on the shelters of the low-income households that have few resources since they are the ones that occupy the sites with the greatest danger. Most are labourers who moved with their families to look for jobs. They live in shelters built on such dangerous sites because these are preferable to the only other affordable alternative - temporary lodging. The most serious impact is often on households with many children headed by women.

The fact that there is only one adult wage earner makes moving away from these sites even more precarious, since this would threaten the sole source of income. Few deaths are recorded after each "huaico", but many are injured. Many lose their houses, furniture and personal belongings. After the "huaicos", serious shortages of food, medicine, potable water and shelter can develop.

Obviously, actions during the rainy season that would bring major benefits would be daily inspections of the high slopes where "huaicos" begin and a warning system to enable the evacuation of those most likely to be affected. Mapping the higher risk areas that have warning systems would also allow better preparations to be made to deal with the effects. Thus, the impacts of the "huaicos" could be reduced with simple political determination. It requires foresight and coordination within the public system.

Although many Latin American cities are built in coastal areas comparatively few are in the coastal lowlands that experience significant sea tides. The most severe situations are to be seen on the northwestern coast of South America and especially in Guayaquil, the largest city of Ecuador, which has over one million inhabitants. Guayaquil has experienced a very rapid growth since the 1950s. Located not far from the mouth of the Guayas River, much of its growth has taken place in a vast area subject to the daily tides of the Pacific ocean and the recurrent flooding of the river. Close to a half million people live in precarious shelters, many built upon stakes connected by passarels also built in the same way. The site is half-way between the city centre and the port thus offering location advantages to its inhabitants.

Filling sections of the district with earth to provide solid ground for transportation does not hide the precarious habitat where many live, still using canoes for transportation. When heavy rains, in September 1982, added to the regular flow of the tributaries that drain into the Guayas, Guayaquil, and also a few smaller cities like Machala (a key sea port), Babahoyo, Quevedo and Milagro were hit by unusual floods, disrupting the already poor water and sewer systems and causing a health emergency in many districts. As usual, the shortage of supplies caused a sharp increase in food prices at a particularly critical moment in the economic life of Ecuador, owing to the fall of oil prices.

A rise of the seas as a result of climate change would probably affect many settled areas, apart from agriculture and cattle production and fishing and industrial activities. The low coast of southeastern Brazil, where the city of Rio Grande do Sur is located, the vast cattle area of the Salado River, several mid- and small-size centres in the province of Buenos Aires, the port of Bahia Blanca, several sea ports on the west coast of south and central America, such as Guayaquil, Buenaventura, Punta Arenas, and several cities in the Caribbean Basin could be affected. Subregional data, I believe, are missing and the true impact will depend on regional differences of climate and a correct appraisal of landscapes, but I do not think that any country in Latin America, is considering how such possible changes could affect future settlement patterns.

During the late spring and early summer, newspapers frequently report on the damage caused by tornadoes in rural areas and in the smaller towns on the outskirts of large metropolitan areas. I am not aware of any systematic study of the impact of tornadoes on urban areas or of the amount of destruction they inflict on housing, sheds, fragile structures and crops.

The damage wrought by hurricanes, on the contrary, has been recorded for a long time, even from the independence days. Mostly contained within the Caribbean basin, hurricanes have caused many losses of lives, housing, productive investments and crops in that region. Better warning systems have prevented the loss of many lives but little can be done to improve the safety of the fragile buildings built by the poorer social groups themselves.

Heat waves are also recorded by the newspapers, especially when they hit the larger cities causing an unusual number of deaths and admissions to hospital. As in most countries, Latin Americans love to talk about climate changes. Heat waves are not unusual in cities that are geographically located in warm latitudes, but I have never seen a study of the impact of heat waves on any city except the reports of the press, which could be analysed systematically in order to reach some conclusions. Those most affected by heat waves are the poor who live in shelters they have built themselves, where the temperatures inside can reach 45°C or more and where the access to water is more difficult.

8. CONCLUSIONS

Four hundred and fifty years ago no one could have foreseen the scale of the demographic and physical growth that was going to occur in the environs of the old colonial cities.[14] Inevitably, the so-called natural disasters have and will continue to have an impact on larger numbers of people, who now live more concentrated and in higher densities on dangerous sites.

Until several years ago, natural disasters in Latin America were the concern of natural scientists and of engineers only. It was not a subject that interested social scientists, and environmentalists were few in number and were generally concerned about other issues.

Some regional and national universities and research institutions are beginning to include "natural disasters" as a permanent subject in their research agendas.[15] Knowledge about the possibilities and limitations of different regions has increased as a result of advances in ecological research. But governments still have very little idea about how such disasters could be prevented or at least about how their impact could be minimized. The concept of "disaster-preparedness", where measures are taken to plan ahead in disaster-prone areas to limit the scale of injury, death and damage in the event of disaster, is hardly ever considered.

Governments seem to be reluctant to admit the links between the extreme vulnerability of the large numbers of low-income people living in degraded human environments and the increasing toll that "natural" disasters take in death and injury, damage to property, and social and economic dislocation. There are no popular educational programmes to create the necessary awareness about these problems, at least among those more likely to be affected by a disaster, and about what preventive measures are necessary. But inevitably one becomes cynical about the values of educational programmes when the public and private sectors are responsible for the destruction of forests and soils that increase the flow of water, or for holding urban lands for speculation, thus eliminating the poor from any possibility of buying house-plots on safe sites free from the risk of flood or landslides. Granted, the investment required to protect areas subject to floods or to relocate the population living in those areas and on the slopes of hills may be very high. But the social and political costs of ignoring such situations is even higher, especially for fairly weak governments.

Virtually all natural disasters are periodic and most are foreseeable. When they hit an urban area, they impact on a socially segregated society where some have enough resources to continue living as usual, whereas others lose all their possessions. Some have the wealth or income to live in the areas of the city least threatened by periodic disasters and in houses protected against earthquakes, floods or landslides. As we have seen, the poor majority do not. We simply ignore the impact of disasters in different sectors of the population. The emotional impacts on the privileged, protected few and on the large numbers of unprotected poor groups are different. Their capacities and time spans to return to a normal life are also different. To discuss how to prevent the worst impacts of natural disasters on urban societies is to respect people, to become aware of their needs and to understand the processes that are building and rebuilding settlements day after day. In nations hit by economic crisis and recession, essential urban investments cease, real salaries decline, and the shortage of jobs, housing, social services and public utilities hits ever-increasing numbers. The economic crisis has such proportions that it will not allow short-term conventional solutions. The frequency and growing impact, in social and economic urban dimensions, of natural disasters should be a warning to governments and the private sector that unless they reconsider their ambivalent financial and administrative positions they may well be surprised by events.

The crisis has fallen hard on local governments. Their roles have declined while central governments have concentrated power in their own hands, removing many of the local governments' traditional functions and resources. As a result of their weaker political and economic roles, they cannot act as forcefully as needed. Somehow, the responsibility of finding solutions when a natural disaster affects an urban area also falls on the local government, because its role is to plan and implement urban land use, to set norms, regulations and standards and, in principle, to coordinate public and private investment in urban areas. However, local governments depend on national and provincial governments and the private sector to finance, construct and even manage water supply and sewer systems, electrical, housing, health and educational services, productive activities, etc. Obviously, when a landslide, earthquake, flood, "huaico" or hurricane hits an urban area, there are many agencies and interested groups involved. The level of coordination generally varies from poor to appalling, especially after the emergency has passed. In most cases, citizens are simply spectators of the important decisions that day after day shape their lives. The scale of the people's intervention, through their organisations, is inevitably far too small and too subordinated to prevent the worst impacts of a disaster, but agencies seem to ignore the creativeness and organizing abilities of poor communities.

In a world immersed in the early stages of a deep technological revolution that could introduce major changes in the organization of labour and the quality of life of many, it is ironic how out-dated, ill-coordinated and prejudiced seem to be most, if not all, of the key aspects associated with the construction and management of cities. From many points of view the situation in the urban areas of Latin America is far worse than it was two decades ago. Among the scenes we witness daily are countless numbers of abandoned children and beggars, of women and children queueing around a water faucet or waiting for a water tanker or for help outside a health clinic. Bus services are overcrowded and often unreliable and for large areas of each city, no solid-waste disposal service operates, so that garbage piles up in corners of the squatter settlements. We see the destruction of the natural landscape, which also reveals the failure of agricultural policies and practices. Present trends suggest to us a continuing worsening of environmental problems.

We can certainly build better cities, more humane cities, with the resources and knowledge we have. But political decisions in each city and internationally are delayed because of ignorance or greed or contempt of human values and the needs of others.

Shortsightedness is not easily changed. However, the future of each nation might well be shaped by the future attitudes of people towards people, since the psychological and biological development of human beings will be shaped by the human environments where they live and by the way people relate to each other.

We don't seem to know how to face uncertainties, even though the mapping of regionally and locally dangerous areas could be carried out and updated, even if many gaps would remain. We need some new and adaptive ways of thinking, coordinating and acting, Otherwise, the present "perplexity" shown by all groups involved in preventing and minimizing the impact of a disaster or in setting up rescue operations will be tainted by incompetence and shortsightedness. The current economic crisis cannot be presented as an excuse for no action. Prevention, emergency, rehabilitation and reconstruction must be incorporated as parts of the development process in areas prone to disasters. We can begin with what we have. We need researchers and professionals with technological skills and social sensibility. They have to learn to work with people in order to understand their daily plights. But mapping the dangerous urban areas is irrelevant if alternative sites for their homes are not offered to low-income groups. Enforced controls have never worked unless the causes of the environment of poverty are understood and are then removed. After all, a city built with equity also means a city built with an understanding of and a respect for the informal processes that are building the contemporary Latin American city.

NATURAL DISASTERS AND THE HUMAN COSTS IN URBAN AREAS OF LATIN AMERICA

[1] In 1450, during the ninth year of the kingdom of Moctezuma I (1441-1469) Tenochtitlan was totally flooded, forcing the inhabitants to live in canoes. The event was recorded by Fray Juan de Torquemada in Monarquia Indiana (first published in Sevilla in 1665), second book, Chapter XLII. Between 1452 and 1455, the central valley of Mexico experienced such a severe drought that many people sold themselves as slaves to other chiefs.

[2] The location of Trujillo in Western Venezuela was moved seven times between 1557 and 1569. San Carlos, in northwestern Argentina, was relocated five times between 1551 and 1660.

[3] Thomas Arana, writing in the early eighteenth century about the destruction caused by the 1717 earthquake, says that Antigua was destroyed nine times between its founding and 1717.

[4] Ninette Morales Ortega, "El sismo de 1972 y su impacto social en la ciudad de Managua", 1987, INIES, Managua. In January 1973, soon after the earthquake, ECLA produced a report on damage and repercussions.

[5] In 1979, when the Sandinista revolution displaced Somoza, 200 illegal subdivisions, covering 30% of the subdivided lands and concentrating 50% of the city's population were recorded in Managua.

[6] Florentin Martinez and Marco Escobar, "Tipo de evaluaciones realizadas sobre el terremoto del 4 de febrero de 1976 ocurrido en Guatemala", 1987, C.E.U.R., Universidad de San Carlos de Guatemala, Guatemala.

[7] Apparently Guatemala received 10.7 million Q in cash, which were incorporated into the national treasury; 115.2 million Q in credits from multilateral and bilateral agencies and private banks; and 39.9 million Q in loans that could be used for new needs. The government issued national bonds for reconstruction projects worth 122 million Q, and it was compulsory for certain enterprises to purchase them.

[8] María G. Caputo, Jorge E. Hardoy and Hilda Herzer; "La inundación en el Gran Resistencia, provincia del Chaco", 1985, 129-156, and Roberto L. Cespedes and Luis S. Rios, "Análisis del impacto de las inundaciones en el Paraguay", 1985, 235-258, both in Caputo, Hardoy and Herzer, Desastres naturales y sociedad en América Latina, 1985; G.E.L., Buenos Aires.

[9] Asunción is built some 300 kilometres north of the point where the Paraguay river flows into the Parana; Resistencia is just south of this point and receives the combined impact of both currents.

[10] At one particular time, 40,000 people were lodged in temporary housing.

[11] The Joaquim Nabuco Foundation, in Recife, Brazil, has made drought and its impact on the society of northeastern Brazil one of its main subjects of research. For the impact of the 1877-79 great drought in the city of Recife see Gerald Greenfield, "Recife y la gran sequía", in: Cultura urbana latinoamericana, 1985, Richard Morse and Jorge E. Hardoy, (eds.), Ediciones CLACSO, Buenos Aires, 203-225. Also Roger Cuniff's Ph.D. thesis, "The great drought: northeast Brazil, 1877-1890", 1970, University of Texas.

[12] A classical example is Euclides da Cunha's, Os sertoes. See also Tratados de terra e gente do Brasil. 1925, by Fernao Cardim, Rio de Janeiro, 1925.

[13] Andrew C. Maskrey: "Huaicos e inundaciones en el calle del Rimac, departamento de Lima, Perú"; In Desastres naturales y sociedad en América Latina, compiled by María G. Caputo, Jorge E. Hardoy and Hilda Herzer, 1985, G.E.L.; Buenos Aires, 167-177.

[14] Just an example, the area of a present mid-size metropolitan area in Colombia, Pereira-Dos Quebradas, with some 300,000 inhabitants expanded from 71 hectares in 1945 to 367 in 1960; 572 in 1970 and 1,580 in 1985. Many plans were prepared to guide such growth; in practice there was not enough political will to implement them.

[15] In September, IIED-Latin America and Latin America's Social Science Council organized a symposium on natural disasters. The papers presented were published under the title Desastres naturales y sociedad en América Latina, 1985, G.E.L., Buenos Aires, 1985. Nine cases of drought and flood were discussed.

ABSTRACT

NATURAL DISASTERS AND THE HUMAN COSTS IN URBAN AREAS OF LATIN AMERICA

There are abundant although quite incomplete records of droughts, floods, earthquakes, landslides, sea waves, hurricanes and other types of natural disaster for different regions of Latin America, covering hundreds of years. Their influence on the lives and economies of the urban and rural population still awaits systematic study.

While Latin American cities grew haphazardly under the pressure of very high annual rates of population growth, lands unsuited for human occupation were filled by homeless households who found enormous difficulties in joining the labour market. For them, access to sources of income and shorter distances from work are more important than an adequate site. They will inevitably occupy the site - an organized invasion of land. Lands subject to periodic floods, slopes of hills subject to landslides during the rainy seasons, dry beds of lakes, deep ravines or arid and distant areas have been occupied by make-shift shelters. There is little hope for these human environments of poverty unless these peripheral settlements are better integrated, physically and socially, into the official cities through new land policies, credits and subsidized building materials.

The purpose of this paper is to explain the processes - both legal and illegal - that are building contemporary cities in the Third World, with an emphasis on Latin America, and the environmental and socio-economic impacts that natural disasters have on low-income urban groups. The paper offers some proposals to minimize these adverse effects.

RÉSUMÉ

LES DÉSASTRES NATURELS ET LEURS RÉPERCUSSIONS SUR LES POPULATIONS URBAINES DE L'AMÉRIQUE LATINE

Même s'ils sont très incomplets, il existe de nombreux documents qui rappellent les sécheresses, les crues, les séismes, les glissements de terrain, les vagues d'océan, les ouragans et les autres types de désastres naturels ayant frappé différentes régions de l'Amérique latine au cours d'une période couvrant des centaines d'années. L'influence de ces phénomènes sur la vie et l'économie des populations urbaines et rurales attend toujours une étude systématique.

Au fur et à mesure que les villes latino-américaines se sont développées de façon anarchique sous la pression de très forts taux annuels de croissance démographique, certains espaces de terrain impropres à l'occupation humaine ont été envahis par des ménages sans logis éprouvant beaucoup de difficultés à s'installer sur le marché du travail. Ces personnes se sont jointes au secteur marginal de l'économie urbaine qui existe dans chaque ville. Pour elles, la proximité des sources de revenus l'emporte sur le choix d'un site convenable. Elles occuperont donc inévitablement le site à la manière d'un terrain envahi de façon organisée. C'est ainsi que se sont retrouvés occupés par des abris érigés en autoconstruction des terrains soumis à des crues périodiques, des flancs de collines soumis à des glissements de terrain pendant la saison des pluies et des lits asséchés de lacs, de profonds ravins ou des zones arides et éloignées. Il n'existe que peu d'espace pour ces milieux de défavorisés, à moins que les établissements périphériques ne soient mieux intégrés, à la fois physiquement et socialement, aux villes officielles grâce à des politiques foncières nouvelles, à des crédits plus considérables et à des matériaux de construction subventionnés.

La présente communication vise à expliquer les processus - tant légaux qu'illégaux - qui président à l'érection des villes contemporaines dans le Tiers Monde en insistant sur l'Amérique latine et les répercussions environnementales et socio-économiques qu'entraînent les désastres naturels sur les groupements urbains à faible revenu. La communication fait certaines propositions pour atténuer ces situations.

HEALTH EFFECTS ISSUES ASSOCIATED WITH REGIONAL AND GLOBAL AIR POLLUTION PROBLEMS

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1. INTRODUCTION

As amply documented by a rapidly expanding scientific literature and summarized by other contributors to The Changing Atmosphere Conference, human activities have come during the past several centuries to exert increasingly more widespread and serious effects on the earth's atmosphere. The range of consequences of these anthropogenic influences have only fairly recently (within the past few decades) begun to be extensively evaluated and more clearly understood. The effects of alterations of the earth's atmosphere due to emissions of air pollutants associated with energy generation, agricultural and industrial production, transportation, and other social/lifestyle factors include notable impacts on both human health and the environment.

At the present time, several types of air pollution problems have been identified as being of particular concern owing to their potential to exert widespread negative effects on the environment and the health of vast segments of human populations throughout many parts of the world. Such problems, as highlighted for discussion at this Conference, include (1) the long-range transport of air pollutants and their transformation products: photochemical oxidants/ozone and acid aerosols; (2) stratospheric ozone depletion; and (3) the "greenhouse effect" and climate change. The main focus of this paper is the discussion of key human health effects already demonstrated or now hypothesized as likely to be associated with each of the above three types of regional or global air pollution problems. Also noted are likely important interrelationships between the three types of problems.

2. LONG-RANGE TRANSPORT OF AIR POLLUTANTS

2.1 Tropospheric Ozone Effects

Extensive information now exists concerning the types of anthropogenic emissions and atmospheric chemical processes that are involved in precursor emissions and transformations underlying "urban smog" photochemical oxidants/ozone formation and associated human health and environmental effects. Such information has been assessed in-depth in the 1986 U.S. EPA Air Quality Criteria Document (AQCD) for Photochemical Oxidants/Ozone (U.S. EPA, 1986) and summarized at a recent U.S.-Dutch International Symposium on Atmospheric Ozone Research and Its Policy Implications (Schneider et al., 1988).

As described in the above assessments, the formation of ozone (O_3) and other photochemical oxidants of importance in producing so-called urban smog effects involve photochemical (UV light-enhanced) reactions between hydrocarbons or volatile organic compounds (VOC) and inorganic (nitrogen oxides; NO_x) air pollutants. The VOC and NO_x emissions are associated with both stationary sources (e.g., electrical power generation plants and petrochemical facilities) and mobile sources (automobiles, trucks and other transportation devices), especially those involving fossil-fuel combustion or the utilization of oil components in the production of commercial products. Also of very major importance are numerous small, widely dispersed sources of hydrocarbon emissions associated with many different everyday human activities. Dimitriades (1988) has noted several notable developments with regard to our understanding of photochemical oxidant/ozone air pollution phenomena and their effects: (1) Organic emissions differ widely in ozone-forming potential, a finding that has led to the concept of discriminate VOC control for ozone reduction. (2) Ozone and related air pollution problems are regional-scale (not just urban-scale) phenomena resulting from multi-day pollutant transport and precursor transformation enroute. (3) The mechanisms of atmospheric chemical processes that produce ozone have been elucidated in great detail; it now takes hundreds of elementary chemical reaction steps to describe the mechanisms as now understood.

Of the chemical species identified as producing effects due to photo chemical oxidant air pollution mixes, ozone (O_3) is the major species of most concern both for human health effects and damage to the environment. Both categories of effects have been extensively assessed in the 1986 U.S. EPA Ozone AQCD (U.S. EPA, 1986; Schneider et al., 1988). Only the most salient points emerging from these recent examinations of tropospheric ozone effects are highlighted below.

First, when considering ozone health effects, two general types of effects are typically of public health concern: (1) transient effects on respiratory function associated with single or occasionally-repeated, acute short-term (i.e., 1-2 h, 6-8 h) episodic exposures to ozone and (2) effects on respiratory tract defense mechanisms and morphological structure associated with chronic continuous exposures or frequently repeated short-term exposures. Several important points should be emphasized with regard to transient effects of ozone on human respiratory function. Both decrements in lung function (e.g.,reduced air flow rates or increased airway resistance associated with neurally-mediated airway constriction, lower forced expiratory volumes, etc.) and certain irritative symptoms (e.g., coughing, wheezing, chest pain, shortnesses of breath, etc.) are of concern - as are the extent to which consequent reduced oxygen intake/availability or personal discomfort result in limitations of normal work or social/recreational activities. The delineation of ozone concentrations and durations of exposures to various concentrations associated with varying severities of respiratory function decrements and symptoms, as well as the implications for limitation of human activities, represent crucial issues addressed in determining what are unacceptable levels of human exposure to ozone. Importantly related to these issues are the determination of whether particular segments of human populations are at special risk for ozone effects and the evaluation of the extent to which various other factors may alter or modify transient human responses to ozone.

The nature and magnitude or severity of ozone-induced respiratory function effects are critically determined by both the concentration (C) and the duration or time (T) of exposure to ozone, i.e., they are dependent upon a "C" x "T" dose-response relationship. That is, respiratory function decrements and symptoms increase in magnitude or severity as the overall accumulated dose of inhaled ozone increases. This means that higher concentrations are needed to induce certain types or magnitudes of transient respiratory function effects or symptoms with more acute (1-2 h) short-term ozone exposures than are the concentrations necessary to induce analogous effects with somewhat longer (6-8 h) exposures. Also of key importance is the fact that the level of exercise or physical activity of individuals during their exposure to ozone is a critical factor in determining the specific C x T dose-response relationships for ozone-induced health effects. That is, the higher the level of physical activity and, therefore, the greater the breathing rate (minute ventilation; V_E) and dose of ozone delivered to the lower respiratory tract, then the larger the transient respiratory function or symptomatic effects seen at any given ozone concentration. For example, Figure 1 shows group mean decrements observed for one measure of lung function (FEV_1) with 2-h ozone exposures during varying levels of exercise. Several other pulmonary function parameters, e.g., measures of airway resistance or airflow rates show similar exercise-dependent dose-response curves. Besides the above pooled study results, other recent studies have found pulmonary function decrements in healthy adults at 0.15-0.16 ppm O_3 and some data suggest such decrements occur at 0.12 and 0.15 ppm O_3 with heavy exercise, the average changes in lung function being generally small ($\leq$5-6%) and controversial with regard to their medical significance.

Of much importance is the fact that there is much variability between individuals in the magnitude of their pulmonary function decrements to ozone. Intrinsically more responsive individuals, or "responders", may constitute 5 to 20% of healthy adults studied and are of concern in exhibiting notably greater-than-average pulmonary decrements than non-responders; for example, in one study, such responders had decrements ranging up to 17% (which may be of some medical significance to the affected individuals) at

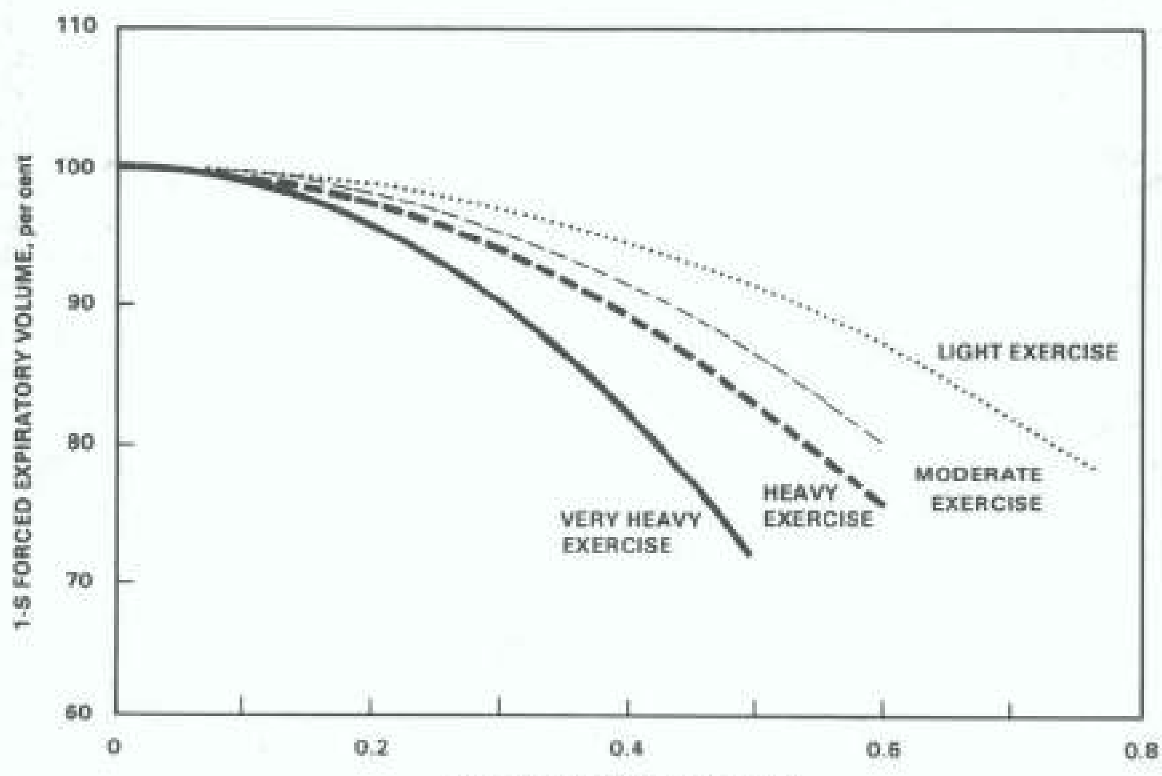

Figure 1.
Group mean decrements in a 1-s forced expiratory volume during 2-h ozone exposures with different levels of intermittent exercise. The concentration-response curves shown are typical of other measures of pulmonary function decrements due to ozone (adapted from U.S. EPA, 1986).

0.12 ppm with heavy exercise. As for other potential special risk groups, no greater responsiveness to O_3 has been found for asthmatics, patients with allergic rhinitis or chronic obstructive pulmonary disease (COPD), cigarette smokers, or older adults. Also of interest is the fact that the occurrence of pulmonary function decrements and respiratory symptoms are highly correlated (i.e., tend to vary together) in healthy adults, and discomfort caused by ozone exposure may be responsible for voluntary limitation of physical activity, as seen for ozone-exposed athletes in one study at 0.2 ppm ozone.

Another important finding is that repetitive exposure to ozone on several successive days, as often occurs during air pollution episodes, results in greater responsiveness on the second day, but thereafter subjects display attenuation of responsiveness (i.e., smaller pulmonary function decrements) that persists for 3 to 7 days. This attenuation of response has been suggested to indicate that individuals living in high oxidant areas "adapt" to ozone effects. However, when subjects are reexposed to ozone after 1-2 weeks of non-exposure, all attenuation is lost; and individuals residing in high-background ozone areas display the same magnitude of response upon first testing as subjects from low ambient ozone areas. Thus, the attenuation phenomenon is by no means permanent and, after a few days of exposure during prolonged ozone episodes, may in fact allow more ozone to penetrate deeper into lung areas and thereby further exacerbate ozone-induced alterations in lung defences and structure.

Also of interest is the fact that, although controlled human exposure studies have not consistently shown an enhancement of respiratory effects by combined exposure to ozone and other commonly occurring co-pollutants (SO_2, CO, NO_2, H_2SO_4, etc.), some field and epidemiology studies have found evidence suggesting effects at ozone levels below 0.10-0.12 ppm. To what extent any observed effects are due to the combined effects of ozone and other co-pollutants (e.g., acidic particulate species) are subjects of much current interest. Certain laboratory animal studies provide evidence for enhanced effects of ozone in combination with other pollutants such as acidic particles.

Newly emerging data, reviewed by Lippmann (1988) or presented by others at the 1988 U.S.-Dutch Symposium, provide evidence for respiratory function effects occurring at ozone levels at or below 0.12 ppm with more prolonged (6-8 h) exposures to ozone that better mimic ambient exposure conditions. Initial indications that ozone effects on lung function may be dependent upon accumulated dose came from certain controlled human exposure studies that found significant respiratory function decrements after 2 h of ozone exposures at concentrations where no effects were observed after 1 h of exposure. Also, observations from field studies of children with high levels of physical activities during ambient ozone exposures indicate that such children experience greater lung function decrements than children exposed at comparable concentrations in test chambers, possibly due to more prolonged, higher cumulative ozone exposures of the camp children over several hours prior to spirometry testing. Recently, controlled human exposure studies have now demonstrated that prolonged exposure of young adults subject to 0.12 ppm O_3 result in progressively larger changes in respiratory function and symptoms with time. The changes in lung function at the end of exposure were similar in magnitude to those previously observed in healthy subjects performing at very heavy levels of exercise at much higher ozone concentrations (>0.2 ppm) for much shorter durations (i.e., $\leq$2 h). Additional studies have confirmed the above findings at 0.8, 0.10 and 0.12 ppm ozone concentrations, with the 0.8 and 0.10 ppm exposures producing smaller changes that also became progressively larger with each succeeding hour of exposure. Thus, the transient respiratory function decrements seen with ozone exposure worsen as a function of increasing time of exposure and can be observed at lower concentrations (0.8, 0.1 ppm) than the present 1-h 0.12 ppm standard with more prolonged exposure durations (6 to 8 h). These new findings are of much importance in current evaluations of ambient ozone standards or guidelines, as are accumulating findings from animal toxicological studies that demonstrate a variety of effects of ozone on lung defense mechanisms and morphological structure.

Accumulating evidence from animal studies reviewed elsewhere (U.S. EPA, 1986; Schneider et al., 1988) points toward multiple deleterious effects being associated with chronic ozone exposure. The constellation of effects includes, for example, changes in respiratory function; airway inflammatory responses; altered particle clearance (including slowed asbestos particle clearance); persisting changes in lung structure possibly associated with lung fibrosis and emphysema; slowed lung development; and reduced ability to fend off respiratory infections. Much remains to be elucidated with regard to many of these types of effects, including the C x T dose-response relationships that may apply and the relative effectiveness of various ozone exposure patterns in producing various types of effects. For some, repeated higher level peak exposures, analogous to ambient episode conditions, may be more deleterious than chronic continuous exposures. Also of importance is the fact that some of the changes, e.g., epithelial damage and inflammatory responses, seem to be cumulative and persistent even in animals that have attenuated respiratory responses. Although it can be hypothesized that humans exposed to ozone likely experience similar effects, there is not yet sufficient evidence to clearly indicate which effects may occur in man.

There is growing recognition in many countries and by international organizations of the need to take strong steps to control tropospheric ozone as a major widespread air pollution problem potentially affecting the crops, forests, buildings and health and well-being of many different populations around the world. At the 1988 U.S.-Dutch Ozone Symposium, for example, representatives of both the United States and the Netherlands noted that new monitoring and modelling results indicate that millions of citizens in each of the two countries are often likely to be exposed to ozone at concentrations that have been shown to be associated with one or more of the types of health effects described above. In many other parts of Europe and elsewhere in the vicinities of major urban centres (e.g., Mexico City) notably elevated surface-level ozone concentrations are frequently experienced as well and will need to be dealt with to protect human health.

International cooperation is clearly needed to study and control such ozone damage. Because polluted air masses do not respect international boundaries, they have the potential to impact on human health and to cause economic damage in neighbouring countries. In less developed countries, both domestically originated and transboundary ozone could further exacerbate existing health care, deforestation, and inadequate food production problems. Controlling tropospheric ozone adequately will not be easy, however, whether through domestic or international action. For example, many of the major population centres in the United States do not meet the current national ozone standard, even though considerable progress has been made in either reducing levels in some areas or in preventing marked further increases in the face of dramatic population growth and increased numbers of motor vehicles or other ozone-related sources. The severity of the ozone problem in many cities in the United States and elsewhere in many countries will likely necessitate the implementation of more stringent air pollution control programs. These new programs are expected to be both costly and controversial. Unlike many other air pollution problems, ozone is not caused by a few large and well-defined sources. Small, widely dispersed sources will have to be controlled in order to reduce ozone concentrations in many areas. For example, everyday human activities such as driving automobiles, refueling at gas stations, dry cleaning clothes, and using household products (e.g., paints and cleansers) all contribute to the formation of ozone. Reducing those kinds of activities, or finding substitutes for those kinds of products, may require substantial changes in lifestyle.

Two further observations add greater urgency to the need for effective tropospheric ozone control. One is that any increases in UV-B radiation projected to occur because of stratospheric ozone depletion would also likely lead to enhanced tropospheric ozone formation. Another concerns evidence suggesting that environmental factors, such as heat and relative humidity, may exacerbate symptoms or physiological impairment observed during and following exposure to ozone. This may be of increasing importance in view of scenarios predicting future global warming trends and other climate changes that may increase the frequency of occurrence of prolonged ozone episodes and/or higher temperatures and relative humidity during such episodes.

2.2 Acid Aerosols Health Effects

Increasing attention has been accorded during the past several decades to emissions of airborne pollutants and atmospheric processes contributing to the formation of acidic air pollutant species; their local and long-range transport (often over hundreds or thousands of kilometres); and the ultimate impacts of such airborne acidic pollutants on human health and the environment. By far, most attention has focused on the effects of acidic deposition (both wet and dry) on aquatic and terrestrial ecosystems. Until recently, much less attention has been accorded to evaluation and discussion of human health effects potentially associated with acidic air pollution, but this area has started to be more extensively evaluated (e.g., Goyer et al., 1985).

With regard to such potential for human health effects, hypotheses exist that postulate possible indirect linkages by which acidic deposition processes might affect human health. For example, one possibility is the leaching of toxic metals, such as lead, from plumbing materials by water that has increased corrosivity due its acidification by the wet or dry deposition of acidic air pollutants. Another possibility is that acidification of soils may cause increased mobilization of metals in soils and their enhanced leaching into streams or lakes, so that the content of metals such as mercury increase in affected waters. This could lead to the bioaccumulation of metals in fish consumed by humans. In contrast to the sparse current evidence for the indirect linkages of acid air pollutants to human health impacts, increasing evidence is accumulating on the health effects associated with exposure directly to acid aerosols. This section, therefore, summarizes below the key points concerning health effects due to direct inhalation of acidic aerosols, as recently assessed by the U.S. EPA (1988).

Strong acid sulphates - sulphuric acid (H_2SO_4) and ammonium bisulfate (NH_4HSO_4) - appear to be the main species of concern in ambient acid aerosols and are the most studied species. Sulphuric acid, especially, has been the focus of many of the available studies, both in terms of ambient measurements and health effects research. However, other acid species, especially nitric acid (a vapour under typical ambient conditions), may be of concern in certain exposure situations (such as those under high humidities where nitric acid is absorbed by water droplets to form acid fogs in some coastal cities), or may influence neutralization reactions and thus total aerosol acidity. Nitric acid is completely scavenged to droplets in fogs. Weak acids may also be present in the atmosphere, but these have not been measured in conjunction with strong acid aerosol at ground-based monitors.

Sulphuric acid (H_2SO_4) is the acid of main concern for acid aerosols-induced health effects. However, only limited data exist for the H_2SO_4 concentrations and spatial distributions typically encountered in ambient exposure situations. Some peak 1-h values ≥ 40 µg/m^3 have been observed at U.S. sites and, historically, 24-h levels up to 348 µg/m^3 and 1-h peak levels as high as 678 µg/m^3 were recorded during severe London smog episodes. No annual average values are yet available for U.S. cities, but the few values available for measurements averaged over 24 to 48 h tend to be low (i.e., <5 µg/m^3). Much more extensive monitoring data for H^+ ions or particular acidic species are needed to estimate more clearly the likely general population exposure levels and patterns. In the meantime, efforts to assess potential health risks associated with acid aerosols are generally heavily dependent upon use of ambient sulphate concentrations as a reasonably good, but imperfect, surrogate for more direct acidity measurements (assuming acid sulphates to be of most importance).

The accumulation of acid aerosols in air masses over the United States derives most heavily from particulate sulphate species, with NO_x being a generally secondary contributor except in some areas (e.g., Los Angeles area acid fogs). High sulphate concentrations not only cluster over the main areas of SO_2 emissions along the Ohio River Valley or other scattered urban areas, but a widespread regional distribution of sulphate particles can also extend across large areas of the Eastern United States, from southern areas along the Appalachian mountains north-northeastward into the Mid-Atlantic States and New England. The formation and persistence of sulphate species (with typically highest Eastern U.S. concentrations in the summer) crucially contribute to the potential for acid-aerosols formation, with highest acidity values accumulating during episodic stagnation periods also typified by high concentrations of photochemical oxidants.

Ammonia (NH_3) neutralization is a key factor in determining the persistence of atmospheric sulphate species. The potential for such neutralization is highly dependent upon the amount of ammonia available in the atmosphere to react with sulphuric acid and the formation of ammonium salts: NH_4HSO_4 and $(NH_4)_2SO_4$. The main sources of atmospheric ammonia are (1) animals and humans (resulting from excretion via skin or in urea) and (2) fertilizer manufacturing and/or utilization. Regional mappings of estimated domestic animal and human ammonium emissions have been prepared for the United States, with animal sources being most heavily concentrated in Midwestern farm states and with human sources in major population centres, such as those heavily clustered in the north-central and Northeastern states. The potential for ammonium neutralization is highly dependent upon the movement of sulphuric-acid contaminated air masses over land areas having ammonia sources and upon the degree of contact of any air mass with the surface. In addition to the general regional distributions of ammonia emissions, there can exist very localized areas with high ammonia emissions or marked gradients across somewhat larger areas, e.g., much higher emissions over densely populated central sections of large cities but distinctly lower levels in the surrounding suburbs or nearby rural areas. This means that the potential for the induction of acid aerosols health effects by exposure to any acid-laden air mass will likely be a complex function of both the rate of formation of acidic species and the rate of ammonia emissions across a particular region or in localized areas.

Numerous factors ultimately affect the toxicity of acid aerosols, once they are inhaled by humans or other mammalian species. For example, the chemical composition of the specific acid aerosol inhaled is an important determinant, with the following potency typically found for the induction of health effects responses by sulphur species: H_2SO_4 > NH_4HSO_4 > $(NH_4)_2SO_4$. Also, the health effects due to sulphuric acid aerosol, the most potent of the group, are likely mainly due to H^+ rather than SO_4^{2-}-influences. Importantly, the neutralization of inhaled acid aerosols by ammonia in the oral cavity or respiratory tract can occur (analogous to ammonia neutralization in ambient air) and may reduce the effects of inhaled acid aerosols. More research is needed to understand the mechanisms that determine oral or respiratory ammonia levels and their effects on various types of toxic responses. Smaller acid aerosols ($\leq$0.5 µm) appear to be subject to more rapid chemical transformation by ammonia. Airway surface fluids also buffer acid deposited in airways, with the total respiratory tract capacity to buffer or "neutralize" acids being quite considerable, but with the buffering capacities of different respiratory tract regions varying considerably. Another factor affecting toxicity is the deposition pattern of acid aerosols in various respiratory tract regions. The irritant potency of sulphuric acid aerosol is site-dependent within the respiratory tract and linked to the extent of hygroscopic growth and the buffering capacities of specific regions. For example, the larger the particle growth, the less likely is deep penetration into the lungs; also, oronasal buffering of particles deposited in upper regions lessens irritant potency, whereas the deposition of particles in lower regions heightens the possibility of toxic acid effects in the tracheobronchial region (e.g., impacts on mucociliary clearance) or the lungs (e.g., effects on alveolar macrophages). Thus, sulphuric acid may exert toxic actions throughout the respiratory tract, but the specific site affected and type of effect are dependent upon particle size and mass concentration.

As for acid aerosols health effects <u>per se</u>, selected key findings can be highlighted as derived from (1) controlled human exposure and experimental laboratory animal studies of acid aerosol effects on pulmonary function and respiratory defense mechanisms; (2) experimental studies of the effects of mixtures of acid aerosols and other pollutants; and (3) epidemiology studies of the effects of ambient exposures of humans to acid aerosol-laden air. Controlled human exposures of healthy adults to sulphuric acid aerosol ranging up to 1,500 µg/m^3 had no effects on lung function at concentrations below 500 µg/m^3, and adult asthmatics were affected at 400 to 1,000 µg/m^3. In contrast, adolescent asthmatics appear to be the most sensitive at-risk group for pulmonary function effects, with effects noted at concentrations as low as 65 to 110 µg/m^3. Also, prolonged exposure of rabbits to 250 µg/m^3 H_2SO_4 for 1 h/day, 5 days/week, for up to 12 months produced hyperresponsiveness in airways, which may put them at greater risk for the pathogenesis of airway diseases (e.g., bronchitis). Overall, these results suggest possible effects of acid aerosols (H_2SO_4) on pulmonary function in humans and animals most clearly at concentrations $\geq$100 µg/m^3 and perhaps at lower concentrations ranging down to about 60 μg/m³. Whether similar effects occur at lower concentrations with longer exposure durations (e.g., 6 to 8 h) remains to be evaluated. Of note, delayed responses occur including both symptoms and functional effects that persist or worsen during 24 h after exposure.

As for changes in respiratory defense mechanisms associated with exposure to strong acid aerosols, several salient findings can be highlighted for effects seen with exposure to ≤5 μm (MMD) H_2SO_4. Acute exposure for healthy human adults and asthmatics resulted in reduced mucociliary clearance rates of 50% and 1- or 2-h exposures to 100 μg/m³ H_2SO_4. Experimental animal studies of more chronic exposures have found analogous effects, e.g., (1) decreased bronchial clearance in the donkey with exposure to 100 μg/m³ H_2SO_4 for 1 h/day, 5 days/week for 6 months and (2) increased numbers of secretory cells and decreased bronchial clearance in rabbits exposed to 250 μg/m³ H_2SO_4 for 1 h/day up to 52 weeks. Such results potentially relate to the pathogenesis of chronic lung disease, but much remains to be elucidated in this regard and to discover if analogous effects might be seen at lower concentrations with long duration acute single exposures or chronically repeated daily exposures.

As for the effects of acid aerosols mixtures with other pollutants, the most notable results are for exposures to combinations of sulphuric acid (MMD ≤5 μm) and ozone. For healthy human adults, a 2-h exposure to combinations of 100 μg/m³ H_2SO_4, 0.37 ppm SO_2, and 0.37 ppm O_3 did not decrease $FEV_{1.0}$ more than that seen with O_3 alone. However, exposure of rats to 100 μg/m³ H_2SO_4 and 0.2 ppm O_3 for 6-7 h increased lavageable protein content of lungs in comparison to ozone or sulphuric acid exposure alone. Also, whereas little effect on mouse bacterial infectivity was seen with H_2SO_4 exposures up to 150 mg/m³, 3-h combined 240 μg/m³ H_2SO_4 and 0.1 ppm O_3 exposures resulted in synergistic increases in susceptibility to infection. Other results suggest the sequence of exposure to be important, so that H_2SO_4 added at commonly encountered ambient ozone levels (0.1 ppm) may exacerbate certain ozone-induced health effects. This is especially of concern for "summer haze" events, where both sulphuric acid and ozone tend to occur together. Some Ontario epidemiology studies qualitatively suggest increased hospital admission rates occur during such summer haze conditions, but limited direct measures of ambient acid levels thus far greatly constrain the evaluation of the relative roles of acid aerosols and ozone.

Other epidemiology studies during the past several decades provide evidence, generally inferential and qualitative, that suggests that exposure to ambient air acid aerosols (especially sulphuric acid) may contribute to mortality and morbidity effects in the general population. Most such studies have been markedly limited owing to no or only sparse measurements of ambient acidity or specific types of acidic particles. For example, examination of London air pollution episodes in the 1950s and 1960s, during some of which acid measurements were made, tended to reinforce a key role for sulphuric acid, but no definitive analyses clearly confirmed this. Rather, major emphases were placed on analyses showing substantial evidence for strong statistical associations between airborne particles in general (measured as British smoke, BS) or SO_2 and measures of mortality and morbidity (e.g., increased symptoms in bronchitis patients) during London episodes and non-episodic periods. Newer analyses of "old" London mortality data and previously unanalysed acid measurement data yield interesting results. That is, preliminary analyses of daily direct acid aerosol measurements in London during 1958-1972 found unadjusted mortality rates to be more strongly associated with acid aerosol concentrations than BS or SO_2, with lags of one day providing better fits for pollution than same-day pollution values. These results, while not definitive (more sophisticated statistical analyses using time-series methods and appropriate adjustments in mortality for other factors are under way), provide more substantial support for long-standing hypotheses about acid aerosols contributing to air pollution-related human health effects in London.

Analyses of a more recent large-scale European air pollution episode provide further indications of possible acid aerosols effects on public health. During January, 1985, large areas of Europe experienced a major air pollution event, tracked by monitoring stations in several countries as the polluted air mass moved from east to west. Unfortunately, few measurements of ambient acidity were obtained; but those and other data suggest that sulphuric and nitric acid concentrations may have exceeded 50 $\mu g/m^3$ in some areas during the episode. German investigators have reported preliminary estimates of increases in mortality, in hospital admissions, in outpatients visits, and in ambulance transports during the episode (when daily total suspended particulate (TSP), SO_2, and NO_2 concentrations reached 600, 830 and 410 $\mu g/m^3$, respectively, over FRG areas). Dutch investigators monitored the air mass moving over the Netherlands (daily TSP, respirable particles <3.5 µm, and SO_2 levels all reached the range of 200-280 $\mu g/m^3$). Pulmonary function measurements for Dutch school children were lower when compared with baseline measurements taken 4 to 6 weeks earlier and remained depressed when retested 16 days later. These results illustrate the potential for (1) contemporary multinational air pollution episodes (likely including acid aerosol components in the case of the 1985 episode); (2) elevated pollutant levels extending over multiple-day periods (approaching one week in some areas during the episode); and (3) a variety of health effects being associated with such episodes.

American and Canadian epidemiology/field studies during the 1980s are also of interest. For example, in several studies of children at U.S. summer camps, transient respiratory function decrements were found to be associated with acute ozone exposures, but not to acidity typically ranging up only to 4.0-6.5 $\mu g/m^3$ across several studies or NH_4SO_4 up to 20 $\mu g/m^3$ in one study. The health endpoint measure (respiratory function), however, is likely not sensitive to acute acid exposures at such low concentrations, based on controlled human exposure results. In studies of children in Canadian camps, pulmonary function decrements were seen during or immediately after air pollution episodes when ozone concentrations were elevated, and sulphuric acid concentrations ranged up to 40-47 $\mu g/m^3$ and total sulphates to 80 $\mu g/m^3$ in some cases. However, no analyses have been published demonstrating associations between observed respiratory decrements and acid aerosols monitored in these latter studies. Much, thus, remains to be done to assess acute acid aerosols exposure effects, with the possibility that transient respiratory function decrements may not be detectable unless higher (>50-100 $\mu g/m^3$) acid aerosols levels are present or more prolonged exposure periods yield cumulative (C x T) doses in that range.

At lower chronic exposures, experimental evidence suggests sensitive health end-points to be altered mucociliary clearance, other impacts on lung defenses, and possible associated increases in susceptibility to infectious diseases. However, few studies have yet related health effects to direct measures of ambient acid concentrations over extended periods of time (e.g., annual averages for sulphuric acid). Still, some have reported associations between health effects and ambient fine-particle or sulphate concentrations averaged over extended periods of time. Methodological questions have typically precluded definitive acceptance of such study results but, overall, qualitative associations between fine-particles or sulphates (highly correlated with acidity potential) and some types of health effects are strongly suggested. Probably the most useful recent epidemiology results providing clearer evidence for acid aerosols-health effects relationships are those from the Harvard University "Six-Cities" Study in the United States, which has found a fairly close association between increases in bronchitis rates in children and annual averages of inhalable particles (<15 µm MMD) and even stronger relationships to hydrogen ion concentrations measured in five of the six cities.

What are the implications of the information reviewed above for international pollution control efforts? First, there appears to be evidence that both mortality and serious morbidity effects are likely associated with acute, high-level exposures to acid aerosols at concentrations that have been encountered in past multi-day air pollution episodes involving rather high concentrations of particulate matter and SO_2. Given the available information on periodic or frequent occurrences in some cities of elevated concentrations of such pollutants approaching values seen in past episodes (e.g., in London in the 1950s), then strong steps may need to be taken in many heavily polluted urban airsheds scattered across the world to reduce the emissions of precursor substances that contribute to marked accumulations of acid aerosols, especially during episode periods. The specific steps to be taken will probably vary greatly, depending upon the particular atmospheric chemistry of specific acid events, their geographical scale (e.g., local source impacts, acid fogs or large-scale regional episodes), and other relevant factors. Of emerging special concern are situations where air pollution episodes involve both photochemical oxidants/ozone and the high potential for acid aerosols formation. A wide latitude exists with regard to the development of effective control strategies that appropriately address the particular circumstances that prevail in any given country. However, at the same time, the need for effective international cooperation will likely also be of key importance in many cases. Of particular concern are large regional episodes, characterized by high H_2SO_4 and/or NH_4HSO_4 occurring for long daily periods and extending over several successive days - especially when transboundary transport of such air masses occur (with precursor inputs from adjacent or distant countries) and potentially affect millions of people in many nations. Lastly, notable interrelationships can also be expected to occur between acid aerosols problems and projected future stratospheric ozone depletion or global warming trends. That is, each can be anticipated to likely exacerbate both tropospheric ozone formation and acid aerosols problems as well.

3. STRATOSPHERIC OZONE DEPLETION EFFECTS

The natural distribution of ozone in the earth's atmosphere, concentrated most heavily in a thin layer in the stratosphere, is crucial in helping to protect humans, biological organisms, and man-made materials from the harmful effects of certain wavelengths of sunlight. Stratospheric ozone exerts its beneficial effects by partially blocking ultraviolet radiation in the 295 to 320 nm (ultraviolet-B, UV-B) range from reaching the earth's surface. Also, the vertical distribution of stratospheric ozone and the relative dryness of the air in the stratosphere help to maintain the radiative balance of the earth. Depletion of the stratospheric ozone layer can, therefore, be expected to lead to damaging effects on human health and the environment: (1) directly by the increased penetration of UV-B radiation to the earth's surface, and (2) indirectly by the influences of changes in the vertical distribution of stratospheric ozone and water vapour that contribute to global warming effects and altered climatic conditions (discussed in Section 4). Detailed discussions of evolving concern about stratospheric ozone depletion and the assessment of scientific bases underlying such concern can be found in recent national and international expert working group reports (e.g., U.S. EPA, 1987) or symposia (Schneider et al., 1988). This Section concisely summarizes key points from such sources and discusses their implications for developing effective international efforts to cope with ozone-layer depletion.

Many gases emitted owing to man's industrial and agricultural activities can accumulate in the earth's atmosphere and ultimately contribute to alterations in the vertical distribution and concentrations of stratospheric ozone. Among the most important are trace gases having long residence times in the atmosphere, allowing for their accumulation in the troposphere and their gradual upward migration into the stratosphere where they contribute to the depletion of stratospheric ozone. The atmospheric and chemical processes involved are extremely complex, as reviewed elsewhere (U.S. EPA, 1987). Trace gases of particular concern include: (1) certain long-lived chlorofluorocarbons (or CFCs) such as CFC-11, CFC-12 and CFC-113, that have atmospheric residence times of approximately 75 to 110 years; (2) carbon tetrachloride (CCl_4), with a 50-year residence time; and (3) Halon-1301 and Halon-1211, with 110 and 25-year residence times, respectively. Given the long periods of time involved in the transport of these gases to the stratosphere, their long residence times there, and slow removal processes, any effects already seen on stratospheric ozone are likely due to atmospheric loadings of these trace gases due to anthropogenic emissions several decades ago and those gases already in the atmosphere, will continue to exert stratospheric ozone depletion effects far into the future - that is, well into the next century.

What are the types of effects that can be expected from stratospheric ozone depletion? The general types hypothesized can be categorized as follows, as summarized recently by U.S. EPA (1987) or Kripke (1988):

1. Human Health Effects (increased skin cancer; increased cataract formation and retinal effects possibly leading to blindness; and immune system effects contributing to skin cancer and possible increases in certain types of infectious diseases).

2. Environmental Effects (damaging impacts on terrestrial plants, including possible reduced yields of rice, other food crops and commercially important trees; deleterious effects on aquatic life, including reduced ocean zooplankton and phytoplankton, which are important base components of marine food-chains supporting the existence of commercially important, edible fish and other seafood; impacts on climate, including contributions to global warming phenomena; and exacerbation of tropospheric ozone problems and, possibly, contributions to acid aerosols formation).

3. Other types of effects (faster rates of polymer weathering due to increased UV-B radiation and other effects on man-made commercial materials and cultural artifacts secondary to climate changes or exacerbation of air pollution problems).

Probably the best defined human health effects are increases in skin cancer cases expected as the result of even small increases in UV-B radiation reaching the earth's surface. Detailed discussions or extensive summaries of information on the subject have recently been provided (U.S. EPA, 1987; Kripke, 1988; and van der Leun, 1988), as concisely highlighted below.

Of various skin cancers types (non-melanoma and melanoma), the most definitive evidence exists for non-melanoma basal and squamous cell carcinomas of the skin being linked to UV-B radiation and, therefore, being likely to increase owing to ozone-layer depletion. Cutaneous basal and squamous cell carcinomas occur most frequently on sun-exposed body sites of light-skinned Causasian peoples, and their incidences increase with age. These and other data on the geographic distribution of rates for such cancers in relation to the extent of likely sun exposure all suggest that cumulative lifetime exposure to sunlight plays an essential role in the induction of these skin cancers. Increases in skin cancers during the past several decades in the United States are probably partly due to the increasing exposure to both natural and artificial sources of UV-B radiation (e.g., more sunbathing at younger ages in bathing suits covering less body surface and using ultraviolet tanning salons, respectively) and greater longevity allowing for appearance of such cancers after typical long latencies (several decades) before their manifestation. Given such a long latency associated with UV radiation, it is unlikely that the already observed increases in skin cancer rates can be attributed to any of the small measurable decreases in stratospheric ozone observed during the past decade or so.

Extensive other evidence exists, however, that allows for reasonable predictions of increases in basal and squamous cell skin cancer rates (above higher rates seen during the past few decades) if stratospheric ozone depletion occurs at an increasing rate. As noted by van der Leun (1988), if stratospheric ozone is depleted, the greatest increase in UV-B radiation will be nearer to 295 nm than to the 310-nm upper end of the affected wavelength range. The subject skin cancers are most affected by UV light around 300 nm, as demonstrated by experimental animal studies; and the percentage incidence of tumors is a function of dose (D) times exposure duration or time (T), i.e., D x T, with no evidence for any threshold. That is, the probability of cancer induction increases with any degree of exposure to UV light (even low daily doses can have strong effects) and the number of new skin cancer patients can be predicted to increase at a greater-than-linear rate due to several factors. Such factors include both (1) optical amplification and (2) bioamplication effects.

The optical amplication effects are partly geographically dependent, with greater increases in skin cancer rates projected in human populations as a function of their distances from the equator towards the poles owing to higher amounts of UV-B radiation expected to reach the earth's surface nearer the poles. Both optical and bioamplification factors will contribute to differential increases in rates for the two types of non-melanoma skin cancers, although greater than proportional increases in each are likely in relation to percentage ozone depletion. Thus, if both amplification factors are taken into account, then the following quantitative consequences can be expected: (1) With a 1% decrease in stratosphere ozone, effective UV-B irradiance will increase by 2% and, in turn, lead to increases in incidence of basal cell carcinomas by 4% and of squamous cell carcinomas by 6%. (2)

With a 5% decrease in stratospheric ozone, increases can be expected in incidences of basal cell carcinoma by 22% and of squamous cell carcinomas by 33%. The above projections (combined with population statistics and adjusting for geographic gradients noted earlier) lead to estimates that markedly increased numbers of cases of non-melanoma skin cancers will eventually occur owing to stratospheric ozone depletion. The lighter-skinned white populations of the world are expected to be most affected, with 70,000 new cases of non-melanoma skin cancer per year (world-wide) projected with 1% stratospheric ozone depletion and 360,000 new cases annually with 5% ozone depletion.

The full importance of such numbers is presently difficult to define. It is true that the non-melanoma skin cancers, if detected early, have a very high cure rate (current death rate is about 1% of known cases) and that certain changes in personal habits, lifestyles or occupational practices (e.g., decreased everyday outdoor activities, decreased recreational sun exposures, use of more extensive protective clothing by farmers or other outdoor workers, etc.) might help to hold down the ultimate skin cancer increases due to ozone depletion. However, it is nevertheless clear that notably greater and costly demands will be placed on health care systems of affected countries to screen for and treat increased numbers of non-melanoma skin cancer cases, if even only 1% to 5% stratospheric ozone depletion were to occur as predicted by some scenarios. The dramatic changes in personal lifestyles and occupational practices required to have more than marginal effects on expected increases in skin-cancer rates carry with them many readily evident economic costs (e.g., increased indoor air conditioning or heating costs) as well as likely alterations in social and recreational activities.

It should also be noted that sufficient evidence exists for sunlight playing a role in much more dangerous (often fatal) forms of skin cancer and their higher incidence in persons with non-melanoma tumors to raise concern about potential future increases in melanomas due to stratospheric ozone depletion. The key uncertainty is the extent to which UV-B radiation, versus other sunlight components, may specifically contribute to induction of cutaneous melanomas; and the lack until very recently of any viable experimental animal model in which to study these light-activated skin pigment cell cancers impeded research progress. Two new animal study findings, noted by Kripke (1988), however, may be harbingers of future advances in this area: (1) the demonstration by investigators in Albuquerque, New Mexico, of UV-B radiation increasing both squamous cell carcinomas and melanomas in an animal model having photoactivated skin cells and (2) new data from Kripke's laboratory showing much greater growth of melanomas transplanted into skins of UV-radiated animals, suggesting that UV radiation may not only trigger the growth of melanomas but also have promotor effects as well. It is thus clear that appropriate caution must be taken not to prematurely rule out possible increases in melanoma-type skin cancers due to stratospheric ozone depletion. In fact, prudence would now tend to argue with an assumption that such an impact may occur and to weigh the then added impacts on health care systems and possible increases in fatality rates associated with melanoma skin cancers as part of considerations concerning health effects of ozone-layer depletion.

Another important health endpoint likely to be affected by stratospheric ozone depletion - with possible much more extensive impacts on more diverse human populations of the world than the skin cancer effects - is immune suppression. As discussed by Kripke (1988), UV-B radiation appears to be able to modify immune function in several different ways, including changes occurring locally at the point of skin irradiation and other systemic effects at distal sites away from exposed areas. Locally induced effects include UV-B impairment of Langerhans cells, those macrophage-like skin cells mainly responsible for engulfing antigens and presenting them to helper T-cell lymphocytes involved in mediation of immune responses that destroy antigens (i.e., foreign substances entering the body) and abnormal endogenous cancer cells. After exposure to UV-B radiation, Langerhans cells no longer present antigens to the helper T-lymphocytes and, when contact allergens are applied to UV-B exposed skin, no contact allergy ensues. Instead, suppressor lymphocytes are activated that prevent any subsequent immune response to the same antigen. UV-B radiation induced activation of suppressor T-cell lymphocytes, which are normally involved in regulating the magnitude and duration of immune responses, prevents the development of natural immune responses against UV-B induced skin cancers and thereby contributes to their growth and spread to other parts of the body. Besides the above effects, circulation of UV-B activated suppressor lymphocytes throughout the body and an associated reduction in the numbers of helper lymphocytes results in a general, systemic suppression of certain immune functions. Thus, not only do UV-B irradiated mice fail to exhibit contact allergy responses to chemicals applied to irradiated skin, but they also have an impaired ability to respond to chemicals applied to non-radiated skin and decreased lymphocyte-mediated immune responses to foreign substances injected under the skin (i.e., delayed hypersensitivity reactions). The systemic suppression of immune function due to UV radiation has been demonstrated to occur in several animal species, to increase as a function of increasing UV-B dosage, and to persist beyond the initial period of UV exposure.

Kripke (1988) has noted that the above types of findings raise the possibility that suppression of certain lymphocyte-mediated immune responses by UV radiation may also result in impairment of analogous immune responses to some infectious agents. For example, the parasite Schistosoma and the leprosy bacillus gain entry via the skin, and such entry of these disease-producing organisms through UV-irradiated skin may lead to the activation of suppressor lymphocytes and impaired immune reactions that would otherwise counter the infections. Also, as noted by Kripke (1988) many other infectious agents (viruses, bacteria, fungi, etc.) produce skin diseases, and other organisms are normally held in check by delayed hypersensitivity immune reactions. In each case, UV-B induced immune suppression may increase the severity of infections and impair the development of immunity against reinfection. Consistent with this hypothesis are findings for the two infectious agents studied thus far: (1) the demonstration by U.K. researchers that the injection of Herpes simplex virus into the skin of mice exposed to UV-B radiation resulted in suppressed immune response to the virus that lasted for several months; and (2) the demonstration by Gianinni in the United States that UV-B irradiated mice infected with Leishmania (a protozoan parasite) failed to exhibit delayed hypersensitivity immune responses induced in non-irradiated mice.

The full significance of the above findings for human health remains to be better elucidated. However, evidence does exist that UV-B exposure in humans produces analogous impairments in immune system function, including (1) damage to Langerhans cells in the skin and depressed allergic reactions to foreign substances applied to UV-irradiated skin; (2) decreases in immune system killer cell activity and increases in the number and activity of suppressor lymphocytes with human exposure to UV-B radiation or sunlight; and (3) the persistence of some of these effects beyond two weeks after exposure. Thus, although much still has to be learned through further research, prudence again argues for viewing immune suppression effects and associated increased incidences of some infectious diseases as being likely to occur with stratospheric ozone depletion.

Various other potential health effects of stratospheric ozone depletion likely to be mediated via increased UV-B radiation have been identified, as discussed by U.S. EPA (1987) and van der Leun (1988). Probably most notably among these other effects are adverse ocular effects of UV-B radiation. One possibly increased ocular effect of solar UV radiation, snowblindness, is typically transient (i.e., lasting for only a few days), but its possible increase may be interest in view of anticipated greater UV-B irradiation at higher (snowier) latitudes as the result of ozone depletion. Of much more concern, however, are the prospects of increases in cataracts cases. New evidence indicates that small percentages of UV-B radiation can penetrate into the lens of the eye and that UV-B radiation increases cataract formation. Of much importance is the likelihood that ozone-layer depletion would be expected to increase the incidence of cataracts (a permanent clouding of the lens of the eye most often seen in the elderly) in exposed populations, regardless of racial or ethnic origins. Calculations of possible increases in cataract formation have been attempted (U.S. EPA, 1987) and suggest that 1% stratospheric ozone depletion would increase its prevalence by about 0.25 to 0.6% (roughly equivalent to about 24,000 to 57,000 more U.S. cases per year at present population levels). Of much concern is that, even in the United States where surgical operations prevent most cataracts from causing blindness, cataracts still remain the third leading cause of blindness; and, in less-developed countries with much more limited surgical capabilities, cataracts represent an even greater threat.

Lastly, in regard to indirect routes by which stratospheric ozone depletion might affect human health, the high probability of increased UV light facilitating tropospheric ozone formation should be re-emphasized. As noted earlier, this could be of additional concern in terms of secondarily increasing acid aerosols formation due to increased surface ozone concentrations. The health effects associated with both tropospheric ozone and acid aerosols (as summarized in Section 2) would then be expected to occur with greater frequency and severity. Importantly, tropospheric ozone increases the susceptibility to respiratory infections and sulphuric acid may synergistically increase such effects, as might the UV-B radiation induced immune suppression effects noted earlier. Figure 2 schematically illustrates the possible interrelationships between stratospheric depletion and the types of direct and indirect health effects summarized here.

The information summarized above indicates that stratospheric ozone depletion has the potential to exert very substantial effects on human health and the environment. However, our ability to predict with confidence and precision the likelihood of particular effects occurring and their anticipated full scope or scale varies greatly owing to differences in the current level of our state of knowledge about particular types of effects. Table 1 illustrates differences in our state of knowledge regarding various types of anticipated effects and their potential global impact, as viewed by an expert subcommittee of EPA's Science Advisory Board and discussed by Kripke (1988). One of our present dilemmas is the fact that our current state of knowledge is low with regard to certain effects that have the greatest potential for widespread global impacts. For example, the current state of knowledge concerning the potential effects of increased UV-B radiation on immune system function is relatively low, but the global impact on human health could be quite high.

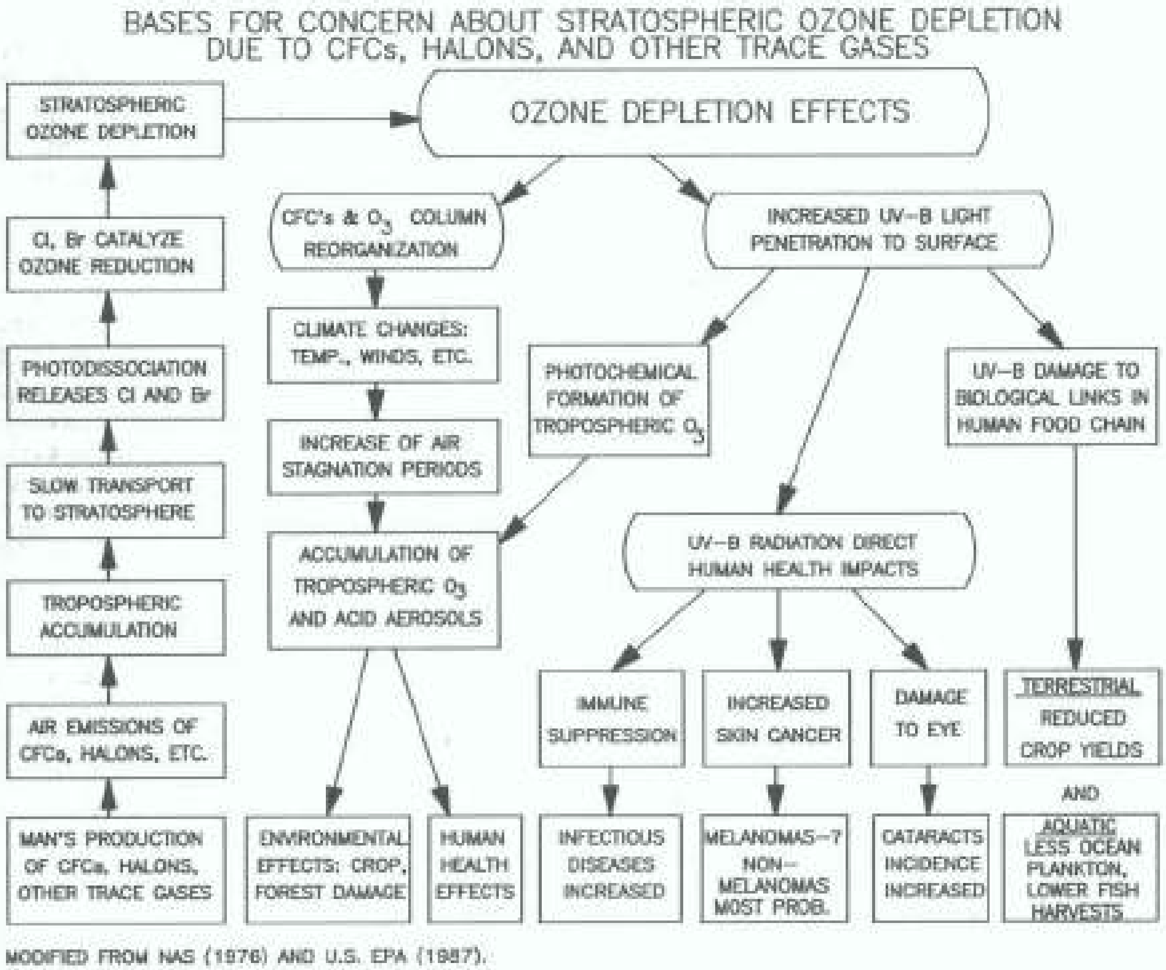

Figure 2.
Bases for concern about stratospheric ozone depletion, caused by man's production of CFCs, halons and other trace gases are shown on the left. The types of effects hypothesized include both direct effects on human health (e.g., increased skin cancer rates, immune suppression, etc.) due to increased UV-B radiation and indirect effects manifested via enhanced tropospheric ozone formation or UV-B damage to biological links in the human food chain (modified from NAS (1976) and U.S. EPA (1987)).

What is to be done in view of the above situation? Obviously, as noted by other contributors to this conference in regard to other types of effects, the projected or hypothesized likely effects of stratospheric ozone depletion on human health are of such potential magnitude and global concern that immediate action must be taken to address the problem. This includes both (1) increased research to improve our ability to predict probable future impacts on human health and the environment and (2) effective action on the development and implementation of policies and strategies to ameliorate or reduce the extent of future stratospheric ozone depletion – actions that need to be initiated and carried out even now, in parallel with the research needed to allow better sharpening and adjustments of future strategies.

In seeking ways to address the stratospheric ozone and associated global warming problems, the unusual nature of these new challenges are being recognized and taken into account by this Conference and other international meetings and, very importantly, by the development and signing of the 1987 Montréal Protocol on Substances that Deplete the Ozone Layer. The Montréal Protocol is viewed by many as one of the most significant historical events in international relations concerning environmental protection, with concerted action beginning to be taken by a large group of nations in anticipation of what could be a major global environmental problem. International cooperation is critical to the long-term success of the Montréal Protocol and all nations need to move forward to ratify and implement it as quickly as possible.

Crucial to effective implementation of the Montréal Protocol are certain research efforts that can contribute importantly to the future risk assessments scheduled to be conducted in the 1990s under terms of the protocol. Five specific areas of future research and assessment are especially important for understanding and dealing with stratospheric ozone depletion effects on human health and include activities: (1) to investigate mechanisms of immunosuppression in animals and humans, (2) to identify infectious diseases that include a stage or process that could be worsened by exposure to UV-B radiation, and to develop models to explain these diseases, (3) to investigate wavelength dependence and develop dose-response information for humans concerning the effects of UV-B exposure on the incidence of infectious diseases, (4) to determine the impact of UV-B immunosuppression on vaccination efficacy, and (5) to investigate the biology and epidemiology of cataracts and methods to reduce the risk of eye diseases. Special emphasis should be placed here on noting the urgency for obtaining further scientific information on these human health subject areas. They are not only of concern to the industrialized countries but, also, should be of much concern to all nations and peoples, regardless of racial or ethnic backgrounds or geographic locations.

4. GLOBAL WARMING AND CLIMATE CHANGE EFFECTS

Various trace gases emitted due to man's activities, including several noted above as contributing to stratospheric ozone depletion, can act as "greenhouse gases" (GHGs). That is, as their tropospheric concentrations increase, they retard the escape of infrared radiation from the earth's surface and thereby contribute to the trapping of heat near the surface (the "greenhouse effect") and, ultimately, to consequent global warming and climate changes. Thus, considerable concern has evolved with regard to increases in the naturally very low concentrations in the atmosphere of some of these gases, especially: carbon dioxide (CO_2); nitrous oxide (N_2O); methane (CH_4); chloroflurocarbons (CFCs); and tropospheric ozone (O_3).

The atmospheric processes involved in mediating the global warming effects due to GHGs have been extensively reviewed elsewhere, (Villach, 1985; Villach-Bellagio, 1987; U.S. EPA, 1987) and are summarized by others in this Conference. The main focus here will be on a concise summarization of the health effects hypothesized as likely to be associated with global warming and climate change due to the atmospheric accumulation of GHGs, with key points being highlighted from U.S. EPA (1987) and other associated draft analyses.

Estimating likely future global warming trends and associated climate change due to GHGs is extremely complex, with modelling results being highly dependant upon key assumptions about the rates of future increases in various GHGs and numerous other factors. Modelling of the magnitude of the warming directly associated with the radiative forcing by GHGs (without feedback enhancement) projects temperature increases, for example, of about 1.2°C for a doubling of CO_2; another 0.45°C for a simultaneous doubling of NO_2 and CH_4; and an additional 0.15°C from a uniform 1-ppb increase in both CFC-11 and CFC-12. Indirect effects (feedbacks) are expected to occur due to the initial warming - feedbacks that would likely increase temperatures further. Increased water vapour (trapping heat) and snow/ice melting (reducing reflection of radiation back into space) are two examples of such feedback factors expected to increase temperatures. However, major uncertainties exist with regard to feedbacks between global warming and clouds, which could either amplify or, perhaps, reduce a temperature rise. Taking assumptions about rates of increase (or decrease) in GHG concentrations, consequent initial warming effects, feedbacks effects, and accompanying uncertainties into account, numerous modelling efforts have attempted to project likely future trends in global warming. Despite the complexity and uncertainties inherent in such modelling efforts, all typically agree that some global warming will occur during the coming decades, but the ranges of quantitative estimates vary considerably depending on specific assumptions incorporated into the models. Thus, for example, "low" scenarios assuming stabilization or reductions in GHG emissions (that may result from implementation of the 1987 Montréal Protocol) project much lower temperature changes than other scenarios assuming varying rates of increase in GHG emissions and/or differing feedback-effect patterns.

Given the wide range of estimates of global warming trends and patterns of associated climate change emerging from modelling efforts, the estimation of likely human health effects associated with global warming on any quantitative basis is extremely difficult. The onset of any notable global warming effect is also important, with various analyses indicating that temperature trends for the past several decades have been rising steadily (but not clearly beyond average levels within the range of variation seen with cycles of global warming or cooling over the past several centuries before marked anthropogenic emissions of GHGs occurred). Also posing difficulties for the quantitative estimation of human health effects are the expected wide regional variations in temperature and climate characteristics (e.g., rain and snowfall amounts) that may be reasonably projected to result from various global warming trend scenarios. Lastly, it should be noted that, despite general warming trends in long-term average temperatures, wide extremes in both high <u>and</u> low temperatures may occur more frequently in some areas because of changing wind patterns and other factors.

Given the above considerations, little effort is made here to provide quantitative estimates of the probable human health effects associated with global warming and climate change. Rather, this section only qualitatively highlights several general types of health effects that can be reasonably hypothesized as potential direct or indirect consequences of global warming. Effects summarized include (1) potential increases in mortality associated with temperature extremes; (2) possible increased incidence of certain infectious diseases that involve temperature-sensitive vectors as key determinants of their occurrence; and (3) secondary effects that may occur as the result of global warming induced sea-level rise. Analyses that evaluate the potential for these types of effects having an impact on the United States are emphasized as representative examples that may also have relevance by analogy to many other countries, depending on their specific circumstances (e.g., predicted regional temperature changes, presence of temperature-dependent disease vectors, and extent of coastal urban development). Figure 3 illustrates the types of hypothesized human health effects discussed here that may be associated with global warming.

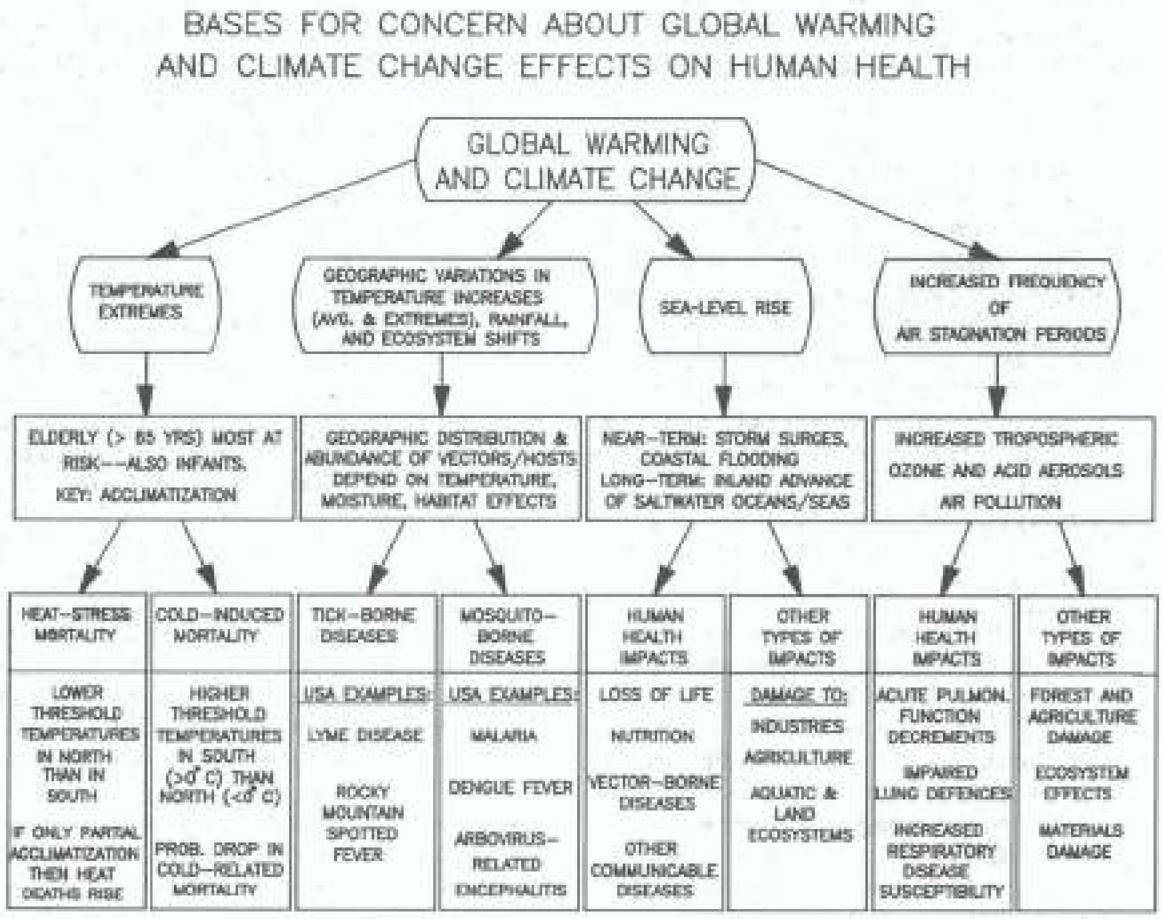

Figure 3.
Bases for concern about global warming and climate change effects on human health. Types of hypothesized likely human health effects include (1) increases in mortality directly linked to temperature extremes; (2) increases in incidence and spread of vector-borne infectious diseases; (3) impacts secondary to projected sea-level rise; and (4) impacts secondary to increased tropospheric ozone or acid aerosols air pollution.

With regard to potential increases in temperature-related mortality, U.S. EPA has commissioned analyses (Kalkstein, 1987) that are evaluating past mortality trends in major urban areas geographically scattered throughout the United States in various climatic regions. These preliminary modelling efforts and earlier published analyses of temperature effects on mortality have helped to identify important factors that affect the magnitude of temperature-dependent mortality and provide initial bases for projecting future temperature-related mortality trends. Key points derived from these efforts are highlighted here. The historical evaluation of 48 U.S. cities indicates that: (1) weather-sensitive mortality occurs mainly as a function of extremes of temperature beyond certain threshold points (for increasing or decreasing temperatures) that are characteristic of any particular city; (2) the extent of the mortality is generally dependent upon the duration of the periods (days) during which the threshold points are exceeded more so than upon maximum temperatures; (3) the major population segment typically most severely affected are the elderly ($\geq$ 65 years old), with the maximum temperature reached being important for this group as well as the duration of the heat-stress period; and (4) excess mortality effects are not fully limited by the amount of time spent indoors during temperature stress periods, suggesting that psychological or other factors (e.g., exposure to indoor air pollutants) may also contribute to weather-associated mortality.

Preliminary threshold temperature findings (Kalkstein, 1987) for summer and winter in U.S. cities suggest that weather effects on mortality are relative (i.e., they vary in relation to the typical conditions to which local residents have become acclimatized). Thus, for example, the highest summer threshold temperatures for mortality were found for the South and Southeast and the lowest in the Pacific and Northeast U.S. regions. That is, heat-related summer mortality increases occurred at much lower temperatures (e.g., starting around 92°F in New York City) in cooler climates than in normally hotter climates (e.g., no evident threshold for Jacksonville, Florida, for maximum temperatures up to around 100°F). Conversely, the lowest threshold temperatures (often well below the 32°F or 0°C, the freezing point) for winter mortality were found for cities in the coldest regions, whereas notably higher thresholds for cold-associated deaths were found for warmer region cities (e.g., Miami, Florida, or Los Angeles, California) with some threshold values for such mortality being well above the freezing point. The lag times for summer-induced mortality were invariably short (not over 1 day), whereas the winter lag times were generally longer for most cities (up to 3 days). Also, the total accumulated number of "cooling degree-hours" and the times of occurrence in the season of particular weather events were important determinants of mortality levels during the summer. Thus, hot conditions early in the spring and summer had a larger impact than similar conditions later in the summer, and the length of the heat-stress period also had a larger impact than the maximum temperatures reached.

Acclimatization is an important factor in determining weather-related mortality, and the greatest initial increases in heat-related mortality might be expected in cities where temperatures are normally cooler and/or in areas where global warming-induced climate changes lead to the increased frequency and durations of high-temperature episodes. On the other hand, eventual acclimatization may occur over the years when higher-than-usual temperatures become the new norm for cities in currently cooler, more northern regions. As for cold-associated deaths, if average winter temperatures were expected not to drop as low in various regions, then it might be predicted that winter mortality would generally decrease owing to fewer days falling below existing winter threshold levels for many cities; however if acclimatization occurs to higher average winter temperatures but wider variations in temperature extremes occur in some areas due to global warming climate changes, then those periods of lower maximum temperatures (especially over several days duration) in some areas could cause even higher-than-past mortality rates previously observed with comparable winter conditions. Further, more sophisticated modelling is also needed to take into account weather-related increases in air pollutants as possible mortality determinants. For example, increases in SO_2 and particulate sulphate species associated with increased coal or oil combustion to generate more heat (in winter) or electricity (in summer for air conditioning) during periods of extreme temperatures may add to any increased mortality due to temperature changes.

What are the implications of the above information? Too many uncertainties currently exist with regard to the numerous factors that would be important in mediating temperature-related mortality increases or decreases to allow for confident predictions at this time. Much more sophisticated modelling needs to be carried out and, obviously, efforts should be expanded to include more than just U.S. cities. Efforts should also be made to validate model predictions as well, tracking future weather-related mortality in various cities during the next several years in comparison with model predictions. Regardless of the outcomes of modelling efforts to obtain specific quantitative predictions of temperature stress-induced mortality, it nevertheless seems clear that major, costly adjustments will likely need to be made in housing conditions and lifestyles in many countries to cope with any future global warming trends.

In addition to the concern about possible increases in mortality due to temperature extremes, the global warming and the consequent climate change may also impact on human health through increases in certain types of infectious diseases. U.S. EPA has begun to evaluate the potential for such effects to occur, as discussed at a recent EPA-sponsored Workshop (ICF/ Clements Associates, Inc., 1987). The most salient points derived from that workshop are summarized here. For many parts of the world, infectious diseases remain among the leading causes of death, as had occurred earlier in industrialized or "developed" countries (where diseases such as influenza, pneumonia, and tuberculosis were among the leading causes of death in 1900). Since then, the incidence and associated mortality for these and other infectious diseases such as diphtheria, typhus and polio have been dramatically reduced in industrialized countries. In these countries, it is unlikely that global warming induced climate changes will cause general increases in the incidence of such diseases, unless serious disruptions of the social structures occur or, in some coastal areas, breakdowns in sanitation happen as a consequence of sea-level rise (as discussed later). The latter eventuality is likely of greater concern for many less-developed countries, where inadequate medical care systems, immunization programs, housing conditions and nutrition make them more vulnerable to the general spreading of infectious diseases.

Of particular shared concern for both developed and less-developed countries with regard to potential global warming impacts are those types of infectious diseases spread by climate-dependent vectors. Vector-borne diseases are those for which the infectious microbial agent is transmitted to humans via another agent (the vector), such as the flea, tick, or mosquito. Well known examples of vector-borne diseases are malaria (transmitted to humans via mosquitos) and bubonic plague (transmitted via fleas or, at times, via animals directly to man as a respiratory disease). Climate changes can affect vector-borne diseases by various direct impacts on the infectious agent, the vector, or intermediate hosts through variations in temperature, humidity, rainfall or storm patterns that alter (1) the multiplication rates of the infectious agent or the vector; (2) the biting rate of the vector; (3) the geographic distribution of the intermediate animal hosts, or (4) the amount of time that intermediate hosts or human hosts are exposed to the vector. Climate changes can also indirectly affect the rates or incidences of vector-borne diseases by their impacts on agricultural practices, ecosystem mixes (of grasses, trees, underbrush, etc.), surface water levels, or other factors that determine intermediate host or vector distribution or survival. The variety of vector-borne diseases is considerable, with diverse ones being of more concern than others for particular countries, depending upon specific climatic conditions and existing pools of infected hosts (both human and intermediate animal hosts). Space does not allow for an exhaustive catalogue of all such diseases that may be affected throughout the world by global warming climate changes. Rather, the following selected examples will be discussed as illustrative of concerns that may apply to many countries for the same or analogous vector-borne diseases: Lyme disease, Rocky Mountain Spotted Fever, dengue fever, malaria and viral encephalitis.

As evaluated by ICF/Clements, Associates, Inc. (1987), Lyme disease (named for its initial recognition in Lyme, Connecticut, in 1975) is an inflammatory disease caused by a spirochete, Borrelia burgdorferi, that is transmitted by several subspecies of Ixodes racinus ticks. The two-year life cycle of the tick vector includes (1) laying eggs in spring that hatch into larval form in one month; (2) feeding of the larva on blood of the host once during the first summer; (3) resting over the first winter; (4) moulting the next spring of the larva to nymph form, which attaches to an animal host, and (5) moulting by the end of the summer into adults found in brush where they attach to larger mammals. Numerous species of birds and mammals have been found to be hosts for the various subspecies of the tick vector, with varying geographic distributions. Lyme disease has four major foci in the United States, is spreading rapidly, and has also been found in several European countries (Germany, Switzerland, France and Austria). The disease is typically contracted during May to November, usually peaking in June-July in parallel with the May-to-July peak period for the nymph stage mainly responsible for its transmission. The distribution of human cases of the disease in the United States tends to match areas where the tick vector is abundant; and deer populations represent key determinants of tick abundance, along with other factors such as temperature, humidity and local vegetation. The precise impact of global warming and climate change on the distribution of Lyme disease is difficult to estimate. The lengthening of warm weather periods and the shortening of winter weather could be expected to enhance the abundance of the tick vector and its potential spread into adjoining areas - if the climate changes (temperature, precipitation, etc.) also favour the wider distribution of deer or other important animal or bird hosts. Shifts of human populations into or out of the affected areas in response to the changes in local climate would also be important for determining if Lyme disease incidence would increase in particular areas.

Rocky Mountain spotted fever (named for its initial identification in western mountain areas but actually much more prevalent in the southeastern U.S. states) is a highly fatal disease if not promptly diagnosed and treated. Caused by the coccobacillus, Rickettsiae rickettsii, the disease is spread by ticks and is also known as tick fever, with analogous diseases being found in many other countries besides the United States. The main North America vectors are the dog tick, D. variabilis and the wood ticks, D. andersoni and D. occidentalis, with varying geographic distributions. The geographic distributions of the ticks parallel rather closely the typical distribution of disease cases seen in the United States with the highest incidence occurring across the south and southeast, especially in the Carolinas. Crucial to the spread of Rocky Mountain spotted fever is the wide variety of intermediate hosts available to the ticks, including many woodland mammals and birds. Temperature is also very important in the transmission of the disease. Certain optimum ranges of high temperatures (24 to 30°C) likely speed the rickettsial growth in the ticks (based by analogy on observations of the growth of a related agent, R. mooseri for mouse typhus).

Also, ambient temperatures are important in determining the breeding season length and the cycles for the ticks as well as their activity levels and biting rates. Each are enhanced by higher temperatures, and the abundance of the vector is held in check in part by the frequency and length of time that the winter temperatures drop well below freezing, thus killing overwintering adults. Lastly, relative humidity conditions and rainfall are important as well, in that hot, dry weather results in the desiccation of the ticks and their eggs, reducing their reproduction. Global warming and associated climate change might dramatically increase the range of the ticks responsible for Rocky Mountain spotted fever into more northward areas of the United States and, possibly, into Canada. This would be expected if milder winters and longer warm seasons were to occur. This assumes, however, that any climate changes also include sufficient rainfall to sustain adequate habitats for host species and adequate moisture for the survival of ticks and eggs. Hot, dry periods associated with possible prolonged drought conditions that might occur in the central United States or in Canadian plains areas under some global warming scenarios would not be conducive to the increased incidence of the disease in such areas.

Malaria, once widespread in the south and southeastern United States, remains endemic in many areas of the world and is caused by four agents Plasmodium vivax, P. malariae, P. ovale and P. falciparum. The agents cause clinical syndromes of varying severity, the most serious being due to P. falciparum, which is typified by fever, chills, sweating and headache and may progress to more dangerous complications and death (>10% fatality in untreated children and non-immune adults). The other forms, although less severe, are nevertheless debilitating and are typified by recurring episodes of fever, chills and sweating. The malarial agents are transmitted from infected humans, as the main host pool, by the bite of various subspecies of anopheles mosquitos. Environmental temperatures of at least 15-18°C are crucial for the development of the malarial agents within the mosquitos. Temperature levels are also important in determining the breeding season length and survival rates for the anopheles mosquito, with the higher tropical temperatures being most favourable. Man's agricultural activities, in providing irrigation ditches and more stagnant water habitats has contributed to the spread of the anopheles mosquito and to its abundance in many areas of the world. Malaria is now rarely endogenously transmitted in the United States, the pool of infected humans as hosts having been very substantially reduced owing to mosquito eradication programs. Prior to such programs, the disease was endemic throughout widespread areas of the Southern United States up to the 1940s, but since then outbreaks mainly have occurred owing to infected immigrants entering the country or U.S. military veterans returning from overseas endemic areas. Global warming leading to higher temperatures in more northerly areas of the United States and Europe could enhance conditions for the spread of the disease. Both the range and abundance of competent vectors, various anopheles subspecies, would likely be increased, especially if increased irrigation were required to support agriculture owing to higher temperatures. Also, higher temperatures in more northerly areas would extend the range of adequate temperatures (>15-18°C) needed for development of the malarial agents in the mosquitos. The remaining key factor in determining the likelihood of the spread of malaria, however, is the infected host pool, with the numbers of infected human hosts moving into or out of areas of enhanced vulnerability likely being of crucial importance.

Dengue fever is another mosquito-borne disease, which is caused by four serotypes of a Group B arbovirus. Fever, general muscle ache, severe headache, and retroorbital pain typify dengue fever, which is usually not fatal. However, it can sometimes progress to dengue haemorrhagic fever (DHF) or dengue shock syndrome (DSS), which can be fatal. Once endemic in the southern United States, along the Gulf and south Atlantic coasts, dengue fever is now rarely endogenously transmitted in the United States. The Aedis aegypti mosquito is the primary vector for dengue fever, with a wide distribution across the southern United States. The breeding season of A. aegypti is temperature-dependent, with breeding year-round in southern Florida, nearly year-round in the rest of Florida and along the Gulf coast, and distinctly shorter periods for successively more northward bands of geographic distribution. Another potential vector Aedes triseriatus is endogenous to states east of the Mississippi; and Aedes albopictus, a proven vector for dengue introduced from northern Asia, has been identified now in scattered U.S. sites. Higher temperatures also seem crucial for the transmission of dengue, since the transmission of Den-2 occurred experimentally only if A. aegypti mosquitos were kept at 30°C, and since the extrinsic incubation period for the virus to develop in the mosquitos was shortened if temperatures were increased to 32-35°C. Consistent with this, increases in cases of dengue haemorrhagic fever have been observed at non-U.S. sites when daily mean temperatures were 28-30°C during hot seasons, but decreases occurred during cooler seasons when daily mean temperatures were 25-28°C. Global increases in temperature in temperate areas with A. Aegypti or A. albopictus present would tend to expand the range of these vectors competent for the spread of dengue fever. This includes the potential spread especially of A. albopictus farther north in the United States and, perhaps into, Canada - in view of its adaptation to cold weather as well. However, whether or not increases in dengue actually occur will likely depend on the distributions of moisture content and rainfall, the effects of agricultural practices (e.g., increased irrigation), and the movements of infected human hosts into or out of areas with increased vector density.

Arbovirus-induced encephalitis syndromes vary in severity but include several that can be highly fatal and are related to several other types of arbovirus-related syndromes (e.g., yellow fever, dengue and other haemorrhagic fevers, hepatitis, arthritis, rashes and various tropical fevers). The different types of mosquitos that serve as competent vectors for the arbovirus-encephalitis types of concern for the United States display differential patterns of distribution and differentially infect various other hosts besides man, e.g., birds and large vertebrates (horses, etc.) for some, birds and swine for another, and small woodland animals for others. All appear to have temperature-dependent components involved in the development or transmission of the viruses, but specific effects vary for different types. For example, the maximum temperatures allowing the western equine encephalitis (WEE) vector to transmit the virus effectively are below 25°C, and this allows the earlier spread of the disease in warm periods and the possible more northern spread of the disease. On the other hand, St. Louis encephalitis (SLE) arbovirus development and transmission are markedly enhanced by temperatures exceeding 25°C. Rainfall and moisture patterns are also important, with most vectors (e.g., Cx tarsalis) benefitting from higher rainfall; but at least one (Cx pipiens) is enhanced by less rainfall, with outbreaks of its encephalitis syndrome being more common during high-temperature drought periods. Thus, the likely effects of global warming and climate change on the incidence and spread of arbovirus-related encephalitis syndromes are difficult to predict. However, in general, it would appear that higher temperatures should enhance the abundance and wider geographic distribution of most of the competent mosquito vectors in the United States. Or, for some, shifts in major areas of their distribution may occur from the present favourable areas to newly more favourable ones. All of this again assumes that higher temperatures and rainfall patterns will be such so as to allow adequate habitats for other hosts besides humans in the potential new range areas. Lastly, as noted before for the other infectious diseases discussed, the movement of populations into or out of the affected areas will also be important in determining any increased (or decreased) incidence of arbovirus-related encephalitises. Also, of particular concern would be the introduction of any new arboviruses not now currently endemic to the United States; for example, Japanese B encephalitis (VBE) is not currently found in the United States, but it is closely related to SLE in terms of involving Culex mosquitos and birds, and several Culex subspecies in the United States have been found to be effective vectors for the virus.

The above discussion concerning the potential effects of global warming and climate change on the incidence and spread of infectious diseases is further complicated by considerations of the possible impacts of expected sea-level rise in response to global warming. Some low-lying coastal areas now serving as excellent habitats for certain mosquitos, for example, might come to be inundated by seawater and would no longer be available for breeding areas. Or, on the other hand, increased storm surges or expansion of marshy areas reaching farther inland might contribute to the creation of conditions in some areas more favourable to enhance mosquito breeding. Besides such potential effects of sea-level rise, perhaps of much more immediate and clear concern is the potential for the disruption of sanitation systems. The spread of infectious diseases, besides the vector-borne types discussed above, could be markedly increased if the flooding of coastal cities increases. The inundation of sewage treatment facilities and sewage lines might not only result in the immediate spread of disease-containing fecal or other material, but damage to such sanitation system components could result in the long-term disruption of waste-removal capabilities and in the spread of disease, until adequate repairs could be accomplished.

Lastly, another concern with sea-level rise is the potential for flooding waste disposal sites, e.g., garbage dumps, along coastal areas. This could also result in an increased spread of infectious diseases, depending upon the specific materials present in such dumps and the extent of their dispersal due to flooding. The flooding of dump sites containing hazardous chemical wastes represents yet another potential concern associated with sea-level rise. The spread of various toxic chemicals from such waste disposal sites would carry with it increased threats of many types of possible health effects, as well as a wide variety of potential environmental effects (vegetation damage, contamination of crop lands by toxic chemicals, etc.). All of these potential eventualities argue for the careful consideration of the steps that may need to be initiated now to cope with projected sea-level rise (e.g., protective diking or relocation of waste disposal facilities along coastal areas, etc.).

5. CONCLUSION

The preceding discussion has highlighted human health effects associated with tropospheric ozone and acid aerosols air pollution as major regional air pollution problems involving the long-range, often transboundary transport of pollutants or their precursors. The effects of stratospheric ozone depletion and global warming were also discussed as issues more global in scope of importance for international evaluation and cooperation. With regard to the latter two problems, it is crucial to emphasize their likely interrelationships with the first two, i.e., the anticipated worsening of both tropospheric ozone and acid aerosols air pollution problems as a consequence of stratospheric ozone, global warming and associated climate change. It is also very important to note the contribution of tropospheric ozone as to global warming effects and the commonality between sources (i.e. fossil-fuel combustion) contributing both to global warming (through the release of CO_2 and other GHGs) and acid aerosols formation (through the release of SO_2, NO_x, etc., as acidic species precursors). Thus, all of the types of problems discussed here are interlinked and, in many ways, contribute to feedback effects that exacerbate the causes of the other problems and/or their resulting effects. The fostering by the present Conference of an increased understanding of all of these issues and their interrelationships should aid greatly in developing effective international cooperation in dealing with them.

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Table 1. Potential effects of increased UV-B radiation resulting from decreased stratospheric ozone[1].

Effects	State of Knowledge	Potential Global Impact
Skin Cancer	Moderate to high	Moderate
Immune System	Low	High
Cataracts	Moderate	Low
Plant Life	Low	High
Aquatic Life	Low	High
Climate Impacts*	Moderate	Moderate
Tropospheric O_3	Moderate	Low**
Polymers	Moderate	Low

* Contribution of both stratospheric ozone depletion itself and gases causing such depletion to climate changes, including sea-level rise.

**Impact could be high in selected urban or rural areas typified by local or regional-scale surface-level O_3 air pollution problems.

[1] Modified from SAB-EC-87-025 "Review of EPA's 'An Assessment of the Risks of Stratospheric Modification' by the Stratospheric Ozone Subcommittee", Science Advisory Board, U.S. Environmental Protection Agency, March, 1987.

STRATEGIES TO COPE WITH CLIMATE CHANGE

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United Nations Environment Programme
Nairobi, Kenya

1. INTRODUCTION

Mr. Chairman, Distinguished Delegates, Ladies and Gentlemen:

It is a privilege for me on behalf of the United Nations Environment Programme to have the opportunity to address this Conference.

We are very grateful to our Canadian hosts for their initiative and their hospitality.

The conference addresses an urgent need and the most important global environmental issue.

I can think of no more appropriate country to play host to this subject. All of us will agree that Canada is inseparably associated with an earlier related major initiative - The Montréal Protocol on Substances that Deplete the Ozone Layer, signed by 24 nations and the EEC last September. Once again Canada is in the vanguard of initiatives concerned with the atmosphere, the global environment and the global commons.

Let me at this point inject some good news related to the protocol. And that is that, with Uganda's ratification of the 1985 Vienna Convention on the Protection of the Ozone Layer last week, we now have the 20 ratifications needed for the Convention to enter into force in September.

For 10 years UNEP worked - with government, international agencies, scientists, industry and legal experts - to help define the ozone issue, develop the options to deal with it, and shape the international agreements at Vienna and Montréal.

The road to Montréal was long. The road beyond Montréal to strategies and policies to cope with climate change will be longer ... and more difficult. This conference is an important milestone along that road. It is one of the many milestones we will have to pass before we reach a practical solution to this huge environmental issue.

The ozone agreement saw many milestones. It was the product of a step-by-step international procedure, which included:

- Assessments of the nature and scale of the depletion issue and its anticipated effects
- Identification and definition of the most appropriate responses
- The mobilization of the community of nations to reach agreement on and take concerted measures to deal with the problem

This procedure involved international meetings, a World Plan of Action for Research and Assessment, a Coordinating Committee of governmental and scientific experts, and a series of discussions, panels and workshops that gradually drew upon the experience and expertise of scientists, industry, diplomats, lawyers and policy-makers.

In this process UNEP armed itself and all the interested parties with the issues, the information, the options and the legalities required for decisions and agreements. As a consequence, all parties came to Montréal with as complete an understanding as possible, of facts, assessments and options.

From the earliest examination of ozone destruction theory to adoption of the final act it took over 10 years, almost five of which was necessary for developing the international agreements. This marshalling of the global response was fairly swift, particularly when it is appreciated that the protocol is unprecedented in international law.

The Montréal protocol may, like many other international accords, be considered by some to be less than an ideal solution as it presently stands.

But it is a pragmatic document that balances environmental, political and economic interests. It can be tuned or amended should new evidence emerge of any changes in the risks to the ozone layer.

But of overriding importance, the protocol provides for an agreed framework within which governments can work together on the problem and its solution.

Unless and until the protocol is ratified that framework does not exist.

Therefore, our primary objective - and it is UNEP's - must be to achieve early governmental ratification and implementation. We hope this will be accomplished before year's end.

The challenge we are addressing this week - climate change - will most certainly have profound impacts on the social fabric of the earth's inhabitants. It must be a top priority for the international community; it is a top priority for UNEP.

Because the problem is man-made and global, no effective solution is possible without broad international cooperation.

The international effort to manage the problem - to the extent we can - will have to embrace an approach that will

- Enable us to expand our understanding and reduce uncertainties through improved monitoring, assessment and modelling
- Develop a greater research programme to improve our knowledge of the causes, mechanisms and effects
- Establish machinery that will enable us to achieve national and internationally agreed policies for the reduction of the causative gases
- Adopt strategies that will minimize damage and help us cope with the unavoidable climate changes and sea-level rise.

As we heard yesterday, a key element in any strategy to manage the greenhouse effect will be to emphasize energy efficiency, promote conservation of energy, adjust the energy mix in favour of less polluting fuels, and develop environmentally safe renewable energy sources - solar, wind, biomass and geothermal. Nuclear energy too must be one of the alternatives considered, but only if it can be developed safely. Proliferation, high cost, health and waste disposal are still key issues.

Because deforestation is a source of carbon dioxide and other greenhouse gases, steps to reduce deforestation and increase afforestation must be part of the broad climate-change solution.

Likewise, urgent implementation of the Montréal Protocol will help cut back on greenhouse gases. Early scientific review of the protocol's adequacy after ratification is clearly called for.

Development of and exchange of information on technologies related to fuel efficiency, removal of CO_2 and trace gases, disposal of CO_2 in the deep ocean, genetically-engineered food crops and the like are all needed.

In this connection a key consideration must be how to provide assistance to developing nations, in terms of technology transfer, financial assistance, commodity sales and debt relief. The full participation of all nations will be essential to success.

We mentioned yesterday on a number of occasions that many of these urgently needed actions to help deal with climate change are actions that are equally sound for other reasons. Reforestation provides ground cover, preventing erosion and protecting watersheds. Energy efficiency saves money. Therefore we must enlist those other interests as allies in managing climate change. They would form a grand coalition for sustainable development. We will want to know more about the financial and societal costs of these zone alternatives. Many argue that they can be carried out without sacrificing economic growth, and they will give us additional time to adapt to the unavoidable aspects of climate change.

We must begin now as well to undertake strategies that will minimize damage and cope with anticipated changes. Here it is clear that river, estuarine and coastal zone policies will be needed to address sea-level rise. Shifts in agricultural practices may be called for. Costs of some of these changes should be considerable.

However, it is hard to imagine the sort of adaptation some island or low-lying coastal and island nations would be able to make when condemned by current prediction to become coastal shallows.

Whereas most projected climate change impacts will probably be unwelcome, some could bring benefits. Potential agricultural land presently unused because of long winters and excessive cold, and the present ice and permafrost limits to the northward extension of shipping routes and human habitation could be different in a warmer world. Therefore we will have to be ready to take advantage of these new opportunities, while recognizing that because of the many changes and disruptions those benefits are not likely to outweigh the losses. We will have to face additional considerations like population, for example, as mentioned by our distinguished Chinese representative.

Let me address a question that is part of UNEP's thinking and was raised several times earlier in our discussion: "Could the ozone layer convention and protocol serve as a model for addressing climate change, and other global problems?"

UNEP's view is that the experience and achievement of the ozone agreements may well give us a valuable guide for approaching the modification of climate. We must recognize that the climate problem is infinitely more complex than the ozone one. But, nonetheless, the deliberate, collaborative and structured approach used by the international community to address the ozone depletion problem could be followed generally in the climate change problem. The ozone convention model of a broad, general agreement to bring governments together to address the problem, conduct research, exchange information and analyse the issues was a sound approach. Decisions on the need for additional protocols to the framework convention, if desired, could be addressed later as was done for the Montréal protocol.

We must, however, in the meantime put a high priority on learning more about the climate-change problem and our possible responses to it. In particular, what are the likely regional impacts and the extent of the controls on greenhouse gases that are sufficient to contain climate change within a familiar range, say, a temperature increase of 1° Celsius and a sea-level rise of 12 cm per century. It is possible to learn such things. The knowledge will help people in various parts of the world to focus more clearly on their own, and others, challenges. And unless there is a climatic surprise equivalent to the ozone hole about to spring unexpectedly upon us, there may be time to develop a mixture of appropriate responses that could avoid irreversible change and keep effects within acceptable bounds.

Our discussions in the past few days have convinced us that long-term problems do have an urgency. Recall the story of the great French general of World War I, Marshal Lyantey who during retirement asked his gardener to plant a tree. The gardener objected saying "Marshal, this tree is slow growing and will not reach maturity for a hundred years". Lyantey replied, "In that case, there is no time to lose. We will plant it this afternoon." And so must we.

Based on our experience with the ozone question, UNEP has initiated a programme of studies to identify the range of possible national, regional and global responses to climate change and to establish the process through which the best practical solutions can be put into effect.

The basis of the programme is greater scientific understanding. In addition to these national research programmes, the WMO/ICSU World Climate Research Programme and the International Geosphere/Biosphere Programme are already studying the uncertainties relating to man's impact on climate and the interactive relationships between the land, the atmosphere and the oceans.

Since 1979, UNEP has managed the Climate Impact Studies Programme as part of the World Climate Programme, in cooperation with WMO and ICSU.

We are proceeding on the impact studies through assessments and carefully structured research programmes designed to enhance our understanding of the future impact of climate change. Next, we are seeking the appropriate management options using sustainable development for environmental integrity.

The WMO/UNEP/ICSU meeting at Villach in 1985 established the primary direction and guidelines for our efforts. It identified the issues and provided recommendations for the research needed to quantify the unknowns.

- Villach called for dissemination of knowledge on climate change; UNEP has published books, prepared audio-visual materials and TV films to educate a wider audience on the issue.
- Villach recommended encouraging a dialogue with the scientific and political communities on climate change; UNEP has organized or supported a series of meetings, including this one, designed to provide an interdisciplinary assault on the problem.
- Villach pointed out the need for a greater understanding of regional climate change and policy considerations; UNEP is encouraging regional studies around the world; some of those are conducted by nations

themselves, including Canada's Great Lakes Study, and U.S. and Dutch studies. In the developing world we have initiated regional studies in South-East Asia, in Latin America and Africa. Using a variety of analytical methods we are seeking to identify the environmental sectors vulnerable to climate change, then to quantify the possible impacts and to develop the array of possible response options.

- Villach identified the problem of sea-level rise; UNEP has commissioned a vulnerability analysis of global, coastal, delta and estuarine regions susceptible to sea-level rise. Our Ocean and Coastal Areas Programmes is conducting a climate change and sea-level impact study for each global region.

Beyond the Villach directions, UNEP has collaborated with the Beijer Institute and others in a series of conferences in Villach, Bellagio and elsewhere designed to identify regional climate vulnerability and various policy options. The results of these meetings are before you at this conference. Within this framework of studies, meetings and panels, we have been proud to play a supportive role in this conference. We believe that it will inform participants, foster a creative dialogue, and draw world attention to a global environmental problem of utmost urgency. But more importantly we see our conference here as providing hope and direction by furnishing a blueprint for international cooperative action on climate change. The results of this conference will be fed into additional workshops and panels on policy options and assessments leading to policy recommendations.

Yesterday, Secretary General Obasi referred to another step WMO and UNEP are taking together - the establishment of an Intergovernmental Panel on Climate Change. It will comprise a representative cross-section of government representatives actively interested in climate-change research programmes. The panel will arrange international assessments, seek to establish an international consensus on climate change-problems and pave the way for the kind of coordinated international response called for by our speakers here in the past two days. It will begin its work in the autumn.

If governments decide that an international <u>convention</u> is needed to promote climate-change management, then their legal and technical experts could be brought together to elaborate appropriate legal instruments. These could deal generally or specifically with aspects of climate change or address existing and future atmospheric problems.

<u>This approach</u> could help the international community to enter the twenty-first century less in the state of a victim of disturbed nature and more in a position to exercise control over the climate-change problem, prepared for anticipated change, ready to take adaptive measure and reap whatever benefits are possible.

The actions I have outlined are only a modest, indeed humble, start on the world's largest and most far reaching environmental concern. The task ahead will be long and hard, it will involve our entire society, and we have barely begun. Nonetheless, if we are to leave future generations a liveable world we have little choice but to address climate change with all the energy, wisdom and determination we have.

In 1962 President John Kennedy of the United States made a State Visit to Canada during which he undertook an environmental task. He planted a tree and while doing so he sprained his back. Upon returning to Washington he received a sympathetic message from Prime Minister John Diefenbaker. Kennedy replied: "Mr. Prime Minister. Thank you for your thoughtful message. The tree will be there long after the discomfort is gone."

And I believe, if we devote the needed energies to managing climate change, the planet's trees and climate will be intact long after our discomfort is gone.

ABSTRACT

STRATEGIES TO COPE WITH CLIMATE CHANGE

No more important task confronts us than the preservation of the integrity of the atmosphere. None more clearly demonstrates the international nature of environmental issues and the need for concerted international co-operation to address them. As we will have to act together, so must we conduct together the assessment of global warming and its effects and define the alternatives available to us. The difficulty and duration of the scientific tasks set by the "greenhouse" phenomena give us a brief time to consider the policy options and the necessary action that will flow from them. The international protocol signed at Montrêal in 1987 to protect the ozone layer set an encouraging precedent showing that statesmen and scientists have the ability to face a remote environmental threat. But even with the precedent to guide us, it must be recognized that the policy options to combat or cope with global warming are likely to be far more difficult to implement than the solutions to ozone depletions are. It was difficult enough to obtain an agreement to reduce the consumption and production of ozone-damaging substances. Reducing the buildup of carbon dioxide and other greenhouse gases involves decisions that would necessarily be much more effective.

Effective action on this global problem cannot be taken by any individual government or even group of nations. For the process by which international action could be agreed on and implemented will raise great economic, political and diplomatic challenges. Global warming is a crucial issue for mankind and requires the urgent attention of everyone.

RÉSUMÉ

STRATÉGIES RELATIVES AU CHANGEMENT CLIMATIQUE

Rien n'est plus important à l'heure actuelle que la sauvegarde de l'intégrité de l'atmosphère et rien ne traduit plus clairement la nature internationale des problèmes environnementaux et le besoin d'une coopération internationale concertée pour traiter ces problèmes. Comme il nous faudra agir ensemble, nous devons évaluer ensemble le réchauffement mondial et ses effets et déterminer ensemble les solutions qui s'offrent à nous. La difficulté et la durée des travaux scientifiques que nécessite l'étude du phénomène de l'effet de serre nous donne un bref intervalle de temps pour examiner les options politiques et les mesures nécessaires qui découleront de cette étude. L'accord international conclu à Montréal en 1987 pour protéger la couche d'ozone constitue un précédent encourageant quant à l'aptitude des dirigeants et des scientifiques à faire face à une menace environnementale lointaine. Toutefois nous devons reconnaître que malgré ce précédent, il est probable qu'il soit beaucoup plus difficile d'appliquer des options politiques pour lutter contre le réchauffement global ou pour nous adapter à celui-ci que de mettre en place des solutions pour lutter contre la diminution de l'ozone. Conclure un accord visant à réduire la consommation et la production des substances qui détruisent l'ozone fut une tâche difficile. Réduire l'accumulation du gaz carbonique et des autes gaz à effet de serre nécessite des décisions d'une portée bien plus grande que dans le cas de l'ozone. En outre, des mesures efficaces contre ce problème mondial ne peuvent pas être prises individuellement par certains gouvernements ou même par des groupes de nations. En effet, le processus par lequel on conviendra d'appliquer des mesures internationales soulèvera de grands problèmes économiques, politiques et diplomatiques. Le réchauffement mondiale est un problème crucial pour l'humanité, problème qui nécessite l'attention urgente de chacun.

PANEL SUMMARY

RESUME DE LA TABLE RONDE

PANEL DISCUSSION ON ENVIRONMENT AND DEVELOPMENT

On the final morning of the Conference, following the presentation of the Statement, there was a panel discussion on Environment and Development, in which eight senior political and scientific officials made oral presentations designed to give their regional perspective on the challenges of sustainable development. It also provided them with an opportunity to comment on the Conference Statement and to present their views on how human activities must be managed to secure future development of the world's resources and environmental quality.

As a means of summarizing the highlights of the discussion, direct quotations have been selected from the presentations and are reproduced below in the Proceedings. Audio tapes of the complete statements are available by contacting the Library of the Atmospheric Environment Services, Downsview, Ontario, Canada M3H 5T4.

Stephen Lewis (Panel Chairman)
Ambassador and Permanent Representative of Canada to the United Nations

> "I have never attended a Conference that was so substantial and thoughtful in its content. The Conference has not yet reached its conclusion but the process at arriving at that conclusion has been extraordinarily sound.
>
> We seek a general consensus. Unanimity is not necessary and probably cannot be achieved. We are not seeking a definitive comment on these issues for all time. We are simply attempting, collectively, in good faith, and in the spirit of the proceedings that have gone before, ... to agree to certain broad principles, statements and objectives."

Dr. Jose Goldemberg, President
University of Sao Paulo, Sao Paulo, Brazil

> "Some will think that the industralized countries that have been responsible for the greater portion of CO_2 and other gases thrown in the atmosphere up to now will set up limits and other regulations on further emissions applicable to all countries and, therefore, to the developing ones, which are almost innocent in perpetuating these offenses. In other words, they will be punished for being latecomers. This might be particularly the case in China and the Soviet Union, which have plans for greater expanded production, but it is also true for Brazil and other Latin American countries that are permitting the destruction of their tropical forests.
>
> The argument will be repeated that development should come first, and environmental concerns later. This argument sounds particularly strong when it is said - and it was repeated here several times - that energy is so essential for development. These reactions will have to be faced frontally by the ones who have attended this Conference and know that the argument above is incorrect and a misrepresentation of the truth. The truth is that developing and developed countries do not have to repeat the mistakes of the past.
>
> Unfortunately, there is the widespread belief around the world, parti-

cularly in the developing world, that energy consumption goes up together with development and that there is an ideal link-relationship between energy consumption and gross domestic product. That, for example, is the rationale for quadrupling coal production in China during the next 15 years. It turns out that this link has been proven to be weak and that it can be broken. The use of modern, efficient technologies and a different mix of energy sources can assure progress with a lower energy consumption. This has been proved in an unambigious way by what has happened in the OECD countries in the last 15 years, where the Gross Domestic Product has grown approximately 30% without any increase in energy consumption.

It is important for the world to realize that increased CO_2 emissions and other gases in the atmosphere is a world-wide phenomenon and that cutting trees indiscriminately in the Amazon valley will contribute to temperature rises in New Delhi or Chicago the same way as coal burned in the Ruhr Valley will contribute to a raising of the sea-level in the coastal areas of Bangladesh or Rio de Janeiro. Since there is an immense need for development, an infrastructure building lies ahead for developing countries. They should leap-frog industrial countries and adopt efficient, modern technologies. Energy is not an end in itself. It is a means to attend to basic needs and the craving for amenities, which is so strong in the developing world. Development can be achieved by using less energy than in the past, and also in a less polluting way thus preserving the quality of our atmosphere. The preservation of the atmosphere is not inconsistent with development. This Conference says that and the Conference Statement is very clear in making this statement. This, I think is the new gospel that we will have to spread."

E.H.T.M. Nijpels
Minister of Public Housing, Physical Planning and Environment, The Netherlands

"To tackle the problem of climate change, we need a new ethic. We are no longer dealing with local or regional pollution problems, but with a world-wide problem. All countries - some more than others, depending on their level of development - contribute to global pollution. That means that there must be a fundamental recognition of our shared responsibility for the atmosphere of the earth. We must act together. No country - no matter how big or how small - can solve this problem, but at the same time each country must pay its contribution to solve the problem, whether there is a global commitment or not. This requires an awareness of our interdependence and our common responsibility.

Industrialized countries are responsible for most of the greenhouse gas emissions. We are creating most of the problems, so we should provide most of the solutions. We should start to reduce our emissions even before international agreements are signed. Only then we can gain enough credibility to ask developing countries to contribute their share and to be a partner in an international convention. We cannot expect developing countries to be able to pay, so we need a funding mechanism ... the possibilities of a fund based on a small levy on every litre of fuel being used in industrialized countries is worth strong support.

There are two essential conditions that have to be fulfilled before effective action to bring the problem of climate change under control can be taken. First of all the degree of certainty about the scientific data has to be sufficiently high. We must be 95% sure that we have a problem. This condition is already fulfilled. The second condition is the political will to act. Although each country must take action itself, I am convinced that the solution to our problem requires an international treaty for the protection of the atmosphere. It is not only necessary to get a world-wide reduction of greenhouse gases, but also to eliminate unequal competition and to formulate goals. I think the process designed by UNEP and WMO to get such an agreement deserves the warmest support and I mean political support."

Dr. Yuri Sedunov
State Committee for Hydrometeorology and Control of Natural Environment, Moscow, U.S.S.R.

"One of the basic concepts of Soviet external policy is the promotion of a comprehensive system of global security, interlinking ecological and economic security.

It is evident that global climate change may completely undermine the resource bases of social-economic development. In this respect the experimentation of the World Climate Programme of WMO seems to us to be most important as well as the formulation and experimentation of new interdisciplinary programmes such as the International Geosphere Biosphere Programme.

The change of the radiation balance in polar regions may be one of the most significant sources of the impact of global climate change. The process of the fast accumulation of CFCs in the atmosphere constitutes one of the most serious potential threats to the ozone layer especially in polar areas. The upper atmosphere and the ionsphere in polar regions are also affected by human activity. It is, therefore, necessary to initiate an international program to study the possible effects of human activity on the ionsphere and upper atmosphere. In this case the multilateral and bilateral co-operation of circumpolar countries is considered essential.

The significance of the transboundary pollution problem became evident during the Chernobyl accident. The development of the system of international controls and identification in the case of a nuclear accident has been initiated. The ecological consequences of nuclear war and the armament race are under constant attention by the world community and the United Nations.

The U.S.S.R. will undoubtedly participate in international activities aimed at understanding and mitigating the unfavourable consequences of climate change. Urgent actions are required. Much remains to be done so that these actions would not be only the acts of goodwill of individual states, but rather of a concerted scientifically motivated program. Final objectives should be clearly formulated and their possibility should be evaluated from the viewpoint of sustainable development on both national and international levels. The aim of starting with a 20 or 50% CO_2 reduction without an assessment of the implications for national and world economies is obviously not sufficient. Every country and every individual should have equal rights to life in an adequate environment, to have enough food and to have sufficient energy - a view shared by the U.S.S.R.

The following urgent actions are necessary:

- modification of future development
- development of a system of global monitoring of environmental pollution and its ecological consequences for each state
- development of long-term global and regional strategies for atmospheric protection
- development of a series of interrelated, international documents containing concrete ways of realizing a long-term global strategy for atmospheric protection
- improvement of international and national mechanisms for environmental protection, in particular, the protection of the atmosphere, including the exchange of and free access to technology in this field;

I have reasons to believe that the process of reconstructing the Soviet economy will provide a solid basis for our participation in the implementation of such actions."

Marcel Masse
Minister of Energy, Mines and Resources Canada

"As Minister of Energy, I believe that nothing is more important than the concerns that have been discussed at this Conference over the last few days. Ministers of energy, as well as ministers of the environment, must take strong action to protect our environment.

The consequences of sudden climate changes must be calculated in terms of many millions of human lives and hundreds of billions of dollars. Some of the world's hottest regions would become hotter; and some of those most in need of precipitation, drier. Coastal zones, where more than half of humanity now lives, are already under siege from population growth, pollution and flooding. A rise in sea-level threatens them with extinction.

The potential for disaster appears to be very great, but surely no greater than the combined efforts we might make to ensure that the future does not conform to bleak predictions. We do have choices. First, we can do nothing. In other words, we can cling to habits of thought that have become bureaucratized and difficult to change. We can maintain patterns of consumption to which we have become attached. We can continue to live frantically in the present, developing policies that discount the future. We can ignore the evidence that we are one world, one planet. We can arm ourselves against our supposed enemies instead of building friendship and cooperation. On the other hand, we can try to adapt to environmental change and limit further stress on the atmosphere. We can set this process in motion by taking the following steps:

- First, we can make gains in energy efficiency in every sector of the economy, thereby also conserving fossil fuels and allowing developing nations greater access to the world's scarce nonrenewable resources.

- Second, in the short-medium term, we can move from a dependence on coal and oil to a greater reliance on natural gas, which has the lowest emission per unit of energy among fossil fuels, and give greater emphasis to electricity.
- Third, we can accelerate the shift to renewable sources of fuels, which is essential to offset the consequences of continued population growth and economic expansion.

As the minister responsible for energy matters in Canada, I am acutely aware of the importance of ensuring that energy production and use is compatible with our ability to sustain the natural environment, and in this regard, I would like to express my support for Prime Minister Brundtland's five-point international action plan. I have set a clear priority for my department, of the search for ways to further the more efficient use of energy in Canada and to diversify Canada's energy mix.

From now on, the arguments for stronger political action to protect the atmosphere must be championed by ministers of energy as much as by ministers responsible for the environment.

Looking ahead, I cannot see that we have any option but to extend the same principles of cooperation that should exist between departments to regions and nations. It would only be a logical extension of enlightened self-interest, which can often afford a sufficient political motive for action."

Marcel Masse
Ministre de l'Énergie, Mines et Resources du Canada

"J'aimerais préciser que, pour le ministre de l'Énergie que je suis, rien ne dépasse en importance les préoccupations qui ont été soulevées au cours de cette conférence. Les ministres de l'Energie, tout comme ceux de l'Environnement, doivent prendre des mesures vigoureuses pour protéger l'environnement."

Les conséquences de modifications climatiques soudaines doivent se calculer en pertes de plusieurs millions de vies humaines et de centaines de milliards de dollars. La température monterait encore dans certaines des régions les plus chaudes du globe; quelques-unes des zones les plus arides deviendraient encore plus sèches. Les régions côtières, qui abritent actuellement plus de la moitié de l'humanité, sont déjà aux prises avec la surpopulation, la pollution et les inondations. Une hausse du niveau des océans menacerait leur survie.

Les risques de catastrophe semblent en vérité être considérables, mais pas plus, certainement, que les efforts concertés que nous pourrions déployer pour que l'avenir ne ressemble pas à ces sombres pronostics. Nous avons pourtant le choix. Tout d'abord, nous pouvons nous croiser les bras. Autrement dit, nous pouvons nous accrocher à des habitudes de pensée qui sont devenues sclérosées. Nous pouvons garder les modes de consommation auxquels nous sommes habitués. Nous pouvons continuer à nous enliser dans le présent le plus immédiat, à élaborer des politiques où l'avenir n'a aucune place. Nous pouvons refuser de voir l'évidence, à savoir que la planète est unique et irremplaçable. Nous pouvons nous armer contre nos ennemis présumés, au lieu d'établir des liens d'amitié et de coopération. Autre solution, nous pouvons essayer de nous adapter à l'évolution de l'environnement et de limiter les contraintes imposées à l'atmosphère. Nous pouvons amorcer ce processus en prenant les initiatives suivantes :

- en premier lieu, nous pouvons utiliser l'énergie de manière plus rentable dans tous les secteurs, en économisant du même coup les combustibles fossiles, et en permettant aux pays en développement d'avoir davantage accès aux ressources limitées de notre planète;
- en deuxième lieu, à court et à moyen termes, nous pouvons réduire l'importance relative du pétrole et du charbon au profit du gaz naturel, qui est le combustible le moins polluant par unité d'énergie produite, et donner plus de place à l'électricité;
- en troisième lieu, nous pouvons accélérer la montée en puissance des sources d'énergie renouvelables, qui nous permettront de compenser les effets d'une croissance démographique et d'une expansion économique constantes.

A titre de ministre responsable des questions énergétiques au Canada, je suis peut être plus conscient que quiconque de la nécessité de veiller à ce que la production et l'utilisation d'énergie soient compatibles avec notre capacité de soutenir l'environnement naturel, et à cet égard, j'aimerais assurer le Premier ministre Bruntland de mon appui aux cinq points du plan d'action international. J'ai assigné à mon Ministère une tâche clairement prioritaire : celle de promouvoir une utilisation plus rentable de l'énergie au Canada et de diversifier le bilan énergétique au pays.

Les ministres de l'Energie, aussi bien que les ministres responsables de l'Environnement, doivent désormais se faire les porte-parole d'un renforcement de l'action politique en vue de protéger l'atmosphère.

Pour l'avenir, nous n'avons pas d'autre solution, à mon avis, que d'étendre aux régions et aux nations les principes de coopération qui devraient présider aux relations entre ministères. Ce ne serait qu'un prolongement logique de l'intérêt bien compris, qui peut souvent constituer une motivation politique suffisante pour justifier une action.

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Cheikh Cissokho
Minister of Rural Development, Senegal

"This Conference must shake the conscience of the world. During the past 20 years in Africa, particularly in the Sahel, we have lived climatic change. We have been subjected to 20 years of drought and desertification, 20 years of climate disruption, 20 years of resource depletion for farmers, fishermen, cattle breeders, etc...

Developing countries are generally more exposed to damages from atmospheric changes than developed countries. We do not have enough scientific knowledge for prevention, and for technological tools to remedy the damage that is caused by the atmospheric pollution coming mainly from developed countries.

Solutions must be global if they are to be effective and workable. A global solution resides in the affirmation of interdependence and co-responsibility. Scientific and technical atmospheric data must be shared globally so that the public will understand what the future has in store for us if we don't change our way of life. Real technological transfer to the developing countries must be implemented for the study and control of atmospheric change. Resources must be shared to remedy damage. The developing countries must be helped socially and economically (mainly those that suffer from desertification) so that they can find new approaches to development and, also, to contribute to restoration. Remission of debts is one of the first actions needed to reverse the actual negative north-south transfer.

We need conferences of this type to establish real cooperation between nations. This Conference resulted in a serious and well-balanced declaration that will set new and objective foundations for our future."

Chiekh Cissoho
Ministre du développement rural, Senégal

"Une Conférence qui doit, une fois de plus, ébranler la conscience de toutes les populations de ce globe. L'Afrique, et particulièrement le Sahel, subit depuis vingt ans un changement climatique. Nous avons connu 20 ans de sécheresses et de désertification, 20 ans de désordre climatique, 20 ans de diminution des ressources pour les agriculteurs, les pêcheurs, les éleveurs, etc . . .

Les pays en développement sont en général plus exposés aux conséquences dommageables des changements atmosphériques parce que nous ne disposon pas des connaissances scientifiques suffisantes pour les prévenir et des utilités technologiques pour apporter les remèdes adéquats aux dommages causés par la pollution atmosphérique qui nous vient principalement des pays développés.

Les solutions doivent être globales pour être efficaces et réalisables. Une solution globale requiert l'affirmation de la solidarité et de la co-responsabilité. Il faut procéder à la diffusion à l'échelle mondiale des données scientifiques et techniques relatives à l'atmosphère afin que le public comprenne ce que demain sera si nous ne changeons pas de conduite. On doit favoriser un vrai transfert de technologie pour l'étude et le contrôle des changements atmosphériques en faveur des pays en développement. On doit favoriser le développement économique et social des pays en développement, particulièrement ceux agressés par la désertification, pour leur permettre d'adopter non seulement une nouvelle approche à leur développement, mais aussi pour contribuer au rétablissement. Une telle démarche passe, à notre avis, par une remise de la dette afin de renverser la tendance actuelle de transfert Nord-Sud négatif.

Il nous faut des conférences de ce genre pour établir une véritable coopération entre les nations. Cette Conférence a abouti à une déclaration que je veux dire sérieuse et équilibrée, qui va nous donner des bases nouvelles et objectives pour bâtir notre avenir."

Congressman George E. Brown, Jr.
36th District - California, U.S. House of Representatives, Washington, D.C., U.S.A. (presented by Congressman Brown's legislative assistant, Ms. Anne Polansky.)

"Keeping the climate change issue alive in the public mind is essential. It will not be an easy task and doing so will require steady, uncompromising vigilance.

We must be mindful that limited resources and stricter budget constraints will force Congress to set legislative and research priorities. Strategies that have benefits other than their ability to slow the warming trend should be undertaken first. Increasing energy efficiency is a shining example of such a strategy; the Japanese perceive climate change as a potential for energy-efficient products.

Establishing and maintaining comprehensive monitoring program to take the earth's vital signs and to check our progress in limiting harmful pollutants and greenhouse gases is paramount."

Dr. Stephen Schneider
National Center for Atmospheric Research Boulder, Colorado, U.S.A.

"A fundamental problem is being confronted, namely the demand of many people in bureaucracies to provide detailed scenarios of the future in which costs and benefits can be carefully weighted using the old economic paradigm.

How will sustainable development play in the United States? Other than famine photos, most of the American public has few images of North-South issues. I doubt if I stopped a hundred people on the street that even 95 of them would be aware that there was even a debate, for example, over the new international economic order. I think that even though we have turned the corner on the greenhouse effect and can probably get relatively quick actions on efficiency, alternative technology and so forth, I think we have much left to do in the United States in order to get adequate funds, ample for sustainable development. I would argue that in addition to our greenhouse metaphors, we need to spend much more time working on that question.

This Conference has gone a long way to help get that development question on the agenda. And it is not even the details that come out but the fact that the Conference itself took place. Getting the kind of group here together with the degree of unanimity really will go a long way in the public consciousness for the importance of this issue. We really should not lose the momentum."

Professor Emil Salim
Minister of State for Population and Environment, Indonesia

"In developing countries, development means the eradication of poverty. That we hope to achieve by satisfying basic needs and by diversifying our economy from a soil-based agricultural economy towards a more balanced economy.

The goal is to aim at a humane quality of life. This is to be accomplished through a development process that takes into account the maintenance of the functioning of nature's life support system and the environment in general. But development requires the exploitation of natural resources, such as land, water and air. To prevent the destruction of these natural resources, government policies are applied, such as the resource-use plan within the framework of spatial planning, the application of environmental impact analysis, and the choice of environmentally-sound technologies. But in implementing these technologies the governments in most developing countries are usually constrained by external factors, such as the world economy with declining commodity prices for such products as rubber, coffee, palm oil, crude oil, tin and other mining products; the appreciation of foreign currencies, leading toward an increased debt burden; the restriction of trade into the developed countries through high import duties or import quotas; changes in the terms of trade in favour of the industrialized countries; and a decline in the foreign investment and foreign aid flowing into the developing countries. This has led to low growth rates, below 5% per annum in most Asian countries.

By the year 2000, we will need intensive agricultural development aid to maintain food self-sufficiency, the movement of industrial development away from a soil-dependent economy towards the service sectors, such as tourism, banking, trade, insurance, and marine resource development.

The World Conference on The Changing Atmosphere has given us sufficient scientific material about atmospheric change and its implications for man and society. The Conference Statement does not promote the zero growth model but rather it proposes ingredients for sustainable development. It has wisely put the discussion in this Conference not on the basis of a North-South or East-West controversy, but rather on that of trying to identify the ways and means for a development pattern with different energy strategies and more environmentally sound development policies. It aims at working towards a net reduction in the emission of greenhouse gases by the year 2000 through cooperation between the developed and developing countries. It calls for a coalition of reason along with a rapid reduction of both North-South and East-West inequalities and tensions to secure a healthy future for Planet Earth".

CONFERENCE DOCUMENTS AND REPORTS

DOCUMENTATION ET RAPPORTS DE LA CONFERENCE

THE CHANGING ATMOSPHERE: IMPLICATIONS FOR GLOBAL SECURITY

CONFERENCE STATEMENT

SUMMARY

Humanity is conducting an unintended, uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to a global nuclear war. The Earth's atmosphere is being changed at an unprecedented rate by pollutants resulting from human activities, inefficient and wasteful fossil fuel use and the effects of rapid population growth in many regions. These changes represent a major threat to international security and are already having harmful consequences over many parts of the globe.

Far-reaching impacts will be caused by global warming and sea-level rise, which are becoming increasingly evident as a result of continued growth in atmospheric concentrations of carbon dioxide and other greenhouse gases. Other major impacts are occurring from ozone-layer depletion resulting in increased damage from ultra-violet radiation. The best predictions available indicate potentially severe economic and social dislocation for present and future generations, which will worsen international tensions and increase risk of conflicts among and within nations. It is imperative to act now.

These were the major conclusions of the World Conference on The Changing Atmosphere: Implications for Global Security, held in Toronto, Ontario, Canada, June 27-30, 1988. More than 300 scientists and policy makers from 46 countries, United Nations organizations, other international bodies and non-governmental organizations participated in the sessions.

The Conference called upon governments, the United Nations and its specialized agencies, industry, educational institutions, non-governmental organizations and individuals to take specific actions to reduce the impending crisis caused by pollution of the atmosphere. No country can tackle this problem in isolation. International cooperation in the management and monitoring of, and research on, this shared resource is essential.

The Conference called upon governments to work with urgency towards an *Action Plan for the Protection of the Atmosphere*. This should include an international framework convention, while encouraging other standard-setting agreements along the way, as well as national legislation to provide for protection of the global atmosphere. The Conference also called upon governments to establish a *World Atmosphere Fund* financed in part by a levy on the fossil fuel consumption of industrialized countries to mobilize a substantial part of the resources needed for these measures.

THE ISSUE

Continuing alteration of the global atmosphere threatens global security, the world economy, and the natural environment through:

- Climate warming, rising sea-level, altered precipitation patterns and changed frequencies of climatic extremes induced by the "heat trap" effects of greenhouse gases;
- Depletion of the ozone layer;

- Long-range transport of toxic chemicals and acidifying substances.

These changes will:

- Imperil human health and well-being;
- Diminish global food security, through increases in soil erosion and greater shifts and uncertainties in agricultural production, particularly for many vulnerable regions;
- Change the distribution and seasonal availability of fresh water resources.
- Increase political instability and the potential for international conflict;
- Jeopardize prospects for sustainable development and reduction of poverty;
- Accelerate the extinction of animal and plant species upon which human survival depends;
- Alter yield, productivity and biological diversity of natural and managed ecosystems, particularly forests.

If rapid action is not taken now by the countries of the world, these problems will become progressively more serious, more difficult to reverse, and more costly to address.

Scientific Basis for Concern

The Conference calls for urgent work on an *Action Plan for Protection of the Atmosphere*. This Action Plan, complemented by national action, should address the problems of climate warming, ozone layer depletion, long-range transport of toxic chemicals and acidification.

Climate Warming

1. There has been an observed increase of globally-averaged temperature of 0.5°C in the past century which is consistent with theoretical greenhouse gas predictions. The accelerating increase in concentrations of greenhouse gases in the atmosphere, if continued, will probably result in a rise in the mean surface temperature of the Earth of 1.5 to 4.5°C before the middle of the next century.
2. Marked regional variations in the amount of warming are expected. For example, at high latitudes the warming may be twice the global average. Also, the warming would be accompanied by changes in the amount and distribution of rainfall and in atmospheric and ocean circulation patterns. The natural variability of the atmosphere and climate will continue and be superimposed on the long-term trend, forced by human activities.
3. If current trends continue, the rates and magnitude of climate change in the next century may substantially exceed those experienced over the last 5000 years. Such high rates of change would be sufficiently disruptive that no country is likely to benefit <u>in toto</u> from climate change.
4. The climate change will continue so long as the greenhouse gases accumulate in the atmosphere.

5. There can be a time lag of the order of decades between the emission of gases into the atmosphere and their full manifestation in atmospheric and biological consequences. Past emissions have already committed planet earth to a significant warming.

6. Global warming will accelerate the present sea-level rise. This will probably be of the order of 30 cm but could possibly be as much as 1.5 m by the middle of the next century. This could inundate low-lying coastal lands and islands, and reduce coastal water supplies by increased salt water intrusion. Many densely populated deltas and adjacent agricultural lands would be threatened. The frequency of tropical cyclones may increase and storm tracks may change with consequent devastating impacts on coastal areas and islands by floods and storm surges.

7. Deforestation and bad agricultural practices are contributing to desertification and are reducing the biological storage of carbon dioxide, thereby contributing to the increase of this most important greenhouse gas. Deforestation and poor agricultural practices are also contributing additional greenhouse gases such as nitrous oxide and methane.

Ozone Layer Depletion

1. Increased levels of damaging ultra-violet radiation, while the stratospheric ozone shield thins, will cause a significant rise in the occurrence of skin cancer and eye damage, and will be harmful to many biological species. Each 1% decline in ozone is expected to cause a 4 to 6% increase in certain kinds of skin cancer. A particular concern is the possible combined effects on unmanaged ecosystems of both increased ultraviolet radiation and climate changes.

2. Over the last decade, a decline of 3% in the ozone layer concentration has occurred at mid-latitudes in the Southern Hemisphere, possibly accompanying the appearance of the Antarctic ozone hole; although there is more meteorological variability, there are indications that a smaller decline has occurred in the Northern Hemisphere. Changes of the ozone layer will also change the climate and the circulation of the atmosphere.

Acidification

In improving the quality of the air in their cities, many industrialized countries unintentionally sent increasing amounts of pollution across national boundaries in Europe and North America, contributing to the acidification of distant environments. This was manifested by increasing damage to lakes, soils, plants, animals, forests and fisheries. Failure to control automobile pollution in some regions has seriously contributed to the problem. The principal damage agents are oxides of sulphur and nitrogen as well as volatile hydrocarbons. The resulting acids can also corrode buildings and metallic structures causing overall, billions of dollars of damage annually.

The various issues arising from pollution of Earth's atmosphere by a number of substances are often closely interrelated, both through chemistry and through potential control strategies. For example, chlorofluorocarbons (CFCs) both destroy ozone and are greenhouse gases; conservation of fossil fuels would contribute to solving both acid rain and climate change problems.

Security: Economic and Social Concerns

As the *UN Report On The Relationship Between Disarmament And Development* states: "The world can either continue to pursue the arms race with characteristic vigour or move consciously and with deliberate speed toward a more stable and balanced social and economic development within a more sustainable international economic and political order. It cannot do both. It must be acknowledged that the arms race and development are in a competitive relationship, particularly in terms of resources, but also in the vital dimension of attitudes and perceptions." The same consideration applies to the vital issue of protecting the global atmospheric commons from the growing peril of climate change and other atmospheric changes. Unanticipated and unplanned change may well become the major non-military threat to international security and the future of the global economy.

There is no concern more fundamental than access to food and water. Currently, levels of global food security are inadequate but even those will be most difficult to maintain into the future, given projected agricultural production levels and population and income growth rates. The climate changes envisaged will aggravate the problem of uncertainty in food security. Climate change is being induced by the prosperous, but its effects are suffered most acutely by the poor. It is imperative for governments and the international community to sustain the agricultural and marine resource base and provide development opportunities for the poor in light of this growing environmental threat to global food security.

The countries of the industrially developed world are the main source of greenhouse gases and therefore bear the main responsibility to the world community for ensuring that measures are implemented to address the issues posed by climate change. At the same time, they must see that the developing nations of the world, whose problems are greatly aggravated by population growth, are assisted and not inhibited in improving their economies and the living conditions of their citizens. This will necessitate a wide range of measures, including significant additional energy use in those countries and compensating reductions in industrialized countries. The transition to a sustainable future will require investments in energy efficiency and non-fossil energy sources. In order to ensure that these investments occur, the global community must not only halt the current net transfer of resources from developing countries, but actually reverse it. This reversal should embrace the relevant technologies involved, taking into account the implications for industry.

A coalition of reason is required, in particular, a rapid reduction of both North-South inequalities and East-West tensions, if we are to achieve the understanding and agreements needed to secure a sustainable future for planet Earth and its inhabitants.

It takes a long time to develop an international concensus on complex issues such as these, to negotiate, sign, and ratify international environmental instruments and to begin to implement them. It is therefore imperative that action on serious negotiations start now.

Legal Aspects

The first steps in developing international law and practices to address pollution of the air have already been taken: in the Trail Smelter arbitration of 1935 and 1938; Principle 21 of the 1972 Declaration of the UN Conference on the Environment; the Economic Commission for Europe (ECE) Convention on Long Range Transboundary Air Pollution and its Protocol (Helsinki, 1985) for sulphur reductions; Part XII of the Law of the Sea Convention; and the Vienna Convention for Protection of the Ozone Layer and its Montréal Protocol (1987).

These are important first steps and should be actively used and respected by all nations. However, there is no overall convention constituting a comprehensive international framework that can address the interrelated problems of the global atmosphere, or that is directed towards the issues of climate change.

A CALL FOR ACTION

The Conference urges immediate action by governments, the United Nations and their specialized agencies, other international bodies, non-governmental organizations, industry, educational institutions and individuals to counter the ongoing degradation of the atmosphere.

An *Action Plan for the Protection of the Atmosphere* needs to be developed, which includes an international framework convention, encourages other standard-setting agreements and national legislation to provide for the protection of the global atmosphere. This must be complemented by implementation of national action plans that address the problems posed by atmospheric change (climate warming, ozone layer depletion, acidification and the long-range transport of toxic chemicals) at their roots.

The following actions are mostly designed to slow and eventually reverse deterioration of the atmosphere. There are also a number of strategies for adapting to changes that must be considered. These are dealt with primarily in the recommendations of the Working Groups.

Actions by Governments and Industry

- *Ratify the Montréal Protocol on Substances that Deplete the Ozone Layer*. The Protocol should be revised in 1990 to ensure nearly complete elimination of emissions of fully halogenated CFCs by the year 2000. Additional measures to limit other ozone-destroying halocarbons should be considered.
- *Set energy policies to reduce the emissions of CO_2 and other trace gases*, in order to reduce the risks of future global warming. Stabilizing the atmospheric concentrations of CO_2 is an imperative goal. It is currently estimated to require reductions of more than 50% from present emission levels. Energy research and development budgets must be massively directed to energy options which would eliminate or greatly reduce CO_2 emissions and to studies undertaken to further refine the target reductions.
- *Reduce CO_2 emissions by approximately 20% of 1988 levels by the year 2005 as an initial global goal*. Clearly, the industrialized nations have a responsibility to lead the way, both through their national energy policies and their bilateral and multilateral

assistance arrangements. About one-half of this reduction would be sought from energy efficiency and other conservation measures. The other half should be effected by modifications in supplies.

- *Set targets for energy efficiency improvements* that are directly related to reductions in CO_2 and other greenhouse gases. A challenging target would be to achieve the 10% energy efficiency improvements by the year 2005. Improving energy efficiency is not precisely the same as reducing total carbon emissions and the detailed policies will not all be familiar ones. A detailed study of the systems implications of this target should be made. Equally, targets for *energy supply* should also be directly related to reductions in CO_2 and other greenhouse gases. As with efficiency, a challenging target would again be to achieve the 10% energy supply improvements by the year 2005. A detailed study of the systems implications of this target should also be made. The contributions to achieving this goal will vary from region to region; some countries have already demonstrated a capability for increasing efficiency by more than 2% a year for over a decade.

  Apart from efficiency measures, the desired reduction will require (i) switching to lower CO_2 emitting fuels, (ii) reviewing strategies for the implementation of renewable energy especially advanced biomass conversion technologies; (iii) revisiting the nuclear power option, which lost credibility because of problems related to nuclear safety, radioactive wastes, and nuclear weapons proliferation. If these problems can be solved, through improved engineering designs and institutional arrangements, nuclear power could have a role to play in lowering CO_2 emissions.

- *Negotiate now on ways to achieve the above-mentioned reductions.*
- *Initiate management systems* in order to encourage, review and approve major new projects for energy efficiency.
- *Vigorously apply existing technologies* in addition to gains made through reduction of fossil fuel combustion, to reduce (i) emissions of acidifying substances to reach the critical load that the environment can bear; (ii) substances which are precursors of tropospheric ozone; and (iii) other non-CO_2 greenhouse gases.
- *Label products* to allow consumers to judge the extent and nature of the atmospheric contamination that arises from the manufacture and use of the product.

Actions by Member Governments of the United Nations, Non-Governmental Organizations and Relevant International Bodies.

- *Initiate the development of a comprehensive global convention* as a framework for protocols on the protection of the atmosphere. The convention should emphasize such key elements as the free international exchange of information and support of research and monitoring, and should provide a framework for specific protocols for addressing particular issues, taking into account existing international law. This should be vigorously pursued at the International Workshop on Law and Policy to be held in Ottawa early in 1989, the high-level political conference on Climate Change in the

Netherlands in the Fall, 1989, the World Energy Conference in Canada in 1989 and the Second World Climate Conference in Geneva, June 1990, with a view to having the principles and components of such a convention ready for consideration at the Inter-governmental Conference on Sustainable Development in 1992. These activities should in no way impede simultaneous national, bilateral and regional actions and agreements to deal with specific problems such as acidification and greenhouse gas emissions.

- *Establish a World Atmosphere Fund,* financed in part by a levy on fossil fuel consumption of industrialized countries, to mobilize a substantial part of the resources needed for implementation of the *Action Plan for the Protection of the Atmosphere.*
- *Support the work of the Inter-governmental Panel on Climate Change* to conduct continuing assessments of scientific results and initiate government-to-government discussion of responses and strategies.
- *Devote increasing resources to research and monitoring efforts* within the World Climate Programme, the International Geosphere Biosphere Programme and Human Response to Global Change Programme. It is particularly important to understand how climate changes on a regional scale are related to an overall global change of climate. Emphasis should also be placed on better determination of the role of oceans in global heat transport and the flux of greenhouse gases.
- *Increase significantly the funding for research, development and transfer of information on renewable energy,* if necessary by the establishment of additional and bridging programmes; extend technology transfer with particular emphasis on the needs of the developing countries; and upgrade efforts to meet obligations for the development and transfer of technology embodied in existing agreements.
- *Expand funding for more extensive technology transfer and technical cooperation projects in coastal zone protection and management.*
- *Reduce deforestation and increase afforestation* making use of proposals such as those in the World Commission on Environment and Development's (WCED) report, "Our Common Future", including the establishment of a trust fund to provide adequate incentives to enable developing nations to manage their tropical forest resources sustainably.
- *Develop and support technical cooperation projects* to allow developing nations to participate in international mitigation efforts, monitoring, research and analysis related to the changing atmosphere.
- *Ensure that this Conference Statement, the Working Group reports and the full Proceedings of the World Conference, "The Changing Atmosphere"* (to be published in the Fall, 1988) are made available to all nations, to the conferences mentioned above and to other future events dealing with related issues.
- *Increase funding to non-governmental organizations* to allow the establishment and improvement of environmental education

programmes and public awareness campaigns related to the changing atmosphere. Such programmes would aim at sharpening perception of the issues, and changing public values and behaviour with respect to the environment.

- *Allocate financial support for environmental education* in primary and secondary schools and universities. Consideration should be given to establishing special units in university departments for addressing the crucial issues of global climate change.

SPECIFIC RECOMMENDATIONS OF WORKING GROUPS

The recommended actions in the Conference Statement are mostly general in nature and common to a number of Conference Working Groups. The specific recommendations of the Working Groups are given in the following section.

ENERGY

1. Targets for energy supply should be directly related to reductions in CO_2 and other greenhouse gases. A challenging target would be to reduce the annual global CO_2 emissions by 20% by the year 2005 through improved energy efficiency, altered energy supply, and energy conservation.

2. Research and demonstration projects should be undertaken to accelerate the development of advanced biomass conversion technologies.

3. Deforestation should be reduced and reforestation accelerated to significantly reduce the atmospheric concentrations of CO_2 and to replenish the primary fuel supply for the majority of the world's population.

4. There is a need to revisit the nuclear power option. If the problems of safety, waste and nuclear arms proliferation can be solved, nuclear power could have a role to play in lowering CO_2 emissions.

5. It is necessary to internalize externalized costs. Policies should be fashioned to achieve broad, complementary social objectives and to minimize total social, economic and environmental costs.

FOOD SECURITY

1. National governments are urged to reduce the contributions of agricultural activities to the concentration of greenhouse gases in the atmosphere. These contributions arise from destruction of forests, inefficient use of inorganic nitrogen fertilizers, the increased conversion of land to paddy rice cultivation and the increased number of ruminant animals.

2. National governments should take the prospect of climate change into account in long-term agricultural and food security planning, particularly with respect to food availability to the most vulnerable groups.

3. National governments and international agencies should give increasing emphasis to a wide array of policy measures to reduce the sensitivity of food supply to climatic variability in order to increase resilience and adaptability to climate change.

4. National governments are urged to increase efforts to build subregional and regional cooperation aimed at achieving food security. International agencies should assist in promotion of these regional cooperative efforts.

5. FAO, World Bank, WMO, UNEP, UNDP, CGIAR and other international organizations should encourage research leading to ecologically sound agricultural management systems.

URBANIZATION AND SETTLEMENT

1. Environmental impact statements and land-use management plans should consider future climatic conditions including the local effects of rising sea-level on coastal communities.

2. Urban authorities should undertake risk assessments and develop emergency planning procedures which take into account the effects of climate change, for example, the increased incidence of natural hazards.

3. National governments and the international aid community should develop policies and actions to deal with the likely increased movements of environmental refugees resulting from climate change.

4. Environmental education must be stressed, particularly with respect to the sustainable development of urban areas and human settlements, and should be strongly promoted by local and national authorities and by international bodies such as WMO, UNCMS, UNEP, UNIDO and UNDP.

5. Comprehensive world-wide assessments should be made by national and international organizations of the vulnerability of specific geographic regions and urban areas to the increased risk of higher incidence of spread of infectious diseases due to global climate change, including both vector-borne and communicable diseases. In these areas, assessments should be made of health care infrastructures of their ability to cope with the projected increased risks of the spread of infectious diseases; and steps should be identified to be taken by local and national authorities and international organizations to improve such capabilities.

6. Assessments should be made of the vulnerability of nuclear facilities, municipal and hazardous waste dumps, and of other waste disposal facilities to the increased hazard of sudden flooding or gradual inundation, and of their potential for the consequent spread of infectious pathogens or toxic chemicals to the surrounding land and sea areas, and appropriate steps should be taken to minimize such risks.

WATER RESOURCES

1. The efficiency of water use and the resilience of existing and planned water resource systems and management processes must be increased to meet existing climate variability.

2. Existing acid rain conventions must be extended to the global scale and modified to include toxic organic pollutants.

3. Integrated monitoring and research programs are urgently required to improve the methods of assessing the sensitivity of water resource systems, to identify critical regions and river basins where changes in hydrological processes and water demand will cause serious problems, and to understand and model the hydrological, ecological and socio-economic impacts of climate change.

4. To alleviate present and future water problems and to achieve sustainable development, we strongly endorse the global principle of inter-regional and inter-generational equity in all actions. International co-operation, open technology transfer, meaningful public involvement and effective public information programs are essential.

LAND RESOURCES

An international fund should be created specifically for development assistance and research in order to:

1. Maintain terrestrial reservoirs of carbon through the careful management and protection of tropical and temperate forests and their soils, tundra and wetlands that represent major carbon pools.

2. Encourage development of sustainable land-use practices through such activities as agroforestry, reforestation, development of varieties for adaptation to climate change, and development of effective management practices for waste treatment and disposal, and through policies for the use, settlement and tenure of land. This requires major changes in aid policy, commercial practices and policies of related organizations (ITTO, FAO/TFAP and ICRAF) as well as possible "debt swapping" for forest protection and access to a reforestation fund.

3. Identify the most productive agricultural lands so as to be able to implement a land reserve system that can be used to mitigate losses resulting from a more adverse climate and sea-level rise.

4. Increase awareness among the public of issues posed by climate change in relation to the continued wise use of lands in a sustainable manner.

5. Broaden existing programs that address the impact on land resources of acid and other toxic depositions, by taking account of their global dimension.

COASTAL AND MARINE RESOURCES

1. Research is required to understand which natural and human factors determine the productivity and variability of marine and coastal resources.

2. Institutional and legal arrangements for the wise use of common property resources must be greatly improved.

3. The flexibility of marine-dependent industries and coastal communities must be greatly enhanced to respond to climate-induced changes.

4. Site-specific impact studies of the effects of sea-level rise must be undertaken. These should include consideration of the human, economic and environmental risks and should result in local education programs.

5. The implications of climate change for coastal-zone planning must be considered, particularly the risk of sea-level rise and/or the potential need to locate new developments inland.

FORECASTING AND FUTURES

1. In order to have any hope in coping with future change, we must acquire and make use of knowledge of the past and develop the ability to anticipate the possible future. No one model can or should be expected to deal with the uncertainties in forecasting, the details needed for making decisions, and the social, technical and economic implications of change. Hence an array of techniques must be used in order to produce useful results.

2. Not only are continued efforts needed to improve forecasting-methodologies and to integrate cause-and-effect modelling, but also improvements are needed in our ability to communicate and convey their implications for the broader culture so that individual and collective decisions can be made appropriately and with foresight. Attitudinal and institutional changes will be necessary because of the projected serious global consequences. Equally important is the need to take action, in an environmentally sustainable way, on the interrelated issues of population growth, resource use and depletion, and technological inequalities.

DECISION-MAKING AND UNCERTAINTY

1. The reduction of uncertainties requires advanced understanding of the chemistry of the atmosphere, of the implications of climate change on health, agriculture, economies, and other social concerns, and of the legal, political and other aspects of the possible responses to climate change (prevention, compensation and adaptation).

2. The industrialized nations should begin to restore the integrity of the environment, making atmospheric change the turning point for an ecological innovation of industrial economy.

3. Emission targets ought to be the subject of an international treaty between the nations that take the first step. Those nations should invite all the others to join them in advancing environmentally sustainable economic development.

4. Open decision-making may well provide for decisions that are not easily accepted by the public. We recommend a democratic discourse about possible responses to the atmospheric threat. Non-governmental organizations should play a decisive role in furthering this discourse.

INDUSTRY, TRADE AND INVESTMENT

Proposed as matters for urgent action are:

1. Creation of a World Atmosphere Fund financed by a levy on the fossil fuel consumption of industrialized countries, sufficient to support development and transfer fuel-efficient technologies.

2. Development of mechanisms for incorporating environmental considerations and responsibilities into the internal decision and reporting processes of business and industry.

3. Formation of an international consultative mechanism at the highest level, reporting to heads of government, to assure:

- accelerated research and development efforts;
- reduction of institutional barriers to the adoption of appropriate low-emission technologies by industries and households;
- improvement of market information to promote the shift of consumption toward ecologically appropriate products.

GEOPOLITICAL ISSUES

1. The particular regions of the world or sectors of the economy that will be damaged first or most strongly by a rapidly changing atmosphere

cannot be foreseen today, but the magnitude and variety of the eventual impacts is such that it is in the self-interest of all people to join in prompt action to slow the change and to negotiate toward an international accord on achieving shared responsibility for care of the climate and the atmosphere.

2. Coordinated international efforts and an all-encompassing international agreement are required along with prompt action by governmental agencies and non-governmental groups to prevent damaging changes to the atmosphere. Such actions can be based on improvements in energy efficiency, the use of alternative energy sources, and the transfer of technology and resources to the Third World.

LEGAL DIMENSIONS

1. More states should observe the international principles and norms that exist and all should be encouraged to enact or strengthen appropriate national legislation for the protection of the atmosphere.

2. The offer of the Prime Minister of Canada to host a meeting of law and policy experts in 1989 should be accepted. That meeting should address the question of the progressive development and codification of the principles of international law taking into account the general principles of law set out in the Trail smelter, Lac Lanoux, Corfu Channel cases, Principle 21 of the 1972 Declaration of the United Nations Conference on the Human Environment, the Convention on Long-Range Transboundary Air Pollution and related protocols, Part XII of the Law of the Sea Convention and the Vienna Convention for the Protection of the Ozone Layer and its Montréal Protocol. The meeting should be directed toward the elaboration of the principles to be included in an umbrella/framework Convention on the Protection of the Atmosphere - one that would lend itself to the development of specific agreements/protocols laying down international standards for the protection of the atmosphere, in addition to existing instruments.

INTEGRATED PROGRAMS

1. A thorough review is required to establish the institutional needs for cooperation in research, impact assessment and development of public policy options at the international, intergovernmental and non-governmental levels, at regional levels and at national levels. This review should be completed by 1992.

2. Extension and further development is required for a United Nations global monitoring and information system that will incorporate technological advances in measurement, data storage and retrieval, and communications in order to track systematic changes in the physical, chemical, biological and socio-economic parameters that collectively describe the total global human environment. The responsibility for development rests with governments. The monitoring system should be in place by the year 2000.

3. Also required is the development of an educational program to familiarize present and upcoming generations with the importance of addressing issues conerning sustainable development including the actions and integrated, interdisciplinary programs needed.

L'ATMOSPHÈRE EN ÉVOLUTION : IMPLICATIONS POUR LA SÉCURITÉ DU GLOBE

DÉCLARATION DE LA CONFÉRENCE

RÉSUMÉ

L'humanité se livre sans frein à une expérience inconsciente qui touche l'ensemble du globe et dont les conséquences définitives ne le céderaient en rien sinon à une guerre nucléaire mondiale. L'atmosphère terrestre change à une vitesse sans précédent en raison des polluants d'origine anthropique, du gaspillage des combustibles fossiles et des effets de l'augmentation rapide de la population dans plusieurs régions. Ces changements représentent une grande menace pour la sécurité internationale et ont déjà des conséquences néfastes dans de nombreuses parties du globe.

Des répercussions profondes découleront du réchauffement mondial et de la hausse du niveau des océans, phénomènes qui se manifestent de plus en plus sous l'effet de l'accroissement de la concentration atmosphérique du gaz carbonique et des autres gaz à effet de serre. D'autres grandes incidences résultent de l'appauvrissement de la couche d'ozone, ce qui aggrave les dommages causés par le rayonnement ultraviolet. Les meilleures prévisions dont nous disposons révèlent la possibilité d'une crise économique et sociale qui pourrait avoir de graves répercussions pour les générations actuelles et futures, aggraver les tensions internationales et augmenter les risques de conflits internationaux et de guerres civiles. Il importe au plus haut point d'agir dès maintenant.

Voilà les principales conclusions de la Conférence mondiale sur l'atmosphère en évolution : implications pour la sécurité du globe, qui s'est tenue du 27 au 30 juin 1988 à Toronto. Plus de 300 scientifiques et décisionnaires de 46 pays, d'organismes des Nations Unies, d'autres organismes internationaux et d'organismes non gouvernementaux ont participé aux séances.

La Conférence invite les gouvernements, les Nations Unies et ses institutions spécialisées, le secteur privé, les établissements d'enseignement, les organisations non gouvernementales et les individus à prendre des mesures particulières pour atténuer la crise imminente qu'entrainera la pollution de l'atmosphère. Un pays agissant isolément n'est pas en mesure de résoudre le problème. L'atmosphère est une ressource commune et la coopération internationale est essentielle pour l'exploitation, la surveillance et la recherche.

La Conférence invite les gouvernements à établir de toute urgence un Plan d'action pour la protection de l'atmosphère. Ce plan doit comprendre une convention-cadre internationale, tout en nous permettant d'encourager d'autres ententes de normalisation, et comprendre aussi des règlements nationaux pour la protection de l'atmosphère mondiale. On invite aussi les gouvernements à créer un Fonds mondial pour l'atmosphère qui serait partiellement alimenté par une taxe prélevée sur l'utilisation des combustibles fossiles dans les pays industrialisés et qui fournirait ainsi une partie importante des ressources nécessaires pour l'application des mesures.

Le problème

L'altération continue de l'atmosphère du globe menace la sécurité dans le monde, l'économie mondiale et l'environnement naturel par les changements suivants :

- le réchauffement du climat, la montée du niveau des océans, le changement du régime des précipitations et la modification de la fréquence des extrêmes climatiques attribuables aux gaz à effet de serre qui retiennent la chaleur;
- l'épuisement de la couche d'ozone;
- le transport à grande distance des substances toxiques et des substances acidifiantes.

Ces changements auront pour effets :

- de mettre en danger la santé et le bien-être publics;
- de diminuer la sécurité alimentaire mondiale en raison de l'érosion accrue des sols et des grandes modifications et incertitudes dans la production agricole, particulièrement dans de nombreuses régions vulnérables;
- de modifier la répartition et la disponibilité des ressources en eau douce;
- d'augmenter l'instabilité politique et le risque de conflits internationaux;
- de compromettre les perspectives de développement durable et de réduction de la pauvreté;
- d'accélérer l'extinction des espèces animales et végétales indispensables à la survie de l'être humain;
- d'altérer le rendement, la productivité et la diversité biologiques des écosystèmes naturels et aménagés, particulièrement les forêts.

Si les pays du monde entier ne prennent pas des mesures rapides dès à présent, ces problèmes s'aggraveront progressivement et deviendront peu à peu difficilement réversibles et coûteux à résoudre.

Preuves scientifiques

La Conférence lance un appel urgent pour que soit établi un Plan d'action pour la protection de l'atmosphère. Ce plan d'action, complété par des mesures nationales, doit s'attaquer aux problèmes du réchauffement climatique, de l'appauvrissement de la couche d'ozone, du transport à grande distance des substances toxiques et de l'acidification.

Réchauffement climatique

1 On a observé au cours des cent dernières années une hausse de 0,5 °C de la température moyenne mondiale, ce qui correspond aux prévisions théoriques tenant compte des gaz à effet de serre. Si l'augmentation accélérée de la concentration des gaz à effet de serre dans l'atmosphère se poursuit, elle entrainera probablement une hausse de 1,5 à 4,5 °C de la température moyenne mondiale en surface avant le milieu du siècle prochain.

2 On s'attend à de nettes variations régionales du réchauffement. Par exemple, sous les hautes latitudes, le réchauffement se traduira peut être par un doublement de la variation moyenne mondiale et s'accompagnera de changements quant au régime des précipitations et quant à la configuration des circulations atmosphérique et océanique. À la variabilité naturelle de l'atmosphère et du climat se superposera la tendance à long terme causée par les activités humaines.

3 Si les tendances actuelles persistent, la vitesse et l'ampleur du changement climatique au siècle prochain dépasseront de beaucoup ceux des variations que la terre a connues les cinq derniers millénaires. Un tel rythme entraînerait des perturbations suffisamment importantes pour qu'aucun pays ne retire que des avantages du changement climatique.

4 Le réchauffement climatique se poursuivra tant que les gaz à effet de serre s'accumuleront dans l'atmosphère.

5 Il peut y avoir un décalage de l'ordre de plusieurs décennies entre l'émission de gaz dans l'atmosphère et la manifestation complète de leur impact atmosphérique et biologique. Les émissions passées ont déjà soumis notre planète à un important réchauffement.

6 Le réchauffement mondial accélérera la montée actuelle du niveau des océans. Cette hausse atteindra, sans doute, 30 cm et peut-être 1,5 m d'ici le milieu du siècle prochain. Les îles et les basses terres littorales risquent d'être inondées et, du fait d'une intrusion accrue d'eau salée, les réserves côtières d'eau douce risquent d'être réduites. Nombre de deltas fortement peuplés et de terrains agricoles adjacents seront menacés. Comme la fréquence des cyclones tropicaux risquent d'augmenter et les trajectoires des tempêtes de changer, les zones côtières et les îles touchées pourraient être dévastées par les inondations et les marées de tempête.

7 Le déboisement et les mauvaises pratiques agricoles contribuent à la désertification et réduisent la capacité de stockage biologique du gaz carbonique, augmentant ainsi la concentration de cet important gaz à effet de serre. Le déboisement et les mauvaises pratiques agricoles libèrent aussi d'autres gaz à effet de serre comme l'oxyde nitreux et le méthane.

Épuisement de la couche d'ozone

1 L'intensification des rayons ultraviolets nocifs sous l'effet de l'appauvrissement de la couche d'ozone stratosphérique causera une augmentation sensible des cas de cancer de la peau et des cas d'affections oculaires. De plus, cet accroissement nuira à de nombreuses espèces biologiques. On s'attend que toute baisse de 1 p. 100 de l'ozone cause une hausse de 4 à 6 p. 100 de certains cancers de la peau. On craint particulièrement les effets combinés possibles, sur les écosystèmes non aménagés, du rayonnement ultraviolet accru et du changment climatique.

2 Cette dernière décennie, on a constaté un déclin de 3 p. 100 de la couche d'ozone sous les latitudes moyennes dans l'hémisphère Sud, déclin probablement associé à l'apparition du trou d'ozone au-dessus de l'Antarctique. Malgré la variabilité météorologique plus marquée dans l'hémisphère Nord, on y relève aussi des indices d'un appauvrissement. Les changements de la couche d'ozone modifieront aussi le climat et la circulation atmosphérique.

Acidification

Dans le but d'améliorer la qualité de l'air dans leurs villes, de nombreux pays industrialisés d'Europe et d'Amérique du Nord ont involontairement envoyé des quantités accrues de polluants au-delà de leurs frontières, contribuant ainsi à l'acidification des environnements lointains. Ceci se traduit de façon évidente par les dommages croissants infligés aux lacs, aux sols, aux végétaux, aux animaux, aux forêts et aux pêcheries. Le problème s'est aggravé dans certaines régions où les émissions des véhicules à moteur ne sont pas réglementées. Les principaux agents nocifs sont les oxydes de soufre et d'azote ainsi que les hydrocarbures volatils. Ils peuvent aussi avoir un effet corrosif sur les immeubles et les constructions métalliques, entraînant, dans l'ensemble, des dégâts annuels s'élevant à plusieurs milliards de dollars.

Les diverses questions qui découlent de la pollution de l'atmosphère par plusieurs substances sont étroitement reliées du point de vue tant de la chimie que des stratégies éventuelles de lutte. Par exemple, les chlorofluorocarbones (CFC) sont des gaz à effet de serre qui, en outre, détruisent la couche d'ozone. Les mesures visant à réduire l'utilisation des combustibles fossiles contribueraient à faire face au problème des précipitations acides et à celui du changement climatique.

Sécurité : Préoccupations économiques et sociales

Comme l'indique le rapport de l'ONU sur la Relation entre le désarmement et le développement : "Le monde peut soit continuer de plus belle à participer à la course aux armements, soit s'orienter délibérément, à bonne vitesse, vers un développement social et économique plus stable et plus équilibré dans un contexte économique et politique international plus sain. Il ne peut faire les deux à la fois. Reconnaissons ici que la course aux armements et le développement sont en concurrence, en particulier sur le plan des ressources, mais aussi dans le domaine vital des attitudes et des perceptions." La même remarque vaut pour la question vitale de la protection du patrimoine atmosphérique mondial contre le péril croissant du changement climatique et d'autres changements atmosphériques. Tout changement imprévu pourrait bien constituer la grande menace non militaire à la sécurité internationale et à l'avenir de l'économie mondiale.

Aucune préoccupation n'est plus importante que celle de l'accès à la nourriture et à l'eau. Compte tenu de la production agricole projetée et des taux de croissance prévus de la population et des revenus, il deviendra très difficile de maintenir la sécurité alimentaire mondiale qui est déjà insuffisante. Les changements climatiques envisagés aggraveront le problème de la sécurité alimentaire. Ces changements sont provoqués par les pays riches mais ce sont les pays pauvres qui en souffrent le plus. Vu la menace écologique de plus en plus grave qui pèse sur la sécurité alimentaire mondiale, il importe que les gouvernements et les milieux internationaux maintiennent l'assiette des ressources agricoles et marines et offrent aux pays pauvres des possibilités de développement.

Les pays du monde industrialisé sont les principaux émetteurs des gaz à effet de serre et, par conséquent, ils doivent assumer à l'égard du monde entier la principale responsabilité des mesures à mettre en application pour régler les problèmes du changement climatique. Par la même occasion, ces pays doivent veiller à ce qu'on aide les pays en voie de développement (dont les problèmes sont fortement aggravés par la croissance démographique) à améliorer leur économie et les conditions de vie de leurs citoyens, et non pas à ce qu'on les en empêche. Il faudra, pour ce faire, prendre de nombreuses mesures, entre autres, utiliser davantage d'énergie dans ces pays et, pour compenser, effectuer des réductions dans les pays industrialisés. Déboucher sur un avenir durable nécessitera des investissements afin d'améliorer le rendement énergétique et de trouver des sources d'énergie non fossiles. Pour que ces investissements aient lieu, le monde entier doit non seulement arrêter le transfert net de ressources des pays en voie de développement, mais aussi l'inverser. Ce renversement de la situation devrait s'appuyer sur les techniques pertinentes tout en tenant compte des répercussions éventuelles dans l'industrie.

Une coalition des cerveaux s'impose, en particulier la réduction rapide des inégalités Nord-Sud et des tensions Est-Ouest, si nous tenons à obtenir la compréhension et à réaliser les ententes nécessaires pour assurer un avenir durable à la planète et à ses habitants.

De toute évidence, il faut beaucoup de temps pour aboutir à l'échelle internationale à un consensus sur des questions aussi complexes, pour négocier, signer et ratifier des accords internationaux sur l'environnement et pour commencer à les appliquer. Il est donc primordial de se livrer dès maintenant à de sérieuses négociations.

Aspects juridiques

On a déjà pris les premières mesures en vue d'élaborter les lois et pratiques internationales pour régler la question de la pollution atmosphérique : le Jugement sur les émissions de la fonderie de Trail (Colombie-Britannique) de 1935 et 1938; le principe 21 de la Déclaration de la conférence des Nations Unies sur le milieu humain; la Convention de la CEE sur la pollution atmosphérique transfrontière à grande distance et le Protocole d'Helsinki de 1985 sur la réduction des émissions soufrées; la partie XII de la Convention du Droit de la mer; et, enfin, la Convention de Vienne sur la protection de la couche d'ozone et le Protocole de Montréal qui en découle (1987).

Ce sont là des mesures initiales importantes que toutes les nations devraient activement appliquer et respecter. Néanmoins, il n'existe aucune convention internationale globale qui s'attache aux problèmes corrélatifs de l'atmosphère mondiale ou aux questions de changement climatique.

BESOINS IMPÉRIEUX DE MESURES

La Conférence lance un appel urgent aux gouvernements, aux Nations Unies et à ses institutions spécialisées, aux autres organismes internationaux, aux organisations non gouvernementales, au secteur privé, aux établissements d'enseignement et aux particuliers pour qu'ils s'opposent à la détérioration continue de l'atmosphère.

On se doit d'élaborer un Plan d'action pour la protection de l'atmosphère qui comprend une convention-cadre internationale, qui encourage d'autres ententes de normalisation et des règlements nationaux pour la protection de l'atmosphère du globe. Ce plan d'action doit être complété par l'application de mesures nationales qui s'attaquent à la racine des problèmes créés par le changement atmosphérique (réchauffement climatique, appauvrissement de la couche d'ozone, transport à grande distance des substances toxiques et acidification).

Les mesures suivantes visent surtout à ralentir et finalement à inverser la détérioration de l'atmosphère. Il existe aussi un certain nombre de stratégies d'adaptation aux changements qu'il faut envisager. Elles font l'objet des recommandations des groupes de travail.

Mesures à prendre par les pouvoirs publics et le secteur privé

- La ratification du Protocole de Montréal sur les substances qui appauvrissent la couche d'ozone. Le Protocole devrait être revisé en 1990 afin que l'on puisse garantir l'élimination presque totale des émissions des CFC complètement halogénés d'ici l'an 2000. On doit songer à des mesures supplémentaires pour réduire les émissions des autres hydrocarbures halogénés qui détruisent l'ozone.

- De façon à réduire les risques de réchauffement mondial, il faut concevoir des politiques énergétiques pour atténuer les émissions de CO_2 et d'autres gaz à l'état de trace. Il faut absolument stabiliser la concentration atmosphérique de CO_2. On estime à l'heure actuelle que cela nécessite une réduction de plus de 50 p. 100 des émissions courantes. Il faut affecter massivement des budgets de recherche-développement aux formes d'énergie qui permettraient d'éliminer ou de réduire de beaucoup les émissions de CO_2 et aux études visant à mieux préciser les objectifs de réduction des émissions.

- À l'échelle mondiale, le premier objectif devrait consister à réduire les émissions de CO_2 d'environ 20 p. 100 de leur tonnage de 1988 d'ici l'an 2005. Il va sans dire que les pays industrialisés doivent montrer l'exemple, tant en adoptant des lignes de conduite énergétiques nationales qu'en signant des accords d'assistance bilatéraux et multilatéraux. La moité de la réduction pourrait être obtenue par l'amélioration du rendement énergétique et par l'application d'autres mesures de conservation et d'économie. L'autre moitié devrait provenir de la modification des approvisionnements.

- Les objectifs d'amélioration du rendement énergétique devraient viser directement la réduction des émissions de CO_2 et d'autres gaz à effet de serre. On pourrait s'efforcer d'accroître le rendement énergétique de 10 p. 100 d'ici l'an 2005. Améliorer le rendement énergétique ne revient pas précisément à réduire les émissions de carbone total. Les lignes de conduite énoncées ne seront pas toutes connues. Il faudrait étudier en détail les incidences de cet objectif sur les systèmes. De même, les objectifs d'approvisionnement en énergie devraient aussi viser directement la réduction des émissions de CO_2 et d'autres gaz à effet de serre. Comme pour le rendement, il faudrait s'efforcer d'améliorer l'approvisionnement en énergie de 10 p. 100 d'ici l'an 2005. Il faudrait aussi étudier en détail les incidences de cet objectif sur les systèmes. Les contributions à cet objectif varieront d'une région à l'autre. Certains pays ont déjà prouvé qu'ils étaient capables d'accroître le rendement de plus de 2 p. 100 par année sur dix ans.

Outre les mesures d'accroissements du rendement, la réduction souhaitée exigera : (i) l'utilisation de combustibles qui dégagent moins de CO_2; (ii) l'examen de stratégies d'adoption d'énergies renouvelables et surtout de techniques perfectionnées de conversion de la biomasse; et (iii) la considération, à nouveau, de l'option nucléaire, discréditée en raison des problèmes de sûreté des déchets radioactifs et de la prolifération des armes nucléaires. Si l'on arrivait à résoudre ces problèmes sur le plan de l'ingénierie et des dispositions institutionnelles, le nucléaire pourrait contribuer à la réduction des émissions de CO_2.

- Il faut dès maintenant entamer des négociations pour déterminer comment l'on pourrait effectuer les réductions susmentionnées.
- Il faut instaurer des mécanismes de gestion afin d'encourager, d'examiner et d'approuver les nouveaux projets importants du point de vue du rendement énergétique.
- Il faut appliquer strictement les technologies existantes pour, tout en conservant les gains qui découlent d'un recours moindre aux combustibles fossiles, réduire : (i) les émissions de substances acidifiantes au seuil critique que peut supporter l'environnement; (ii) les précurseurs de l'ozone troposphérique; et (iii) les autres gaz à effet de serre que le CO_2.
- Il convient d'étiqueter les produits pour permettre au consommateur de juger de l'étendue et de la nature de la pollution de l'atmosphère attribuables à leur fabrication et à leur utilisation.

Mesures à prendre par les États membres des Nations Unies, les organisations non gouvernementales et les organismes internationaux compétents.

- Entreprendre l'élaboration d'une convention-cadre exhaustive de portée mondiale pour les protocoles concernant la protection de l'atmosphère. Il convient que cette convention insiste sur les éléments clés que sont notamment l'échange libre de l'information et l'appui à la recherche et à la surveillance à l'échelle internationale, et qu'elle inspire des protocoles qui s'attacheront à des questions particulières, tout en tenant compte du droit international. Il faut que le Groupe de travail international sur les aspects juridiques et politiques, dont la réunion est prévue pour le début de 1989 à Ottawa, insiste à son tour vigoureusement sur cet aspect, tout comme la Conférence d'orientation de haut niveau sur les changements climatiques qui aura lieu aux Pays-Bas à l'automne 1989, la Conférence mondiale sur l'énergie qui sera organisée au Canada en 1989 et la seconde Conférence mondiale sur le climat qui doit se tenir à Genève en juin 1990. Il faudrait être en mesure de soumettre les principes et les éléments de cette convention à la conférence intergouvernementale sur le développement durable, prévue pour 1992. Ces activités ne devraient pas empêcher la signature d'accords nationaux, bilatéraux et régionaux simultanés visant à résoudre des problèmes précis comme l'acidification et les émissions de gaz à effet de serre.
- Établir un Fonds mondial pour l'atmosphère partiellement alimenté par une taxe prélevée sur l'utilisation des combustibles fossiles dans les pays industrialisés afin d'aider à la mobilisation d'une importante partie des ressources nécessaires à l'application du Plan d'action pour la protection de l'atmosphère.
- Appuyer le travail du Groupe intergouvernemental d'étude du changement climatique pour mener l'évaluation continue des résultats scientifiques et promouvoir entre les États l'examen de ripostes et de stratégies.
- Allouer des ressources accrues à la recherche et à la surveillance dans le cadre du Programme climatologique mondial, du Programme

international géosphère-biosphère et du Programme des réactions humaines au changement climatique mondial. Il importe de corréler les changements climatiques à l'échelle régionale au changement à l'échelle planétaire et, aussi, de mieux élucider le rôle des océans dans le transport thermique mondial et le flux des gaz à effet de serre.

- Accroître sensiblement les fonds affectés aux programmes de recherche-développement et de tranfert de renseignements sur les énergies renouvelables en créant, s'il le faut, des programmes supplémentaires et de crédit-relais; élargir le transfert de technologie en insistant tout particulièrement sur les besoins des pays en voie de développement; et s'efforcer de respecter les obligations de développement et de transfert de technologie prévues dans les accords en vigueur.

- Financer un plus grand nombre de projets de transfert de technologie et de projets de coopération technique concernant la protection et l'aménagement des zones littorales.

- Réduire le déboisement et accroître le reboisement en tenant compte de certaines propositions, comme celle que présente la publication de la Commission mondiale sur l'environnement et le développement intitulée "Notre avenir à tous", et créer un fonds d'affectation spéciale destiné à encourager les pays en voie de développement à aménager leurs forêts tropicales de façon durable.

- Élaborer et appuyer des projets de coopération technique permettant aux pays en voie de développement de participer aux mesures d'atténuation, à la surveillance, à la recherche et à l'analyse internationales concernant le changement atmosphérique.

- Faire en sorte que la présente Déclaration, les rapports des groupes de travail et les actes intégraux de la Conférence internationale sur l'atmosphère en évolution : implications pour la sécurité du globe (publication prévue à l'automne 1988) soient accessibles à tous les pays et aux conférences mentionnées dans ce document, puis diffusés à l'occasion de manifestations qui porteront sur des sujets connexes.

- Augmenter le financement accordé aux organismes non gouvernementaux de façon à leur permettre de créer et d'améliorer des programmes d'éducation sur l'environnement et de lancer des campagnes de sensibilisation du public portant sur le changement atmosphérique. Ces programmes viseront à rendre plus claire la perception des problèmes et à modifier les valeurs et l'attitude du public face à l'environnement.

- Financer l'éducation sur l'environnement dans les écoles primaires et secondaires et dans les universités. Il faudrait songer à créer des groupes spéciaux dans les universités, qui s'attacheraient aux problèmes cruciaux posés par le changement climatique mondial.

RECOMMANDATIONS SPÉCIFIQUES DES GROUPES DE TRAVAIL

Les recommandation qui précèdent sont surtout générales et sont communes à plusieurs groupes de travail de la Conférence. Voici les recommandations particulières des groupes de travail.

ÉNERGIE

1 Les objectifs touchant l'approvisionnement énergétique devraient viser la réduction des émissions de CO_2 et autres gaz à effet de serre. Réduire le total mondial des émissions de CO_2 de 20 p. 100 d'ici l'an 2000 par une utilisation efficace de l'énergie, par le recours à de nouvelles sources d'énergie et par des mesures d'économie de l'énergie constituerait un objectif élevé.

2 Des projets de recherche et de démonstration visant à accélérer la mise au point de techniques perfectionnées de conversion de la biomasse doivent être entrepris.

3 Le déboisement devrait être réduit et le reboisement accéléré afin de diminuer la concentration atmosphérique de CO_2 et, par la même occasion, reconstituer les réserves primaires d'énergie pour la majorité de la population.

4 L'option nucléaire devrait être envisagée de nouveau. Si l'on pouvait résoudre les problèmes de la sûreté, des déchets radioactifs et de la prolifération des armes nucléaires, cette option pourrait aider à réduire les émissions de CO_2.

5 Les coûts extériorisés doivent être intériorisés. Des lignes de conduite doivent être élaborées de façon à réaliser de grands objectifs sociaux et de réduire au minimum le total de coûts socio-économiques et écologiques.

SÉCURITÉ ALIMENTAIRE

1 Nous incitons les États à réduire la part de l'agriculture dans l'accroissement de la concentration des gaz à effet de serre dans l'atmosphère du fait de la destruction des forêts, de l'usage inefficace des engrais azotés inorganiques, de l'extension des rizières et de l'augmentation du cheptel de ruminants.

2 Les États devraient tenir compte de l'éventualité du changement climatique dans la planification agricole et dans celle de la sécurité alimentaire à long terme, en particulier en ce qui touche la disponibilité de nourriture pour les groupes les plus vulnérables.

3 Les États et les organismes internationaux devraient attacher plus d'importance à un vaste éventail de mesures politiques afin de réduire la vulnérabilité des sources d'approvisionnement alimentaire à la variabilité climatique en accroissant l'adaptabilité au changement climatique.

4 Les États doivent s'efforcer d'instaurer des mécanismes de collaboration sous-régionale et régionale destinés à assurer la sécurité alimentaire. Les organismes internationaux devraient contribuer à cet effort.

5 La FAO, la Banque mondiale, l'OMM, le PNUD, le GCRAI et d'autres organismes internationaux devraient encourager la recherche de régimes d'aménagement agricole qui soient écologiques.

URBANISATION ET PEUPLEMENT

1 Les constats d'impact et les plans d'aménagement du territoire devraient tenir compte des conditions climatiques éventuelles, y compris des effets locaux que la montée du niveau des océans aura sur les localités littorales.

2 Les municipalités devraient, dans l'évaluation des risques et dans la planification des mesures d'urgence, tenir compte des effets du changement climatique telle qu'une augmentation des dangers naturels.

3 Les États et les organismes d'aide internationale devraient élaborer des lignes de conduite et des mesures qui tiennent compte de l'augmentation possible du mouvement des personnes déplacées par suite du changement climatique.

4 On doit insister sur l'éducation environnementale, particulièrement en ce qui concerne le développement durable des régions urbaines et des peuplements humains; cette éducation devrait aussi être grandement encouragée par les autorités locales et nationales ainsi que par les organismes internationaux comme l'OMM, la CNUEH, le PNUE, l'ONUDI et le PNUD.

5 Les organismes nationaux et internationaux devraient entreprendre des évaluations complètes, à l'échelle mondiale, de la vulnérabilité de certaines régions géographiques et urbaines au risque accru d'une incidence et d'une propagation plus grandes des maladies infectieuses, y compris de celles qui sont transmises par des vecteurs, ou qui sont contagieuses, du fait du changement climatique mondial. Dans ces régions, on devrait évaluer les infrastructures assurant la santé publique et leur capacité de faire face à l'augmentation prévue des risques de propagation des maladie infectieuses. On devrait aussi préciser les mesures à prendre par les pouvoirs publics locaux et nationaux et les organismes internationaux pour améliorer cette capacité.

6 On devrait évaluer la vulnérabilité des centrales nucléaires, des décharges municipales et de déchets dangereux ainsi que des autres lieux d'élimination des déchets pathogènes infectieux ou de toxiques dans les zones terrestres ou maritimes environnantes. Des mesures appropriées devraient être prises pour réduire au minimum cette vulnérabilité et ce danger.

RESSOURCES EN EAU

1 Il importe de mieux utiliser l'eau et d'accroitre, face aux variations climatiques, la souplesse des réseaux actuels et projetés d'approvisionnement en eau et des mécanismes d'aménagement de cette ressource.

2 Il faut étendre à l'échelle mondiale les conventions actuelles sur les pluies acides et les modifier pour qu'elles visent aussi les polluants organiques toxiques.

3 Il faut, de toute urgence, des programmes intégrés de surveillance et de recherche pour améliorer les méthodes d'évaluation de la vulnérabilité des ressources en eau; pour déterminer les régions et les bassins d'impor-

tance vitale où les changements de processus hydrologiques et de la demande entraîneront de graves problèmes; et pour comprendre et modéliser les répercussions hydrologiques, écologiques et socio-économiques du changement climatique.

4 Nous appuyons fortement le principe universel de l'équité des plans d'action à l'égard de toutes les régions et des générations, présentes ou à venir, afin d'atténuer les problèmes actuels et éventuels dont pourraient souffrir les ressources en eau et afin d'assurer le développement durable. La collaboration, l'échange sans contrainte des connaissances techniques, la participation réelle du public et des programmes efficaces d'information sont essentiels.

RESSOURCES TERRESTRES

Un fonds international devrait être créé spécialement pour l'aide au développement et pour la recherche afin de :

1 maintenir le réservoir terrestre de carbone par un aménagement et une protection avisés des forêts tropicales et tempérées et de leurs sols, de la toundra, et des marécages qui constituent d'importants réservoirs de carbone.

2 favoriser le développement de pratiques d'utilisation des terres d'un rendement soutenu par l'agroforesterie; du reboisement, du développement de variétés adaptables au changement climatique; du développement de pratiques de gestion efficaces pour le traitement et l'élimination des déchets; et de lignes de conduites concernant l'utilisation, le peuplement et l'occupation des terres. Pour y arriver il est nécessaire de transformer les politiques des organismes intéressés (OIBT, FAO, PAFT, CIRAF); il faut aussi envisager la possibilité d'un troc de la dette pour la préservation des forêts et l'accès à un fonds de reboisement.

3 déterminer les terres agricoles les plus productives afin de pouvoir mettre en place un système de réserve des terres qui servira à atténuer les pertes résultant d'un climat plus hostile et d'une montée du niveau des océans.

4 sensibiliser davantage le public aux problèmes que pose la menace du changement climaqtique en rapport avec l'utilisation continue, judicieuse et durable des terres. Elargir les programmes concernant les répercussions des dépôts acides et toxiques sur les ressources terrestres en tenant compte de l'universalité du problème.

RESSOURCES CÔTIÈRES ET MARINES

1 Améliorer, grâce à la recherche, la compréhension des facteurs naturels et humains de la productivité et de la variabilité des ressources marines et côtières.

2 Améliorer considérablement les mécanismes institutionnels et juridiques permettant l'utilisation judicieuse des ressources possédées en commun.

3 Accroître la souplesse des diverses industries et localités tributaires des ressources marines afin qu'elles répondent aux changements provoqués par le climat.

4 Entreprendre des études prospectives locales de la montée du niveau des océans, qui tiennent compte des risques humains, écologiques et économiques et aboutissent à des programmes d'éducation locaux.

5 Examiner les répercussions du changement climatique sur la planification des zones côtières, en particulier le risque de montée du niveau des océans et, éventuellement, le besoin de nouvelles constructions plus loin à l'intérieur des terres.

FORMES D'AVENIR ET PRÉVISION

1 Pour conserver l'espoir de nous adapter au changement, nous devons acquérir et exploiter la connaissance du passé et développer l'aptitude à prévoir les futurs possibles. Nul modèle ne saurait à lui seul dissiper les incertitudes de la prévision, absorber les détails nécessaires à la prise de décision, ni prévoir les conséquences sociales, techniques et écologiques du changement. Il convient donc de recourir à diverses techniques pour obtenir des résultats utiles.

2 Non seulement nous devons améliorer nos méthodes de prévision et poursuivre nos efforts d'intégration des modèles de cause à effet, mais nous devons aussi renforcer notre aptitude à communiquer et à signaler les implications pour la culture au sens large de sorte qu'on puisse prendre des décisions individuelles et collectives d'une façon avertie. En raison des importantes conséquences mondiales qui sont prévues, il faudra modifier les institutions et les attitudes. Il est tout aussi nécessaire de prendre des mesures touchant les questions interdépendantes de la croissance démographique, de l'utilisation et de l'épuisement des ressources, ainsi que des inégalités technologiques. Ces mesures doivent pouvoir respecter l'environnement dans le présent et dans l'avenir.

POLITIQUES ET INCERTITUDE

1 L'incertitude sera réduite par une meilleure compréhension de la chimie de l'atmosphère; des répercussions du changement climatique sur la santé, l'agriculture, l'économie et la société; et des ripostes possibles (prévention, compensation et adaptation) sur les plans juridique, politique et autres, au changement climatique.

2 Les pays industrialisés devraient commencer à réhabiliter l'environnement, en faisant du changement atmosphérique le <u>point de départ</u> d'une innovation écologique de l'économie industrielle.

3 Les objectifs fixés pour les émissions devraient faire l'objet d'un traité international entre les pays chefs de file. Ceux-ci devraient inviter tous les autres à s'engager avec eux dans la voie d'un développement économique durable.

4 La prise de décision sur la place publique peut très bien en arriver à des conclusions difficilement acceptables pour le public. Un débat démocratique devrait avoir lieu au sujet des réactions à la menace atmosphérique. Les organismes non gouvernementaux devraient jouer un rôle décisif dans ce débat.

INDUSTRIE, COMMERCE ET INVESTISSEMENT

Les mesures urgentes qui suivent sont proposées :

1 Création d'un Fonds mondial pour l'atmosphère financé par une taxe sur la consommation de combustibles fossiles dans les pays industrialisés et suffisant au développement et au transfert de techniques d'utilisation efficace des combustibles.

2 Mise au point de mécanismes qui permettent d'intégrer les facteurs d'environnement et les responsabilités en la matière aux processus internes de prise de décisions et de compte rendu des entreprises commerciales et industrielles.

3 Constitution d'un mécanisme international de consultation au plus haut niveau, relevant des chefs d'État, pour assurer :

- l'accélération des efforts de recherche-développement;
- la réduction des obstacles institutionnels à l'adoption, par les industries et les particuliers, des techniques qui produisent peu d'émissions;
- l'amélioration de l'information sur les marchés pour orienter la consommation vers les produits écologiques.

QUESTIONS GÉOPOLITIQUES

1 On ne peut aujourd'hui prévoir quelles seront les régions particulières du globe, ni les secteurs de l'économie qui seront les premiers ou les plus durement éprouvés par l'atmosphère en mutation rapide. Toutefois, l'ampleur et la variété des répercussions éventuelles seront telles qu'il est de l'intérêt de tous les peuples d'unir leurs efforts sans délai pour ralentir les changements et pour négocier la conclusion d'une entente internationale sur le partage des responsabilités en matière de préservation du climat et de l'atmosphère.

2 Les problèmes atmosphériques nécessitent la coordination d'efforts internationaux, mais nous devrions inciter les organismes gouvernementaux et non gouvernementaux à passer rapidement à l'action, tout en cherchant à parvenir à l'entente internationale exhaustive. Ces actions peuvent reposer sur une meilleure utilisation de l'énergie, sur l'utilisation d'énergies de remplacement et sur les transferts de technologie et de ressources au Tiers Monde.

QUESTIONS JURIDIQUES

1 Un plus grand nombre d'États devraient observer les normes et les principes internationaux actuels sur la préservation de l'atmosphère; on les encourage à promulguer ou à renforcer des lois nationales appropriées.

2 L'offre du Premier ministre du Canada d'accueillir une réunion de juristes et de décideurs devrait être acceptée. On devrait alors étudier la question de la conception et de la codification graduelles de principes de droit international, en tenant compte des principes établis dans les cas de la fonderie de Trail; du lac Lanoux; du canal de Corfou; du principe 21 de la Déclaration de 1972 de la conférence des Nations Unies sur le milieu humain; de la Convention sur la pollution transfontière à grande distance; et des protocoles connexes tels que la partie XII de la Convention du droit de la mer, de la Convention de Vienne pour la protection de la couche d'ozone et de son Protocole de Montréal. L'assemblée devrait viser à élaborer les principes à inclure dans la convention générale ou convention-

cadre sur la protection de l'atmosphère qui devrait se prêter à l'établissement d'ententes ou de protocoles particuliers stipulant des normes internationales pour la protection de l'atmosphère, en complément des textes en vigueur.

PROGRAMMES INTÉGRÉS

1 Examiner, d'ici 1992, les besoins institutionnels de collaboration en matière de recherche, d'évaluation et de conception de lignes de conduite sur les plans international, intergouvernemental et non gouvernemental et à l'échelle régionale et nationale.

2 Étendre et améliorer, d'ici l'an 2000, un système mondial de surveillance et d'information des Nations Unies qui utilisera les techniques avancées de mesure, de stockage et d'extraction des données, ainsi que de communication afin de déceler les changements survenus aux paramètres physiques, chimiques, biologiques et socio-économiques qui décrivent collectivement le milieu humain. L'élaboration de ce système relèvera des États.

3 Formuler un programme d'éducation qui fera connaître aux générations actuelles et à venir l'importance de régler les questions de développement durable, y compris les mesures nécessaires et les programmes intégrés et interdisciplinaires nécessaires.

ENERGY

Chairpersons:	J. Goldemberg W. Long	
Rapporteurs:	W. Haéfele R. Torrie	
Members:	D. Abrahamson W. Adams D. Ahuja R. Ayres W. Bach B.-H.L. Batlaha J. Blackstock S. Boyle W. Chandler P.G. Chénard L. DiMarzo J.A. Edmonds P. Faross Fu Lixun D. Harvey B. Hilleman J. Hollins A. Hyde P. Jessup	J. Jovanovich P. Laut R.T. Marshall L.G. McConnell P. McKellar I. Mintzer I. Nazarov F. Neumann G. Persson J. Railton D. Scott I. Segall R.W. Shaw I. Smith R. Socolow Sunling Gong A. Tollan C.A. Werner E.R. Williams

RECOMMENDATIONS

1. The Energy-Climate Connection

It is vital that national and international energy policies explicitly consider the emissions of CO_2 and other greenhouse gases that are contributing to atmospheric warming.

The necessary rates of reduction of CO_2 and other greenhouse gases are so very large that they present unprecedented challenges to energy policies, notwithstanding the uncertainty that still exists as to the eventual reductions in emissions that will be required to stabilize global temperature.

The details of the appropriate policy response will vary from country to country and region to region and there is an urgent need for better analyses of the regional implications of tying energy policies to climate change, and for the monitoring of progress.

Mechanisms must be developed for measuring and monitoring the impact of energy policy on climate change and the associated costs. These mechanisms will support the ongoing assessment and improvement of national planning, regional and global programs, and individual energy decisions.

Above all, it is necessary to buy time.

2. Energy Conservation and Efficiency

The first and most obvious element of the energy policy response to the climate problem is the renewed commitment to conservation of carbon-based fuels and the improvement of energy efficiencies in general. While energy conservation and efficiency was already a goal in the past, this was so under the perspective of energy supply shortages. Now, energy efficiency improvements are also needed because they are directly related to the reduction of CO_2 and other greenhouse gases.

Technology development, technology transfer and energy-related foreign aid should be centred on improvements of energy end-use efficiency much more than in the past.

Targets for energy efficiency improvements should be directly related to reductions in CO_2 and other greenhouse gases. A challenging target would be to achieve energy efficiency improvements that reduce total annual global CO_2 emissions by 10% by the year 2005. Improving energy efficiency is not precisely the same as reducing total carbon emissions and the detailed policies will not all be familiar ones. A detailed study of the implications of this target should be made.

3. Near-Term Energy Supply Actions

On the supply side of the energy equation it is equally necessary to adopt changes that will have an impact in the near term.

Targets for energy supply should be directly related to reductions in CO_2 and other greenhouse gases. A challenging target would be to achieve energy supply improvements that reduce total annual global CO_2 emissions by 10% by 2005, <u>in addition to that achieved through efficiency measures</u>. A detailed study of the implications of this target should be made.

Total emissions of carbon dioxide and other greenhouse gases are affected in numerous ways by fossil fuel technologies. Per unit of energy delivered, natural gas combustion releases half as much carbon dioxide as coal combustion. Efficiency in energy conversion systems is also crucial: reducing the venting and flaring of natural gas and increasing the efficiency of electricity production from fossil fuels are examples.

Biomass is an important energy resource in the developing countries today and is often used inefficiently. Research and demonstration projects to accelerate the development of advanced biomass conversion technologies could make a powerful contribution to conserving the world's biomass stock and reducing the rate of increase of atmospheric carbon dioxide. Reducing deforestation and accelerating reforestation, in addition to replenishing the primary energy supply for the majority of the world's population, could make a significant contribution to reducing the atmospheric concentration of CO_2.

Other renewable energy technologies - solar heat, wind power, photovoltaics, hydropower - deliver energy without carbon dioxide.

The rising concerns over the consequences of CO_2 and other gaseous emissions point out the need to revisit the nuclear power option, which lost some credibility owing to problems related to nuclear safety, radioactive wastes, and nuclear weapons proliferation. If these problems can be solved, through improved engineering designs and institutional arrangements, nuclear power could have a role to play in lowering CO_2 emissions.

4. Long-Term Energy Supply Actions

In the long term, it is possible to base the energy systems of the world on non-carbon primary sources - nuclear and solar energy in their various forms. Combined with electricity and hydrogen as secondary energy carriers, they could constitute a climatologically benign system. Limited fossil fuel use may also be acceptable in such scenarios in view of the deep ocean sink for carbon dioxide.

Transitions to such energy systems take time, and more detailed system analyses for identifying appropriate energy strategies for such transitions are required.

5. Least-Cost Approaches

Economic costs and benefits must be included in the formulation of energy-greenhouse policy measures to reduce climatic impacts.

In so doing, it is necessary to internalize externalized costs, and thereby to consider the costs of energy systems in the broadest sense.

On this basis, policies should be fashioned to achieve broad, complementary social objectives and to minimize total social, economic and environmental costs.

FOOD SECURITY

Chairpersons:	M. Parry S. Sinha	
Rapporteurs:	N. Rosenberg S. Muntemba	
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BACKGROUND

Total food supply, at the global level, at present exceeds basic caloric needs by 20% on average. This margin of security, however, should not give any cause for complacency. The year-to-year variation of supply due to weather is as much as 10%. Despite surpluses in some countries, about a billion people (about 15% of the world's population) do not have access to sufficient quantity or quality of food in order to lead fully productive lives.

MARGINS OF SECURITY

Given the present growth of population and income, the stagnating productivity of world food crops, diminishing returns from fertilizer use, less efficient use of energy in agriculture, and increasing problems with disease and pests, it is probable that, even without a change in climate, food security in certain regions of the world and in years of difficult weather, will continue to be a cause for concern.

Despite technological advances during this century, the production of food and fibre remains very sensitive to climatic variability, especially to the occurrence of extremes, such as droughts, floods, heat waves, frosts and strong winds. Such variations in production due to climatic variability are especially high in semi-arid regions where food security in the twenty-first century is likely to be under increased pressure from population growth and land availability. Climate change would exacerbate these problems.

Climate change due to changing atmospheric composition is likely to increase the frequency of stresses on agriculture and food security. In many regions the direct benefits to plants of a CO_2 enrichment of the atmosphere, demonstrated in controlled environment studies, may be offset by an increased frequency of heat and moisture stress.

Although there remain serious uncertainties over possible regional changes in moisture availability, current estimates of the most significant effects of present trends in increasing greenhouse gas concentrations by the year 2050 are as follows:

i) Reduced potential for wheat and corn production in central North America and the southern European USSR owing to higher temperatures and less soil moisture

ii) Increased potential for cereal production in more northern regions (e.g., the northern Canadian prairies, the north European Plain, central European USSR), though this increase will be limited by soil type and terrain

iii) Increased risks of erosion and flooding (and possibly a reduced length of growing season) in South and South-East Asia owing to changes in intensity of the summer monsoon

iv) Loss of agricultural land in low-lying coastal areas (e.g., Bangladesh, South-East Asia and the Nile Delta) owing to rise in sea-level

v) Major changes in the prevalence of agricultural pests and diseases in both developed and less developed countries

Uncertainties about the likely regional pattern of moisture availability in the vulnerable semi-arid regions are a cause for concern, especially since these may affect water supply for irrigation on which many semi-arid countries are heavily dependent for food security.

The magnitude of these possible effects imply substantial threats to national and international food security. Current national and international food relief and food security programs, which are already unable to meet the needs of the poorest people and nations, will not be able to meet these stresses without their being restructured and strengthened. In addition, international trade patterns in commodities will need re-examination.

While averaged global food supplies may not be seriously threatened, unless appropriate action is taken to anticipate climate change and adapt to it, serious regional and year-to-year food shortages may result, with particular impact on vulnerable groups. Most of these actions will be very costly, and any measures to prevent or reduce the magnitude of climate change are likely to engender substantial savings in the food sector.

RECOMMENDATIONS

1. Greenhouse Gases

   National governments are urged to reduce the contribution of agriculture to increased concentrations of greenhouse gases in the atmosphere. These contributions arise from destruction of forests, inefficient use of inorganic nitrogen fertilizers, increased conversion of land to paddy rice cultivation, and increased numbers of ruminant animals.

2. Planning

   National governments should take the prospect of climate change into account in long-term agricultural and food security planning particularly with respect to food availability to the most vulnerable groups.

3. Increased Resilience

   National governments and international agencies should give increasing emphasis to a wide array of policy measures to reduce the sensitivity of food supply to climate variability in order to increase current resilience and adaptability to climate change. These measures should include the reduction of post-harvest losses, better farm and local storage, improved infrastructure and transportation facilities, the establishment of buffer stocks and the adoption of locally-proven technologies. Less restrictive international trade policies, more innovative approaches to food aid and development funding for improving the local resource base, and greater investments in agricultural research, information and training are also essential.

4. Cooperation

   Because small nations may find their entire resource base greatly altered by climate change we urge national governments to increase their efforts to build subregional and regional cooperation aimed at achieving food security. International agencies should assist in promoting these regional cooperative efforts.

5. Ecological Soundness

   FAO, World Bank, WMO, UNEP, UNDP, CGIAR and other international organizations should encourage research leading to the development of ecologically sound agricultural management systems. This would increase the capability of adapting agricultural practices to climate changes.

URBANIZATION AND SETTLEMENT

Chairpersons: A.R. Magalhaes
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Rapporteurs: R.E. Munn
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Members: H. Acquay, D. Bandhu, G.R. Clements, Duzheng Ye, J. Fenger, L. Grant, A. Whyte, G. Kibedi, N. Kollias, G. Leutert, W.E. Riebsame, P. Toft, C. Hahn Oberlander, J.E. Hardoy

INTRODUCTION

An increasing proportion of the world's population lives in urban areas. Particular attention must therefore be paid to these areas to investigate the effects of climate change on human health and well-being.

The main concerns with respect to urbanization and human settlement include:

i) the relatively greater contribution to global climate change of urban areas owing to their per capita use of energy resources

ii) the increased risk of overtaxing food and water distribution capabilities, of breakdowns of sanitation systems, and of the spread of diseases in areas of dense concentrations of human populations in cities and smaller settlements

iii) the likely movement of rural people into urban areas to avoid climate impacts (e.g., drought)

iv) the likely larger-scale migration of "environmental refugees" from negatively impacted regions to more viable areas, especially into urban settlements and possibly including the crossing of national borders

Climate change impacts on urban settlements and migration patterns will probably take the form of increased frequencies of natural disasters associated with:

i) temperature extremes (more frequent and prolonged heat waves in some areas, colder extremes in others)

ii) shifts in precipitation patterns (wetter "monsoon" conditions in some areas, drought conditions in others)

iii) more frequent violent storm events over land and seas (with associated storm surges and flooding of coastal and estuarine cities)

iv) increased periods of air stagnation over cities and surrounding areas (causing more frequent air pollution episodes)

RECOMMENDATIONS

1. Checks should be placed on the spread of urbanization into prime agricultural land. This is particularly important in regions where crop yields are likely to decline because of climate change.

2. Citizens should be encouraged to undertake environmentally friendly activities.

3. Cities and human settlements should be managed in an environmentally sound manner, e.g., by recycling wastes. In particular, city design, building construction and public transit systems should be energy efficient.

4. Environmental impact statements and land-use management plans should include the consideration of future climate conditions, e.g., reductions in available water in semi-arid regions. In particular, individual environmental impact assessments should be undertaken of the local effects of rising sea-level on coastal communities.

5. Urban authorities should undertake urban risk assessments and develop emergency planning procedures that take into account the effects of climate change, such as the increased incidence of natural hazards.

6. National governments and the international aid community should develop policies and actions to deal with the likely increased movements of environmental refugees resulting from climate change.

7. Environmental education, both formal and informal, should be emphasized, particularly with respect to sustainable development of urban areas and human settlements. Special emphasis should be placed on the collective responsibilities of the people and their leaders to provide young people with environmental information. People are part of the global commons and are entirely dependent on it.

8. Municipal authorities in industrialized and in developing countries should be encouraged to share ideas in devising strategies to cope with the effects of climate change, through their national and international associations and through international bodies such as WMO, UNCHS, UNEP, UNIDO and UNDP.

Public Health Protection

RECOMMENDATIONS

9. Comprehensive world-wide assessments should be made by appropriate national and international organizations concerning the vulnerability of specific geographic regions and urban areas to the increased risk of a higher incidence and spread of infectious diseases due to global climate change, including both vector-borne and other communicable diseases.

10. Assessments should also be made of health care infrastructures in specific geographic regions and urban areas found to be at greatest risk, of their ability to cope with a projected increased risk of the spread of infectious disease, and of steps identified to be taken by local and national authorities and international organizations to improve such capabilities.

11. Assessments should be made of the vulnerability of nuclear facilities, municipal and hazardous waste dumps, or other waste disposal facilities in coastal and estuarine areas to sudden flooding or more gradual inundations, of the potential for consequent spread of infectious pathogens or toxic chemicals to surrounding land and sea areas, and of the appropriate steps to minimize such risk.

WATER RESOURCES

Chairpersons:	Z. Kaczmarek G. Kenney-Wallace	
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INTRODUCTION

There is now a strong consensus, despite some predictive uncertainties, that many of the most destructive impacts of global atmospheric change on society and the environment will be mediated and exacerbated by changes in regional water resource systems. Unless arrested and reversed, climate warming together with the long-range transport of acidic and toxic pollutants will, in many regions of the world:

- increase the demand for water
- decrease the water supply reliability
- increase the vulnerability to droughts and floods
- damage the integrity of aquatic ecosystems
- increase the potential for social tensions and conflict

There is good evidence that such changes have already begun in vulnerable, water-stressed areas of the world.

To confound the problem, these changes will take place against a backdrop of existing water crises in many areas of the world. These crises affect most severely the poor, especially in developing countries, where adequate drinking water supplies and sewage treatment services are lacking and where water is the transmission agent for over 80% of all diseases. Contamination of surface and ground waters is worsening in some parts of the industrial world and rapidly spreading to the developing world. Whereas many industrial countries lack the political will to respond effectively to these acute problems, most poor nations do not even possess the infrastructure, resources, scientific knowledge and technology to do so.

In our considered opinion, it is imperative to develop urgent national and international initiatives that are scientifically and ethically appropriate to respond to these challenges. Global atmospheric change threatens the capacity of our water resource systems to support sustainable human development. The time to plan and act is now.

FRAMEWORK FOR ACTION

Global Equity: Industrialized societies have for a long time derived benefits from economic practices that release harmful products and wastes into the atmosphere and degrade aquatic ecosystems. Many millions of people around the world now suffer from the harmful consequences, usually in inverse proportion to their responsibility for them, their ability to cope and their share of the benefits. Such disproportionality is the greatest impediment to the adoption of environmentally sound practices and must be removed through remedial actions that are based on principles of interregional and intergenerational equity.

All nations must assume a greater responsibility for defining and highlighting the issues, but the industrialized nations must provide the necessary technical assistance and funding for an integrated response.

International Cooperation: Because of existing conflicts over water use, some nations are already collaborating on the research and management of transboundary estuary, lake and river basin ecosystems. Experts are also sharing information on comparative case studies of smaller aquatic ecosystems in some regions. Such transboundary and cooperative initiatives should be expanded to all regions. The regional scale of global atmospheric change should be recognized as a key issue of concern in all these activities.

Knowledge and Technology Transfer: Knowledge of the effects of atmospheric change on water resource systems is fragmented or non-existent. National and international data programs must be expanded and integrated. Better methods for sharing and coordinating water-related information must be fostered by UN specialized agencies and by other intergovernmental and non-governmental organizations. In addition, carefully orchestrated technology transfer programs will need to be developed and implemented by the developed nations. Most important, however, the receiving nations must be assisted in providing themselves with infrastructure, including trained personnel, to avail themselves of the technology.

Involving the Public: Ultimately the responsibility and work to mitigate and adapt to the effects of atmospheric change on water resources will fall to many millions of individuals world-wide. Their understanding of the problem is crucial to success. Where applicable, governments should encourage and facilitate public involvement in the planning and execution of corrective programs. Educational opportunities and access to relevant information must be provided, both directly and through the action of public-interest organizations.

AQUATIC RESOURCE POLICIES

Water Resource Policy: Water resource policy should have an aquatic ecosystem focus. Efficiency and equity should be the guiding objectives. We advocate extreme caution in resorting to large-scale structural measures to mitigate climate change impacts and, instead, endorse primary consideration of less disruptive alternatives such as demand management, water conservation and ecologically-sound land management.

Recommendations

1. Policies emphasizing water-use efficiency are particularly critical and should include equitable water valuation; research, development and dissemination of region-specific water conservation methods; improved weather information and forecasting tied to hydrological events; and flexible water allocation mechanisms.
2. Policies to improve resilience in water resources management require integrated planning for higher variability in supply and demand; conjunctive management of surface and ground-water resources; coordination and harmonization with policies in other sectors (particularly energy, agriculture, fisheries, transport, urban and environment); and emphasis on flexible processes of allocation.
3. Water resource development policies must explicitly take into account increased variability due to climatic change, especially in economic development assistance. Intergovernmental coordination and agreements to manage transboundary issues to minimize conflicts must also be straightened or developed.
4. Monitoring and assessment needs require policies to strengthen existing data collection and management efforts; strengthened training and infrastructure, especially in developing nations; and the development of specific policy-response scenarios that take into account climate change predictions.
5. Existing water resource plans and agreements must be modified to include multi-sectoral objectives and the specific recognition of the above policy recommendations.
6. Concerning responses to water resource impacts from global atmospheric change, a carefully planned review should be held at the 1992 Conference on Sustainable Development on the status of national efforts, especially policies to improve water-use efficiency.

Water quality policy: Water quality policy should also have an ecosystem focus and should recognize that pollutant-free surface and ground water are the cornerstones for the sustainable development of global aquatic resources and the achievement of long-term intergenerational equity in water-use.

Recommendations

7. Facilities for the provision of safe drinking water should be provided or upgraded world-wide and should explicity take into account the probable increases in the frequency and severity of droughts and floods.

8. Existing conventions and protocols for sulphur and nitrogen pollutants should be extended to other areas of the world and broadened to include the toxic trace metals and persistent organic pollutants. Such agreements should be based on ecologically defensible critical loadings of pollutants.

RESEARCH

Decisions made in the broad area of water resources have a critical impact on society. They are not easily reversed and their effects typically persist for many decades. Thus, the present era of global changes puts a premium on a sound knowledge of hydrological and related processes, and in turn reinforces the urgent need for increased monitoring efforts, on both the national and international scales.

Recommendations

9. Research in support of sound water resource development and management should first be directed toward an improved understanding of the relationships between climate, hydrology, soil and biota. This knowledge is an essential prerequisite for the development of transfer functions with which to project large-scale changes of the atmosphere onto hydrological and land-surface processes. These functions serve as the building blocks for models that transform information from General Circulation Models into specific predictions about the regional impacts resulting from global atmospheric change.

10. Development of such transfer functions poses a new and urgent challenge for the science of hydrology and its related disciplines. In particular, there is a need to refocus hydrological attention away from the traditional local scale to the global issues of water circulation and distribution, where progress is needed to implement sustainable development policies. A greatly expanded involvement should be made by hydrologists in existing and planned international, interdisciplinary scientific programs, such as IGBP and GEWEX.

11. Research should also be accelerated on the ecological processes in critical aquatic ecosystems affected by climate change and by acid and toxic rain. As a general rule climate differences of 10°C between locales are associated with 3-fold differences in the rates of ecosystem processes. Climate change may affect a given system over time in a similar way depending on the process involved. This issue deserves deeper interdisciplinary study. Rehabilitation methodologies to aid in lake and river recovery also need further examination.

12. Research in general will also contribute to the development of new and improved operational methodologies for assessing the sensitivity of water resources to atmospheric change in various regions of the world. Such methods will be crucial in the wise regional allocation of both human and fiscal resources.

SUMMARY

There is strong consensus, despite predictive uncertainties, that global climate change and long-range transport of pollutants will decrease the reliability of the water supply, increase the vulnerability to droughts and floods, damage the integrity of aquatic ecosystems and increase the potential for social conflict world-wide. We are ill prepared at present to formulate action plans to manage such change wisely for the long-term good.

To mitigate these expected impacts, there is a critical and urgent need to increase the efficiency of water use and to improve the resilience of existing and planned water resource management systems to both current and anticipated climate variability.

To reduce "toxic rain," we recommend that the existing acid rain (SO_2 and NO_x) conventions be extended to a global scale and modified to include toxic organic pollutants and trace metals.

To help resolve uncertainties, integrated monitoring and research programs are urgently needed (1) to identify critical regions and river basins where changes in hydrological processes and water demand will cause serious problems, (2) to understand and quantitatively model the hydrological, ecological and socio-economic impacts of regional climate change and (3) to improve the methods for assessing the sensitivity of water resource systems.

In responding to present and future water problems in support of sustainable development, we strongly endorse the global principle of interregional and intergenerational equity. International co-operation, open technology transfer, meaningful public involvement and effective public information programs are essential.

LAND RESOURCES

Chairpersons: B. Bolin
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Rapporteur: M. Chadwick

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INTRODUCTION

The Group accepts that the increase in atmospheric concentrations of greenhouse gases, enhanced deposition of acidifying compounds, as well as increasing ultra-violet radiation resulting from changes in stratospheric ozone, will increasingly lead to global climate changes and net adverse effects on terrestrial and coastal ecosystems, their spatial distribution, primary productivity and genetic diversity. It is becoming obvious that this will have far-reaching consequences for the sustainable development of our global society.

The long-term aim must be to halt the adverse environmental changes and restore the stability of terrestrial ecosystems. A strategy towards achieving such a goal must imply a very significant decrease in the rate of potential climate change, currently 0.3°C per decade, during the next few decades. It should aim to stop the increase in atmospheric greenhouse gases within the next 50 years. These goals must be attained if unacceptable global changes in the land resource base of our planet are to be avoided.

The above implies cessation in the use of CFCs, and a 50% reduction in CO_2 emissions. To achieve the latter, it is fundamental that ongoing deforestation be curtailed, and that terrestrial carbon pools be preserved. It is emphasized that a warmer climate may well enhance the return of large amounts of CO_2 to the atmosphere as a result of the increased respiration and decay of peat and soil carbon.

The Group also noted that mangrove swamps are among the most productive areas in the world, and like other important coastal ecosystems, are seriously threatened by the prospect of rising sea-level.

RECOMMENDATIONS

1. An International Fund should be created specifically for development assistance and research in relation to the land resource aspects of climate change listed below.

2. The terrestrial reservoir of carbon should be maintained and increased through the careful management and protection of tropical and temperate forests and their soils, tundra and wetlands that represent major carbon pools.

   Tropical deforestation, in particular, merits attention and therefore, all governments and agencies should intensify their political and financial support for existing national and international programs that seek to control deforestation and to promote the sustainable use of tropical forest resources.

   One program, the Tropical Forestry Action Plan, has received the endorsement of governments, international and non-governmental organizations and serves as the focal point for such activity. Priority actions that would address the role of forestry in climatic change would include:

   a) addressing the causes of global poverty that force the rural poor to be the instruments of forest destruction. This would include land reform, agricultural pricing policies, and access to credit and technical assistance. It also involves maximizing income and employment opportunities for the rural poor in sustained forestry-related activities.

   b) promoting increased agricultural productivity and enforcing effective land-use planning for the orderly transfer of land from forestry to agriculture only when suitable for sustained production, thereby reducing the need for encroachment into the remaining forests for expansion of subsistence agriculture.

   c) intensifying efforts to develop the more effective supply and use of fuelwood and to promote alternative sources of energy for the two and a half billion people in developing countries who, by the year 2000, will rely on fuelwood for heating and cooking purposes.

More efficient use of energy will, in particular, reduce the supply needs and the emission of CO_2.

d) co-operating with financing and aid institutions so that the external benefits of establishing and maintaining forests as carbon sinks are henceforth included in forest management planning. Likewise, other external benefits, such as maintaining germ plasm, and soil and water conservation, should be incorporated.

e) providing increased financial resources for basic and applied tropical forest research, and for policy investigations, in order to correct practices that presently encourage deforestation in many developing countries. Education, training and extension efforts should likewise be increased.

f) continuing studies on the need for and feasibility of establishing a financing facility whereby debt could be applied to reforestation projects, the establishment of national parks and wildlife reserves, creation of conservation centres and other necessary environmental activities.

3. The development of sustainable land-use practices should be encouraged. Emphasis should be placed on agro-forestry, the reforestation of lands already cleared of forests; the restoration of damaged watersheds and those whose hydrological equilibrium is threatened; the production of high-yielding, drought-resistant crop varieties and the development of cropping systems appropriate to adverse climatic conditions, as part of an adaptive strategy for climate change; the development of effective management practices leading to methods of solid waste treatment and land disposal in order to minimize adverse effects on the atmosphere; and the human conditions and policies affecting the use, settlement and tenure of land.

4. The identification of the most productive agricultural land should be a priority so that a land reserve system may be implemented to give high priority of action to these areas, in order to prevent loss of productivity due to adverse atmospheric conditions and the rise in sea-level.

5. Awareness should be increased among the public about issues posed by atmospheric change in relation to the continued wise use of land in a sustainable manner through the establishment of an international task force sponsored by UNEP, working through professional and local interest groups.

6. Existing programmes that address the impact on land resources of acid and other toxic depositions should be broadened to take account of the global dimension that these pollutants are now assuming.

Many of the objectives embodied in these recommendations imply the qualification of certain views that are currently part of conventional economic wisdom. Sustainable development requires a commitment to the protection of environmental goods and services, including land resources, underpinned by a theory of a sustainable economic system that can be rapidly put into practice.

COASTAL AND MARINE RESOURCES

Chairpersons:	M. Glantz J.P. Troadec	
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INTRODUCTION

Oceans cover 70% of the world's surface and are a critical component of the climate system. Major considerations are:

i) Ocean circulation plays a paramount role in determining global atmospheric temperature fluxes and rainfall patterns.

ii) Air-sea interactions determine the long-term impact of atmospheric changes on the marine and coastal environments.

iii) Marine biota, mainly phytoplankton, moderate climate change through the control of atmospheric CO_2 levels. Even though we require a deeper understanding of all these interactions, it is already clear that any alteration of oceanic and biotic components will have a wide and immediate to long-term range of impacts.

Production of plant material in the oceans (30-50 Gt/a) is approximately equal to the annual growth of land plants, but 10-30% of the marine plant growth is stored in the interior ocean through sedimentation. This carbon flux responds rapidly to changes in ocean circulation, exceeds the annual production of CO_2 by deforestation and the burning of fossil fuels and is thus a key element in causing changes in the trends observed in our global climate.

In addition, the warming of the oceans as a consequence of the greenhouse effect will lead to the cumulative effects of changes in sea-level, altered storm tracks and rainfall patterns in the most intensively used portion of our world, i.e., the coastal zone, at great human and financial cost.

An increase in high-latitude temperatures on glaciers and polar sea-ice cover will lengthen the season and extend the areas of open water, and lead to a greater number of icebergs being calved and transported in appreciable amounts into shipping routes. Enhanced possibilities will arise for shipping on the Arctic coasts of Canada, the Scandinavian countries and the USSR.

FISHERIES

A small global warming of the ocean would modify moderately and, possibly positively, the overall world fish production (which contributes one-fifth of societies' animal protein consumption (excluding milk and eggs)). In particular, the regional patterns of production and variability in naturally fluctuating stocks, such as sardines and anchovies, could change markedly. Moreover, the spatial distributions of such stocks could be displaced, thus affecting national, as well as local economies, should the warming be of sufficient magnitude to alter significantly the general ocean circulation patterns.

In coastal areas, the productivity of highly valued species, such as shrimps and anadromous species, and the yields from extensive aquaculture will often be negatively affected by the reduction of the nursery and growing areas associated with the expected rise of sea-level. Depending on changes in rainfall, river runoff will either augment or reduce the above yields.

Atmospheric transported pollutants, such as nitrates, PCBs, and PANs, are having harmful effects on freshwater and marine living resources. Such effects will change in relation to the rates of emissions.

COASTAL ZONES

Today, a third of the earth's human population lives in coastal zones where important economic activities and large cities are concentrated.

Wetlands, mangroves and forest areas are now under stress. In their natural state, wetlands adjust to the sea-level rise by moving landward. This natural move will not be readily accepted by present users and owners. Consequently wetlands and mangrove areas will be reduced. Land used for agriculture and aquaculture will also be lost. Productivity will be adversely affected by salt intrusion. Water management systems will also become degraded. In addition, vulnerability to storm surges and ecosystem disruptions will increase. Inhabited sand and coral reef islands will be threatened.

Individual and collective decision-makers react more readily to discrete events than to slow cumulative changes. Sea-level rise is a long-term, slow but cumulative process. Thus, action will most likely occur only after the expected sea-level rise causes severe flood disasters with loss of lives and damage to property and infrastructure.

The impacts are expected to have a greater effect on developing countries whose populations are more dependent on natural ecosystems and where the means for action are less compared to those of developed countries. Many of the issues encountered in the use of collectively used, natural resources are already acute. Many societies have unsatisfactory records in achieving optimum use of limited and open-access resources as well as in harmonizing modern economies (which tend to favor individual initiatives and exchange) with traditional economies and cultures (based on the collective exploitation of natural living resources). Such interactions between the two modes of economies and cultures are encountered in both developed and developing countries.

RECOMMENDATIONS

1. To determine the role of the world ocean in mediating an atmospheric CO_2 increase, the accuracy of estimating ocean carbon fluxes must rapidly be improved by one order of magnitude, at least.

2. Until recently, fishery science has paid insufficient attention to fish stock variability and the interrelationships between their abundance and their physical and biological environments. As a consequence, the assessment and monitoring of the effects of changes in the atmosphere on fishery resource productivity and the improvement of medium- and long-term fishery management strategies depends heavily on understanding how natural and anthropogenic factors determine the productivity and variability of marine and coastal resources.

3. To respond efficiently to such variability, it will be necessary to monitor changes in the biomass of phytoplankton in key locations in the world.

4. In addition, the flexibility of industries and communities dependent on marine resources needs to be enhanced. This could be achieved by the reduction of excessive fishing capacities, the creation of compensatory schemes, the improvement of marketing strategies, the support for community-based sustainable development strategies, and so forth.

5. Even more important are the development and implementation of institutional and legal arrangements adapted to the flexible sustained use and conservation of fishery resources and the management of their exploitation. Such development must involve groups that are potentially affected by that resource exploitation.

6. To mitigate the detrimental effects of sea-level rise in coastal areas, regional, national and local authorities and agencies should initiate and support the preparation of impact assessments, with proper consideration for human, economic and environmental risks, as well as for the adequacy of institutional and legal systems.

7. Governments should develop analyses and planning for low-lying coastal areas aimed at quantifying the risks of sea-level rise and at identifying the opportunities and constraints associated with the location of new developments inland.

8. Results of site-specific impact studies should be introduced in educational programs and must be used to underscore the need for supporting policies aimed at reducing the emissions of greenhouse gases.

9. Development of navigation in the Arctic and elsewhere will require increased route survey activity by national hydrographic and ice-forecast services.

FORECASTING AND FUTURES

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B.C.J. Zoeteman

INTRODUCTION

In order to cope with future change, we must acquire and make use of past knowledge as well as develop the ability to anticipate possible futures. No one model can or should be expected to deal with the uncertainties in forecasting, the details needed for decisions, and the social, technical and ecological implications of change. Hence, an array of techniques should be used in order to produce useful results.

Not only are improvements needed in forecasting methodologies but a continued effort is needed to integrate cause-and-effect modelling. In addition, improvements are needed in our ability to communicate and convey their implications to the broader culture so that individual and collective decision-making can be made appropriately and with foresight. Attitudinal and institutional changes are also necessary because of rapid global change. Equally important is the need to take action regarding the interrelated issues of population growth, resource use and depletion, and technological inequalities in an environmentally sustainable way.

GENERAL

Models, forecasting methods and futures designs provide essential foresight in times of deep, qualitative change, but responses can be driven by surprises or unexpected events that might overwhelm the adaptive capabilities of individuals, institutions and nations. If models, the processes of forecasting and futures designs are to help, an eclectic set must be developed. No one model, process or design can deal appropriately with all the detail needed for decisions, the space-time interactions needed for realism, and the social, technological, and ecological forcing functions. Individual methods and approaches, never-the-less, have strengths as part of the whole. Quantitative simulation methods are essential for studying the interaction of physical systems. Semi-quantitative or qualitative approaches are more appropriate for the estimation of effects. Projection techniques involving speculation and supposition are the methods to use when building futures scenarios and policy options.

The Conference on The Changing Atmosphere has heard the latest evidence concerning the destruction of the earth's ozone layer by chlorofluorocarbons (CFCs). The projected consequences of a weakening of this protective barrier to the health of individual human beings and to agricultural crops led to the Montréal Protocol, whose goal is to reduce the use and release of chloro- and fluorohydrocarbons to prevent further destruction of this layer. Based on more recent scientific information, it may be necessary to reduce the CFC emissions beyond that set by the Montréal Protocol. This case proves that, in clearly defined global threats to the environment with a consensus among scientific, government and private sector groups, an effective international response can be formulated even in the face of sudden and surprising developments.

The prospect of global warming is a broader, more difficult issue than CFC destruction of the ozone layer. Despite the uncertainties of future climate change forecasts, there is a clear consensus that the potential changes are serious, with likely major economic and social consequences. Further refinement of methods for forecasting climate change, as well as their impacts, is essential to reduce the uncertainty. However, we must now begin detailed elaboration of the possible futures and policy options that can ameliorate our problems. Following the development of climate change forecasting, the development of future options must now be established on a basis of international cooperation. We need to take into account socio-economic factors, such as population pressure, and the unequal division and use of resources, as well as the purely technical aspects of greenhouse gas management. We should take action to affect the future environment in a way that promotes sound economic, energy and environmental policy, much of which is embodied in the concept of "sustainable development".

Cross-cutting policy issues, such as those brought about by climate changes, must be addressed at both national and international levels. International analysis and action, based upon proper foresight and anticipatory planning on the national level, are the necessary prerequisites for coping with such futures problems.

RECOMMENDATIONS

1. Climatic change should be recognized as a variable in long-range economic, hydrologic, agricultural, and socio-economic planning. The sensitivity of these and other sectors to climate change at national, international and regional levels should be identified and responses developed.

2. Possible major changes in biological, energy, economic, social and cultural systems as a result of climate change should be identified and evaluated so that preventative and integrated strategies can be recognized, estimated, evaluated and implemented. To achieve this, governments must analyse their organizational structure so that the forecasting of problems that cut across departmental, ministerial or agency lines of responsibilities are adequately addressed and that they do not "fall through the cracks". This requires, at the very least, developing an integrated capacity of foresight and anticipation on behalf of governments and other agencies. The appropriate mechanisms for such a process must be set up without delay.

3. Appropriate international organizations should assess their present role in addressing issues associated with climate change and develop

structures and methods whereby data and information can be collected, shared and analysed on an international basis.

4. Research institutes producing forecasts of future global and regional climate changes, and of the related impacts, should pay particular attention to identifying sources of uncertainty in their assessments and confidence limits of their predictions.

5. Forecasters and other researchers from various disciplinary sub-specialties need to become increasingly familiar with the concepts and methods of co-workers from other disciplines. Doing this they can produce information useful to interdisciplinary efforts to forecast climate changes, identify the forces that create those changes, and the environmental and societal impacts of the changes. They can then create alternative policy actions that can alter the distribution of those impacts.

CONCLUSION

Past and present civilizations, including our own, have traditionally exercised forms of scientific, economic, political and military controls but these were not designed to contend with the rate or the magnitude of the behavioural changes that seem to be occurring in our social, demographic and natural environments.

DECISION-MAKING AND UNCERTAINTY

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K. Von Moltke
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G.J.R. Wolters

BACKGROUND

The scientific facts presented to us have convinced us that by now the state of knowledge demands political action. Translating the climatological facts into political terms, we find an alarming trend and considerable risks in current economic developments. We are impressed that expectations that have been expressed since the early seventies have been confirmed to such an extent. Thus, the conclusions of the Brundtland report are confirmed that current economic developments are not sustainable and may lead us into serious conflicts.

Still existing uncertainties in the scientific analysis have no bearing on the actual conclusion that political decisions have to be made now. Further steps will require more detailed information with respect to regional developments and to economic as well as societal effects of atmospheric change. This information must be based on further studies in the natural as well as in the social sciences.

RECOMMENDATIONS

1. Global research programmes on the chemistry of the atmosphere should be advanced, as well as agricultural, health, economic, legal, political and other social studies concerning the implications of climate change (prevention, compensation and adaptation).

   There are uncertainties, however, of a political nature that require close examination. The basic question is whether the political system, globally and nationally will be able to respond adequately to the atmospheric threat. To tackle these uncertainties we present the following recommendations:

2. We recommend that those countries primarily responsible for the current threats take the first steps in undertaking solutions. These are the industrialized nations. As Mrs. Brundtland said: "We in the North have a special responsibility". Fortunately, the industrialized countries are also those who have the capabilities technically and economically to find solutions. The responsibility of these countries implies that production facilities that endanger sustainable development should no longer be operated nor transferred to other countries.

3. Environmental politics have only been partially successful so far. In taking climatic risks, mankind has definitely exceeded the limits of an environmentally sustainable economic development. Environmental destruction is now raising questions about basic values. The political system must become perceptive to them. The industrialized nations now definitely should begin to restore the integrity of the environment, making the atmospheric change the <u>turning point</u> for an ecological innovation of industrial economy.

4. To achieve this target it will no longer be enough to stabilize emissions at present levels. Emissions have to be reduced. Simply to freeze today's emissions would be inadequate if we want to ensure the viability of human life and life generally on earth. Our recommendations are that:

   - the Montréal protocol be ratified as soon as possible
   - the remaining countries also join this convention
   - the so-far omitted ozone-depleting gases also be included
   - after ratification, the protocol should be revised to phase out CFCs entirely by the mid-90s (according to the Swedish example)

- CO_2 emissions be reduced by 10-20% by the turn of the century
- the draft NO_x protocol under the E.C.E. Convention being a good first step should be ratified as soon as possible

5. Such emission targets and schedules ought to be the subject of an international treaty between those nations who take the first step. These nations should invite all the others to join them in advancing environmentally sustainable economic development. Here, the Vienna convention can be taken as a model or pathfinding step to a convention (or law) of the atmosphere.

6. The atmospheric threat confirms that environmental policy is basically no longer in opposition to long-term economic goals. Especially, there are convergent interests between environment and sustainable technological progress, energy, transportation systems, agriculture, human health, consumerism, and both national and international security. Considering that such a convergence helps the political system give the atmospheric issue its appropriate priority, we recommend that this priority be accepted immediately.

7. Open decision-making may, as well, provide for decisions otherwise not easily accepted by the public. What is needed first is to increase public awareness and to influence consumer behaviour - and thus to back up otherwise perhaps unpopular decisions. We recommend a democratic discourse about responses to the atmospheric threat. Non-governmental organizations should play a decisive role in furthering this discourse.

8. Certainly, the impact of the developing world on atmospheric changes is not to be neglected. We recommend that the industrialized countries assist the developing world in coping with environmental destruction. Regional approaches are necessary to stop deforestation and to promote reforestation. An international fund ought to be established to finance adequate measures, technology transfer, and the required studies. As one possibility to establish such a fund, we discussed a levy on oil.

9. We hope the existing international institutions as well as the national governments will respond adequately to the call by the World Commission on Environment and Development. We propose a review of the present international system to determine its adequacy.

INDUSTRY, TRADE AND INVESTMENT

Chairperson: P. Winsemius

Rapporteur: R. Dobell

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F. Feldmann
W.C. Ferguson
B. Fritsch
M. Ginsburg
D. Gregory
D. Ireland
H.J. Karpe
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J. MacNeill
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H.W. Quinn
A. Roncerel-Bonin
J. Seeliger
R. Srubar
J. Thompson
P.F. Van Es

BACKGROUND

The evidence is now persuasive that we face formidable problems of atmospheric change - climate warming, ozone depletion, acid rain - of a magnitude greater than can be handled in the normal course of events. The need for determined action by industry, government and households is now inescapable.

The direct impacts of climate change on economic activity and social structures have been discussed extensively in general terms, and include an increased probability of extreme climate events, possibly massive dislocations of production, trade and population patterns, and major adverse impacts on income and wealth distributions.

Nevertheless, given the rates of change involved, the direct impacts of climate change on industry and economic activity can probably be absorbed within the normal processes of industrial decisions, at least for the larger enterprises and more developed countries, which have greater adaptive capacity. Significant problems must be anticipated for smaller enterprises and vulnerable developing countries with many fewer options for adaptation.

The key point, however, is that the general social costs of the associated disruption of economic activity will be much greater than the direct impacts of climate change. Public investment requirements associated with population movements and social infrastructure are likely to be massive.

Thus, social and political corrective actions to reduce climate change and to adapt to the anticipated social costs of the irreducible trends must be considered inevitable. The indirect impacts on economic and social activities through these anticipatory corrective actions will be larger and will occur much sooner than the corresponding direct impacts described earlier.

A brief review of "reduced emissions" scenarios reveals the extremely demanding nature of the adjustments required even to slow the current rates of climate warming or ozone depletion. Further reviews of industrial contributions to these phenomena suggest particular targets within industrial sectors: power generation, heavy industry, transportation and agriculture.

An extensive package of measures to promote energy conservation, technology transfer, and alternative technologies clearly will be necessary to achieve any robust path of sustainable development, but equally clearly is unlikely to be sufficient to assure its attainability.

The Working Group therefore agrees on the necessity of extraordinary action in a package of substantial measures, of which the following should be elements:

RECOMMENDATIONS

1. Creation of a World Atmosphere Fund, financed primarily by the Western industrial countries, designed to mobilize a very substantial pool of capital to support:

   - development of new energy-efficient technologies and applications
   - greater access to existing and new ecologically appropriate technologies
   - transfer of appropriate technologies to developing countries to assure a more fuel-efficient industrialization
   - international exchange of information

   The operation of such a fund might be coupled with appropriate global limits on emissions, and financed through a levy on fossil-fuel consumption (of the order of 1% or more).

2. Development by business and industry of improved mechanisms for incorporating environmental considerations into the internal decision processes of business through:

   - regular environmental performance reviews, to be reported to boards and shareholders
   - corporate codes of environmental conduct
   - active industry participation in the implementation of sustainable development initiatives, and in research and development programs directed towards economy-environment integration

3. Formation of an international multipartite consultative forum at the highest level, representing all major environmental stakeholders (business and political leaders, scientists and community leaders), whose discussions would be directed towards the deliberations of heads of government.

As matters of urgency and immediate priority, this forum should address:

i) mechanisms to establish by 1992 the World Atmosphere Fund already recommended.

ii) accelerated research and development efforts within an adaptive program to develop atmospherically benign technologies and products reflecting goals of energy conservation, elimination of CFCs in industrial production and trade, and reduction of CO_2 emissions. These research and development efforts must be coupled with the intensified promotion of public information and awareness directed towards consumers, politicians and target groups of industries.

iii) reduction of institutional barriers to the adoption of low-emission technologies by industries and households.

iv) improvement of market information to promote the shift of consumption towards ecologically appropriate products. Adverse impacts of product labelling or trade limitations should be offset by positive incentives such as the massive "debt for development" initiatives advocated elsewhere in this Conference. In particular, for example, labelling requirements to discourage consumption of products based on unsustainable exploitation of tropical forests should be developed as part of a broad positive package to protect tropical rain forests against inappropriate land-use decisions.

GEOPOLITICAL ISSUES

Chairperson: H. Cleveland

Rapporteurs: N. Desai
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F. Kinnelly
C.I. Jackson
M. Lemayer
J. MacNeill
D. McDermott
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R. Morgenstern
R.J.D. Page
A. Polansky
D. Runnalls
G. Saint-Jacques
E. Salim
K. Subramahnyan
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Zhou Xiuji

BACKGROUND

Atmospheric problems require international coordinated efforts, but we should seek prompt action by governmental and non-governmental groups, while at the same time striving for a more all-encompassing international agreement. This dual process should evolve new norms of behaviour, such as limits on the emission of heat-trapping gases, as well as recognition of the atmosphere as the global commons most intimately intertwined with human futures.

Prompt actions can be based on the opportunities available in all countries, such as improvements in energy use efficiency, and should be coupled with vigorous and diversified examinations of replacement energy sources. These processes will involve major reductions in fossil-fuel use in the industrialized world and transfers of technology and resources to the Third World.

The particular regions of the world, or sectors of the economy, that will be damaged first or most strongly by a rapidly changing atmosphere cannot today be foreseen with any accuracy, but the magnitude and variety of eventual impacts is such that we believe it is in the self-interest of all peoples to join in prompt actions to slow the changes and to negotiate toward an international accord on achieving a shared responsibility for the care of the climate and atmosphere.

Climate changes will worsen international tensions and the risk of conflict, and will intensify internal discrimination and resource disparities. The impacts of climate changes will be felt by all, but there are important differences in the severity of impacts and the responsibility for the changes. In particular, the industrialized nations of the world bear primary responsibility for the emission of greenhouse gases. Yet the developing countries will be most severely affected by climate changes. These problems will be greatly exacerbated by unprecedented rates of population growth. Developing countries have the fewest resources for adapting to or mitigating the impacts.

Climate change not only requires moving from conflictual to cooperative approaches on "non-military security", but it is linked to the future of arms control and disarmament. For example, if nuclear power is to play a role in reducing greenhouse gas emissions, the public will have to feel assured that the world will be moving toward a future free of nuclear weapons.

The nations of the world must recognize that the atmosphere is a commons and that it must be treated as such. In a commons:

- Sovereignty is not "ceded", but "pooled".
- Participants have rights of use (comparable to easements) not rights of property or appropriation.
- Participants have equal responsibility to help care for and govern the commons. That obligation includes the protection of diversity.
- Individual use is subject in principle to common consent and decisions are by consensus.

RECOMMENDATIONS

1. An international, coordinated effort is needed (such as a Law of the Atmosphere), but we must also look for individual and group, and governmental and non-governmental actions. We must do what can be done now, rather than wait for an all-encompassing international agreement. Specific goals (norms) must be set to reduce the emissions of greenhouse gases and reduce climate impacts.
2. The total costs and benefits of actions needed to protect the commons must be shared in a manner participants agree is "fair". "Fairness" has to do with what happens inside countries as well as among them. For example, energy policy and practices will have to be different for countries in different modes or stages of development. Significant additional energy use will be needed in developing countries. In addition, a transition to a different energy future will require investments in energy efficiency and non-fossil fuel energy sources. In order to ensure that these do take place, the global community must establish mechanisms for the smoother transfer of resources and relevant technologies from industrialized to developing nations.
3. A "Framework" for addressing the issue of climate change should not depend on scientific considerations alone, but also on strategic and political considerations, and a sense of a global community.

4. Institutions and arrangements required for articulating such a framework must be flexible and fair:

   - Norms are agreed globally, but systems are uncentralized ("A two-tier system").
   - Different functions require differing degrees of participation. For some functions or control systems (e.g., nuclear safeguards or a limitation of coal-burning), a "consortium of the concerned" may best serve the purpose.
   - An explicit role needs to be carved out for non-governments, and for combinations of public and private initiatives and actions.
   - State-of-the-art information technologies will be needed for observation, dissemination, and feedback as part of commons management.
   - Funding of research on, and management of the commons is best made by "automatic" revenues. These can include insurance-type arrangements based on the sharing of risks, levies on activities (such as on fossil-fuel use) that use the commons, licence fees, or similar arrangements.

5. The steps required to prevent damaging changes to the atmosphere - slowing the release of pollutants and the eventual stabilization of the composition of the atmosphere - must be international in scope. As such, they bring us face-to-face with long-standing global needs: stabilization of the world's population size, relaxation of military tensions and disarmament, and a decrease in the disparity of wealth, consumption, and opportunity within and among countries. Progress toward any of these historic goals will enhance our ability to slow or eliminate damaging changes to the atmosphere; failure to improve our care of the atmosphere can only increase tensions and damage our ability to improve economies everywhere. Perhaps the newly recognized imperatives for cooperation on crucial climate problems will provide new avenues for consideration of the older issues.

LEGAL DIMENSIONS

Chairperson: J.A. Beesley

Rapporteur: A. Adede

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R.D. Bojkov	M. Pietarinen
G.V. Buxton	K. Ramakrishna
I. Courage	R. Robinson
J. Goffman	S. Shrybman
A. Kessel	J.R. Spradley
M. Kostuch	H. Strauss
F. Mathys	J. Young
A.S. Miller	S. Zwerver

INTRODUCTION

The Legal Working Group emphasized that there is an urgent need for the further progressive development of international law for the protection of the atmosphere on the basis of available scientific evidence. It further noted that while there is already a significant body of international environmental law in existence, the legal regime specifically relating to the atmosphere is relatively fragmented and incomplete.

In discussing how to develop the necessary legal regime for addressing the environmental risk management problems associated with agricultural, chemical, and energy uses that bring about deleterious effects upon the atmosphere, the Working Group was guided by a number of considerations.

RECOMMENDATIONS

1. The legal regime for the protection of the atmosphere should build upon existing precedents for the protection of the environment while adapting them, as necessary, to deal with specific problems of the atmosphere that may require the establishment of new principles, rules and institutional frameworks. The Working Group took into account the precedents existing in international case law such as the trilogy of Trail Smelter, Corfu Channel and Lake Lanoux, that establish the principle that States have an obligation to avoid transboundary harm; that environmental harm may be wrongful; and that victim states have the legal right to insist on the prevention and abatement of such harm. It also took into account Principle 21 of the 1972 Declaration of the United Nations Conference on the Human Environment; the 1979 ECE Convention on Long-Range Transboundary Air Pollution and related protocols; Part XII of the 1982 United Nations Convention on the Law of the Sea; and the 1985 Vienna Convention for the Protection of the Ozone Layer and its 1987 Montréal Protocol (which was considered as a model).

2. The efforts should, therefore, be directed toward the elaboration of an umbrella/framework convention that would lend itself to the further developing specific agreements or protocols laying down international standards for the protection of the atmosphere and to encouraging states to enact appropriate national legislation. In this connection, the offer of the Prime Minister of Canada to host a meeting of law and policy experts in early 1989 in Ottawa was welcomed. The elaboration of such a convention should not delay agreement, in the meantime, on more specific areas, for example, deforestation; nor stand in the way of national initiatives in enacting or strengthening appropriate legislation.

3. The elaboration of the umbrella/framework convention should recognize the variety of means available on global, regional, bilateral or national levels for dealing with the problems of the atmosphere that are of a transboundary or global nature.

4. The further elaboration of an international convention for the protection of the atmosphere would be enhanced by regular meetings of high-level national representatives. An appropriate intergovernmental working group could establish a precise agenda to elaborate new instruments for the protection of the atmosphere on the basis of short-, medium- and long-term strategies.

5. In the elaboration of the various legal instruments, thought should be given to the problem of encouraging compliance, not solely through the concept of liability but also through incentive mechanisms that would, inter alia, take into account the special interests of developing countries.

6. An umbrella convention should provide for the coordination of scientific activities and technological research, the transfer of technology, the exchange of information, the development of national management regimes and plans, and the special requirements of developing countries. In this connection, a preference was expressed to use the existing facilities of appropriate international organizations within the United Nations system for these purposes.

INTEGRATED PROGRAMS

Chairperson: T. Malone

Rapporteur: I. Burton

Members:

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E. Gibbs
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F.A. Koomanoff
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G. Pearman
M. Permut
R. Price
E.F. Roots
C.J.E. Schuurmans
Yu. Sedunov
J. Stone
R.T. Watson

BACKGROUND

Human-induced atmospheric change is recognized as one of the great threats to the security of humankind. Human response to this threat will depend not only upon the advancement but also on the integration of knowledge and upon the development of common understanding.

The institutions that create and disseminate knowledge are not always adequately linked with each other, and the programs of research and action tend to be fragmented, sometimes inconsistent and lacking intercommunication and to pursue objectives that may not be compatible. Thus, there is a need for greater integration of knowledge and for increased cooperation in research and action within and between institutions. A better and more coherent program is needed that will provide an improved and comprehensive understanding of the processes that are changing the atmosphere and of their environmental and socio-economic consequences.

It is encouraging that the ongoing World Climate Programme and the Man and the Biosphere Programme have defined objectives in response to this need, and that major new initiatives such as the International Geosphere-Biosphere Programme, the Human Response to Global Change Programme, and the Intergovernmental Panel on Global Change are coming into being.

Such multidisciplinary and interdisciplinary efforts at both the national and international levels require more substantial and sustained support if they are to fulfil the high demands that will be placed upon them.

It is also encouraging to note that, at a time when the seriousness of the problems of the changing atmosphere is being recognized, there is a renaissance of the bio-geosciences in a new integrated framework of planetary science, in which for the first time, it is becoming possible to study global processes in an holistic way. This intellectual endeavour does not yet fully engage the human sciences but early signs of convergence can be seen.

RECOMMENDATIONS

1. Governments should make renewed commitments to interdisciplinary programmes and should ensure adequate funding.

2. A related encouraging development is the convergence of the natural sciences with the social and human sciences towards a goal of creating and illuminating policy choices at national, regional and international levels. These events should be encouraged and accelerated with all deliberate force. The processes of convergence and integration will be facilitated by the development of shared conceptual frameworks developed by scientists in interdisciplinary research program at national and international levels. Such frameworks should encompass scientific research, policy assessment and institutional capacities to take appropriate action.

3. It is suggested that scientists in interdisciplinary research programs should be involved in the development of appropriate comprehensive frameworks at national and international levels and that these be used as aids in the identification of gaps in research and of areas for common endeavours.

4. All relevant organizations should assess their own capacities to respond to the challenges of atmospheric change and global security in ways that can be fully integrated with the contributions of others. An international review of such assessments should be discussed at the World Climate Conference in 1990, as a contribution to the preparations for the Human Environment Conference in 1992. An independent assessment of world-wide research capacity and of integrated programmes should be carried out at a senior level by an independent group and prepared in time for presentation at the Conference.

5. In the building of integrated program, particular attention should be paid to the identification of critical areas that can be expected to require urgent attention, such as: (i) plausible unanticipated variations in the extremes of temperatures because of their importance to ecosystems, the possible changes in the distribution and in the amounts of precipitation, and other effects of global warming, such as an increase in sea-level; (ii) the vulnerability and resilience of ecosystem structure and its consequences for biodiversity - changes in climatic zones and habitats might result in environmental stresses that would exceed the capacity of some organizations and trophic levels to respond and could lead to severe dislocation of ecosystems, with a greatly reduced species composition and loss of genetic diversity; and (iii) the matching of agriculture, forestry and human-managed landscapes to

changed conditions - care would be needed to ensure that food crops and forest trees are adapted to anticipated changes in conditions.

6. A strong impetus to integration can also be given by the development of monitoring and information systems that will provide a common basis for the harmonization of data on changes in the atmosphere, on the changes that occur in terrestrial and marine ecosystems, and on socio-economic activities. These monitoring and information systems should be built upon those already existing and linked to the needs of the research program.

7. In order to improve understanding of the importance and urgency of the changes in the atmosphere, a wide-ranging education and public information program should be developed. Awareness of environmental problems and of their importance to all human activities should be a component of education at all levels in both developing and industrialized countries. Natural environmental agencies, in cooperation with international bodies such as UNESCO, should take the lead in ensuring that suitable environmental information is made available to education authorities. With regard to higher education, the problems of maintaining a high level of scientific competence, while providing for broad interdisciplinary research on environmental problems, should be overcome.

8. Adequate attention should be given to an integrated program for the provision of information to the media and to non-governmental organizations, which can play an important role in the education of a wide audience, and in the creation of an informed public in all countries that can influence national and international policies.

ÉNERGIE

Présidents : J. Goldemberg
W. Long

Rapporteurs : W. Haéfele
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RECOMMANDATIONS

1. Le lien entre l'énergie et le climat

Il est essentiel que les politiques énergétiques nationales et internationales portent explicitement sur les émissions de CO_2 et autres gaz à effet de serre (GES) qui contribuent au réchauffement atmosphérique.

Les taux de réduction nécessaires du CO_2 et autres GES sont tellement importants qu'ils présentent des défis sans précédent pour les politiques énergétiques, quelle que soit notre incertitude quant aux réductions éventuelles des émissions nécessaires pour stabiliser la température du globe.

Les lignes de conduite pertinentes peuvent varier, dans le detail, selon le pays ou la région et il existe actuellement un besoin urgent pour de meilleures analyses des répercussions régionales quant au lien entre les mesures énergétiques et le changement climatique, ainsi que pour la surveillance des progrès réalisés.

Des mécanismes doivent donc être élaborés pour mesurer et vérifier l'impact de la politique énergétique sur le changement climatique ainsi que les coûts connexes. Ces mécanismes appuieront l'évaluation et l'amélioration continuelles de la planification nationale, des programmes régionaux et globaux, et les décisions individuelles en matière d'énergie.

Il importe avant tout de gagner du temps.

2. Économies d'énergie et rendement énergétique

Le premier élément, et le plus évident, de la politique énergétique qui doit être adoptée en réponse aux problèmes climatiques est le renouvellement de notre engagement à conserver les combustibles carbonifères et à améliorer le rendement énergétique en général. Les économies d'énergie et le rendement énergétique étaient déjà un objectif dans le passé, mais dans la perspective d'une pénurie des réserves énergétiques. À l'heure actuelle, il nous faut aussi améliorer le rendement énergétique pour réduire le CO_2 et les autres GES.

Les progrès technologiques, le transfert de technologies et l'aide étrangère en matière d'énergie doivent être encore beaucoup plus centrés sur l'amélioration du rendement énergétique que par le passé.

Les objectifs d'amélioration devraient se rattacher directement aux réductions du CO_2 et des autres GES. On aimerait bien pouvoir réduire de 10% d'ici l'an 2005 le total annuel des émissions mondiales de CO_2.

L'amélioration du rendement énergétique n'est pas exactement la même chose que la réduction des émissions de carbone total, et les politiques détaillées de chaque pays ne seront pas toutes très connues. Il est donc important de faire une étude détaillée des répercussions de cet objectif.

3. Mesures à court terme en matière d'approvisionnement énergétique

Du côté de l'approvisionnement offre de l'équation énergétique, il est également nécessaire d'adopter des changements qui auront des répercussions à court terme.

Les objectifs reliés à l'approvisionnement en matière d'énergie devraient se rattacher directement aux réductions du CO_2 et des autres gaz de serre. On aimerait bien pouvoir réduire de 10% d'ici l'an 2005 le total annuel des émissions mondiales de CO_2 et ce, en plus des réductions réalisées du fait d'une utilisation plus rationnelle de l'énergie. Une étude détaillée des répercussions de cet objectif devrait être faite.

Les émissions totales de gaz carbonique et autres GES varient de maintes façons selon les techniques d'utilisation des combustibles fossiles. Par unité d'énergie livrée, la combustion du gaz naturel libère la moitié moins de gaz carbonique que la combustion du charbon. Le rendement de systèmes de conversion énergétique est également crucial : mentionnons par exemple la réduction de l'aération et du brûlage à la torche du gaz naturel et l'augmentation du rendement de la production d'électricité à partir de combustibles fossiles.

La biomasse est aujourd'hui une importante ressource énergétique des pays en voie de développement. On l'utilise souvent d'une façon inefficace. Grâce à des projets de recherche et de démonstrations visant à accélérer la mise au point des techniques perfectionnées de conversion de la biomasse, on pourrait nettement contribuer à conserver les stocks de la biomasse du monde et à réduire le taux d'accroissement du gaz carbonique de l'atmosphère. En diminuant le déboisement et en accélérant le reboisement, tout en reconstituant les réserves primaires d'énergie pour la majorité de la population mondiale, on pourrait contribuer beaucoup à réduire la concentration atmosphérique de CO_2.

D'autres techniques d'énergie renouvelable (énergie solaire, éolienne, photovoltaïque, hydroélectrique) fournissent de l'énergie sans émettre de gaz carbonique.

Du fait des préoccupations que suscitent les conséquences des émissions de CO_2 et d'autres gaz, on devrait envisager de nouveau l'option de l'énergie nucléaire, qui a perdu une certaine crédibilité du fait des problèmes reliés à la sécurité, aux déchets radioactifs et à la prolifération des armes nucléaires. Si l'on pouvait résoudre ces problèmes grâce aux perfectionnements techniques et aux dispositions prises entre établissements, l'énergie nucléaire pourrait jouer un rôle dans la réduction des émissions de CO_2.

4. Mesures à long terme en ce qui a trait à l'approvisionnement énergétique

À long terme, il est possible de baser les systèmes énergétiques mondiaux sur les sources primaires sans carbone, comme les diverses formes d'énergie nucléaire et solaire. Combinées à l'électricité et à l'hydrogène comme vecteurs énergétiques secondaires, elles pourraient constituer un système inoffensif pour le climat. L'utilisation limitée des combustibles fossiles pourrait également être acceptable dans des scénarios semblables compte tenu des puits du gaz carbonique des grandes profondeurs marines.

La transition à de tels systèmes énergétiques prend du temps, et il faut faire des analyses plus détaillées des systèmes pour identifier les stratégies énergétiques appropriées à de telles transitions.

5. Approches du moindre coût

Les coûts économiques et les avantages doivent être inclus dans la formulation des lignes de conduite énergétiques en matière d'effet de serre afin de réduire les répercussions climatiques.

Il est donc nécessaire d'intérioriser les coûts extériorisés et, par conséquent, de considérer le coût des systèmes énergétiques au sens le plus large.

Sur cette base, il faudrait façonner les lignes de conduite de façon à pouvoir atteindre des objectifs sociaux vastes et complémentaires et réduire au minimum le total des coûts sociaux, économiques et environnementaux.

SÉCURITÉ ALIMENTAIRE

Présidents : M. Parry
S. Sinha

Rapporteurs : N. Rosenberg
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Membres :		
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	Z.P. Charnoe	R.S. Odingo
	R.S. Chen	P. Oram
	K.A. Dahlberg	G. Ramirez
	W. Degefu	C. Rosenzweig
	M. Gucovsky	R.P. Sarkar
	M. Ilyas	B. Smit
	S. Jodha	D. Stewart
	M. El-Kassas	N. Strommen
	C.J. Lankester	H. Versteeg
	L.G. Lessar	J. Williams

HISTORIQUE

À l'échelle du globe, les réserves alimentaires totales dépassent actuellement les besoins de base en calories de 20% en moyenne. Nous ne devons cependant pas nous satisfaire de cette marge de sécurité. La variation de ces réserves, d'année en année, due aux conditions météorologiques est de l'ordre de 10%. Malgré les surplus réalisés dans certains pays, environ 1 milliard de personnes (soit environ 15% de la population mondiale) ne dispose pas d'une quantité ou d'une qualité suffisante d'aliments pour vivre une vie entièrement productive.

MARGES DE SÉCURITÉ

Étant donné la croissance actuelle de la population et des revenus, la productivité stagnante des récoltes alimentaires mondiales, les rendements de moins en moins élevés de l'utilisation d'engrais, l'utilisation de l'énergie moins efficace en agriculture et les problèmes croissants causés par les maladies et les insectes nuisibles, il est probable que même sans un changement climatique, la sécurité alimentaire dans certaines régions du monde, et au cours des années de conditions météorologiques défavorables, continuera d'être une cause de préoccupation.
Malgré les progrès techniques réalisés depuis le début du siècle, la production d'aliments et de fibres demeure très sensible aux variations du climat, principalement aux variations extrêmes comme les sécheresses, les inondations, les vagues de chaleur, les gels et les vents violents. De telles fluctuations dans la production dues aux variations climatiques sont particulièrement fortes dans les régions semi-arides où la sécurité alimentaire au cours du 21^{e} siècle sera très certainement soumise à d'intenses pressions résultant de la croissance démographique et de la disponibilité des terres. Le changement climatique aggravera ces problèmes.

Le changement climatique dû à la modification de la composition atmosphérique augmentera probablement la fréquence des contraintes exercées sur l'agriculture et la sécurité alimentaire. Dans bien des régions, les bienfaits directs dont peuvent bénéficier les plantes de l'enrichissement de l'atmosphère en CO_2, démontrés dans des études faites en milieu contrôlé, seront probablement compensés par des périodes de chaleur et d'humidité plus fréquentes.

Bien qu'il reste encore de graves incertitudes quant aux changements régionaux possibles en ce qui a trait à l'humidité, les estimations actuelles des effets les plus graves des tendances concernant l'augmentation des concentrations des GES d'ici l'an 2005 sont les suivantes:

i) Possibilité réduite de production de blé et de maïs dans le centre de l'Amérique du Nord et dans le sud de la partie européenne de l'URSS en raison des températures plus élevées et de la diminution de l'humidité du sol.

ii) Possibilité accrue de production céréalière dans les régions plus au nord (comme dans les Prairies canadiennes, les Plaines du nord de l'Europe, et le centre de la partie européenne de l'URSS), bien que cette augmentation soit limitée par le type de sol et le relief.

iii) Risques accrus d'érosion et d'inondation, et raccourcissement possible de la saison de croissance, dans le sud et le sud-est de l'Asie, en raison des changements au niveau de l'intensité des moussons d'été.

iv) Perte de terres agricoles dans les régions côtières basses (comme au Bangladesh, dans le sud-est de l'Asie et le delta du Nil) en raison de la montée du niveau des océans.

v) Importants changements au niveau de la prédominence des ravageurs et des maladies agricoles aussi bien dans les pays industrialisés que dans les pays en voie de développement.

Les incertitudes au sujet des tendances régionales possibles de répartition d'humidité dans les régions semi-arides vulnérables nous préoccupent beaucoup, surtout parce qu'elles peuvent avoir des répercussions sur l'approvisionnement en eau pour l'irrigation dont la sécurité alimentaire de nombreux pays semi-arides dépend énormément.

L'ampleur de ces effets possibles fait peser une menace sérieuse sur la sécurité alimentaire nationale et internationale. Les programmes nationaux et internationaux actuels de sécurité et d'assistance alimentaire, qui ne peuvent déjà pas répondre aux besoins des peuples et des nations les plus pauvres, ne pourront faire face à ces pressions sans être restructurés et renforcés. De plus, l'organisation du commerce international des denrées devra être réexaminée.

Bien que les réserves alimentaires <u>globales</u> moyennes ne soient pas sérieusement menacées, <u>à moins que des mesures appropriées ne soient prises pour anticiper les changements climatiques et s'y adapter</u> il pourrait en résulter de graves pénuries alimentaires régionales saisonnières qui auront un impact particulier sur les groupes les plus vulnérables. La plupart de ces mesures seront très coûteuses et toutes les mesures prises dans le but de prévenir ou atténuer le changement climatique permettront probablement de réaliser des économies substantielles dans le secteur alimentaire.

RECOMMANDATIONS

1. Gaz à effet de serre

Nous incitons expressément les États à réduire la contribution de l'agriculture à l'augmentation de la concentration des GES dans l'atmosphère. Cette contribution découle de la destruction des forêts, du mauvais usage des engrais azotés inorganiques, de l'extension des risières et de l'augmentation du cheptel de ruminants.

2. Planification

Les États devraient tenir compte de la perspective du changement climatique dans la planification à long terme de l'agriculture et de la sécurité alimentaire, en particulier en ce qui a trait à la disponibilité des aliments pour les groupes les plus vulnérables.

3. Adaptabilite accrue

Les États et les organismes internationaux devraient attacher plus d'importance à un vaste éventail de mesures politiques afin de la vulnérabilité des sources d'approvisionnement alimentaire à la variabilité climatique en accroissant l'adaptabilité actuelle au changement climatique. Ces mesures devraient comprendre entre autres la réduction des pertes après la moisson, de meilleures pratiques de stockage à la ferme et au niveau régional, des infrastructures et des installations de transport améliorées, l'établissement de stocks tampons et l'adoption de techniques éprouvées à l'échelle locale. Des politiques commerciales internationales moins restrictives, des approches plus innovatrices en matière d'aide alimentaire et de financement des développements pour l'amélioration des bases de ressources locales, et des investissements plus importants dans la recherche, l'information et la formation agricole sont également essentiels.

4. Coopération

Du fait que les petites nations risquent de voir toute la base de leurs ressources grandement touchée par le changement climatique, nous incitons les États à redoubler d'efforts pour édifier une coopération sous-régionale et régionale destinée à assurer la sécurité alimentaire. Les organismes internationaux devraient contribuer à encourager ces efforts régionaux de coopération.

5. Équilibre écologique

La FAO, la Banque mondiale, l'OMM, le PNUE, le PNUD, le GCRAI et d'autres organismes internationaux devraient encourager la recherche qui conduit à la mise au point de systèmes de gestion agricole écologiques. On accroîtrait ainsi l'aptitude à adapter les pratiques agricoles au changement climatique.

URBANISATION ET PEUPLEMENT

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D. Bandhu	N. Kollias
G.R. Clements	G. Leutert
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J.E. Hardoy	

INTRODUCTION

Une proportion croissante de la population mondiale vit dans les zones urbaines. Il faut donc accorder une attention particulière à ces zones pour étudier les effets du changement climatique sur la santé et le bien-être.

Voici les principaux points de préoccupation en ce qui a trait à l'urbanisation et au peuplement:

i) La contribution relativement plus importante des zones urbaines au changement climatique global en raison de leur grande utilisation de ressources énergétiques par personne.

ii) Le risque accru de surcharge des capacités de distribution de la nourriture et de l'eau, d'arrêt de fonctionnement des systèmes sanitaires, et de propagation de maladies dans les zones de concentrations denses de populations humaines dans les grandes et petites villes.

iii) Le déplacement possible des ruraux dans les zones urbaines pour éviter des impacts climatiques (comme la sécheresse).

iv) La migration probable sur une plus grande échelle des "réfugiés environnementaux", en provenance des régions sinistrées, dans des zones plus habitables, principalement dans les agglomérations urbaines, entrainant quelquefois l'immigration dans d'autres pays.

Les répercussions du changement climatique sur les agglomérations urbaines et les tendances migratoires prendront probablement la forme de désastres naturels plus fréquents associés aux :

i) Extrêmes de température (vagues de chaleur plus fréquentes et plus longues dans certaines régions, froids extrêmes dans d'autres)

ii) Changements au niveau du régime des précipitations (conditions de "moussons" plus humides dans certaines régions, sécheresse dans d'autres)

iii) Orages violents plus fréquents sur terre et en mer (accompagnés de vagues de tempêtes et d'inondations des villes côtières et estuariennes)

iv) Périodes accrues de stagnation de l'air au-dessus des villes et des régions avoisinantes (entrainant des épisodes plus fréquentes de pollution d'air).

RECOMMANDATIONS

1. Il faudrait surveiller l'expansion de l'urbanisation sur les terres agricoles de premier ordre, principalement dans des régions où les récoltes sont susceptibles de diminuer en raison du changement climatique.

2. On devrait encourager les citoyens à s'adonner à des activités plus axées sur l'environnement.

3. Les villes et les peuplements humaines devraient être gérés de façon à respecter l'environnement, p. ex. le recyclage des déchets. La conception des villes, la construction des édifices et les réseaux de transport en commun devraient se fonder sur le principe du rendement énergétique.

4. Les constats d'impacts environnementaux et les plans d'aménagement du territoire devraient tenir compte des conditions climatiques futures, comme la diminution des quantités d'eau disponibles dans les régions semi-arides. Des évaluations individuelles des impacts environnementaux devraient porter en particulier sur les effets locaux de la montée du niveau des océans sur les collectivités côtières.

5. Les autorités urbaines devraient procéder à des évaluations des risques urbains et mettre au point des mesures de planification d'urgence qui tiennent compte des effets du changement climatique comme la fréquence accrue des dangers naturels.

6. Les États et les organismes d'aide internationale devraient élaborer des lignes de conduite et des mesures pour s'occuper du problème des déplacements accrus possibles des personnes déplacées par suite du changement climatique.

7. Il faudrait souligner l'importance de l'éducation officielle et non officielle en matière d'environnement, particulièrement en ce qui a trait au développement durable des centres urbains et des peuplements humains. Il faudrait accorder une attention particulière aux responsabilités collectives des gens et de leurs dirigeants chargés de proccurer aux jeunes toute l'information nécessaire sur l'environnement. Nous faisons tous partie d'un même système en vase clos dont nous dépendons tous.

8. Les autorités municipales des pays industrialisés et des pays en voie de développement devraient être encouragées à partager leurs idées en ce qui a trait à l'élaboration de stratégies visant à contrer les effets du changement climatique, par l'entremise de leurs associations nationales et internationales et celle d'organismes internationaux comme l'OMM, le CNUEH, le PNUE, l'ONUDI et le PNUD.

<u>Protection de l'hygiène publique</u>

RECOMMANDATIONS

9. Les organisations nationales et internationales concernées devraient faire des évaluations mondiales détaillées en ce qui a trait à la vulnérabilité de certaines régions géographiques et urbaines aux risques accrus d'une plus grande fréquence et d'une propagation des maladies infectieuses dues au changement climatique planétaire, y compris des maladies à transmission vectorielle et du autres maladies transmissibles.

10. Il faudrait également évaluer les infrastructures des soins médicaux dans certaines régions géographiques et urbaines les plus exposés, leur aptitude à faire face à un risque accru de maladies infectieuses, et les mesures que doivent prendre les autorités locales et nationales et les organismes internationaux pour améliorer cette capacité.

11. Il faudrait évaluer la vulnérabilité des installations nucléaires, des décharges municipales et des sites d'enfouissement des déchets dangereux ainsi que des autres installations d'élimination des déchets dans les régions côtières et estuariennes à une inondation soudaine ou à des inondations plus graduelles, la prolifération possible de pathogènes infectieux ou de toxiques dans les régions terrestres et marines avoisinantes, et les mesures appropriées visant à minimiser ces risques.

RESSOURCES EN EAU

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G. Kenney-Wallace

Rapporteurs : S. Changnon, Jr.
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Membres :

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L. Black	H. Lo
T. Brydges	M.M. Malliti
J. Byrne	M. Moss
C. Candanedo	J. Nemec
I. Creed	J.-C. Oppeneau
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INTRODUCTION

Il est reconnu, à l'unanimité, que malgré certaines incertitudes prévisionnelles, un grand nombre des impacts les plus destructeurs du changement atmosphérique global sur la société et l'environnement seront accompagnés et aggravés par des changements des réseaux régionaux d'approvisionnement en eau. A moins d'être stoppés et inversés, le réchauffement des températures ainsi que le transport à grande distance des polluants acides et toxiques entraineront dans bien des régions du monde:

- une augmentation de la demande en eau
- une diminution de la fiabilité des approvisionnements en eau
- une augmentation de la vulnérabilité aux sécheresses et aux inondations
- l'effritement de l'intégrité des écosystèmes aquatiques
- l'accroissement des tensions et des conflits sociaux.

Tout porte à croire que ces changements ont déjà commencé dans les régions vulnérables du monde où les réserves d'eau posent un problème.

Pour aggraver les choses, ces changements se produiront dans un contexte de pénuries d'eau sévissant dans de nombreuses régions du monde. Ces crises touchent plus sévèrement les pauvres, particulièrement dans les pays en voie de développement où les approvisionnements en eau potable et les services d'épuration des eaux usées font défaut et où l'eau est l'agent de transmission de plus de 80% de toutes les maladies. La contamination des eaux de surface et des eaux souterraines s'aggrave de plus en plus dans certaines parties du monde industriel et se répand rapidement dans les pays en voie de développement. Alors que de nombreux pays industriels n'ont pas la volonté politique nécessaire pour réagir de façon efficace à ces graves problèmes, la plupart des pays pauvres ne possèdent même pas les infrastructures, les ressources, les connaissances scientifiques et les techniques nécessaires pour engager une campagne de lutte.

A notre avis, il faut absolument élaborer des mesures d'urgence nationales et internationales, scientifiquement et éthiquement appropriées, pour relever ces défis. Le changement atmosphérique global menace la capacité de nos systèmes de ressource en eau à supporter un développement humain durable. Le temps est venu de planifier et d'agir.

PLANS D'ACTION

Équité globale: Les sociétés industrialisées ont depuis longtemps profiter de pratiques économiques qui rejettent des produits et des déchets dangereux dans l'atmosphère et détériorent les écosystèmes aquatiques. Des millions de personnes, partout dans le monde, en subissent actuellement les conséquences dommageables, et généralement de façon inversement proportionnelle à leur responsabilité, leur aptitude à y faire face et leur part des profits. C'est justement cette disproportion qui empêche le plus l'adoption de pratiques écologiques et doit être éliminée grâce à des mesures basées sur des principes d'équité d'une région à l'autre et d'une génération à l'autre.

Tous les pays doivent assumer une plus grande responsabilité en ce qui a trait à la définition et à la mise en lumière des problèmes, mais les pays industrialisés doivent fournir l'aide technique et le financement nécessaires à une stratégie intégrée d'intervention.

Coopération internationale : En raison des conflits actuels que soulève l'utilisation de l'eau, certains pays collaborent déjà à la recherche et à l'aménagement des écosystèmes des bassins d'estuaires, de lacs et de rivières transfrontaliers. Les experts partagent également l'information obtenue au cours d'études comparatives de cas de petits écosystèmes aquatiques dans certaines régions. Ces initiatives de coopération devraient être élargies à toutes les régions. L'échelle régionale de l'évolution globale de l'atmosphère devrait être reconnue comme étant une préoccupation clé dans toutes ces activités.

Transfert de connaissances et de technologie : Les connaissances des effets du changement atmosphérique sur les systèmes en eau sont fragmentaires ou tout simplement inexistantes. Les programmes de données nationaux et internationaux doivent être élargis et intégrés. De meilleures méthodes de partage et de coordination des informations reliées à l'eau doivent être encouragées par des organismes spécialisés des Nations Unies et par d'autres organismes intergouvernementaux et non gouvernementaux. De plus, des programmes très bien orchestrés de transfert de technologie devront être élaborés et appliqués par les pays industrialisés. Il faudrait de plus, et c'est le point le plus important, que les pays bénéficiaires reçoivent l'aide nécessaire pour se doter eux-mêmes des infrastructures requises, y compris du personnel formé pour profiter eux-mêmes de ces technologies.

Participation du public : En définitive, la responsabilité et le travail nécessaires pour atténuer et ajuster les effets du changement atmosphérique sur les ressources en eau incombent à des millions de personnes partout dans le monde. Leur compréhension du problème est essentielle pour le succès de l'entreprise. Le cas échéant, les gouvernements doivent encourager et faciliter la participation du public à la planification et à l'exécution de programmes correctifs. Ils doivent offrir toutes les possibilités d'enseignement et l'accès aux informations pertinentes, directement et par le concours d'organismes d'intérêt public.

LIGNES DE CONDUITE CONCERNANT LES RESSOURCES AQUATIQUES

Politique en matière de ressources en eau: Cette politique devrait porter sur les écosystèmes aquatiques. Le rendement et l'équité devraient être les objectifs directeurs. Nous conseillons d'être extrêmement prudents lors de l'adoption de mesures structurelles à grande échelle visant à atténuer les impacts du changement climatique et, de considérer plutôt des moyens moins perturbateurs comme la gestion de la demande, la conservation de l'eau et l'aménagement écologique des terres.

RECOMMANDATIONS

1. Des lignes de conduite mettant l'accent sur l'utilisation rationnelle de l'eau sont particulièrement critiques et devraient englober une mise en valeur équitable des eaux; la recherche, le développement et la mise en commun des méthodes de conservation de l'eau propre à chaque région; des informations et des prévisions météorologiques améliorées reliées aux incidents hydrologiques; et des mécanismes souples de distribution des eaux.

2. Les lignes de conduite visant à améliorer l'adaptabilité de la gestion des ressources en eau nécessitent une planification intégrée afin d'assurer une meilleure variabilité au niveau de l'approvisionnement et de la demande; une gestion conjointe des ressources en eau de surface et en eau souterraine; la coordination et l'harmonisation avec les mesures d'autres secteurs (particulièrement l'énergie, l'agriculture, les pêches, le transport, l'aménagement urbain et l'environnement); et l'accent mis sur des procédés souples de répartition des eaux.

3. Les lignes de conduite de mise en valeur des ressources en eau doivent tenir compte de la variabilité accrue due au changement climatique, principalement au niveau de l'aide au développement économique. Il faudrait également rajuster ou mettre en oeuvre la coordination et les ententes entre les divers gouvernements visant à régler les questions transfrontalières afin de minimiser les conflits.

4. Les besoins en matière de surveillance et d'évaluation nécessitent l'adoption de lignes de conduite afin de renforcer les efforts actuels de collecte et de gestion des données; d'intensifier la formation et de développer les infrastructures, principalement dans les pays en voie de développement; et de mettre au point des scénarios d'urgence qui tiennent compte des prévisions du changement climatique.

5. Les plans et les accords actuels en matière de ressources en eau doivent être modifiés afin de comprendre les objectifs multisectoriels et la reconnaissance précise des recommandations susmentionnées en matière de lignes de conduite.

6. En ce qui concerne les réactions aux impacts du changement atmosphérique global sur les ressources en eau, une étude soigneusement planifiée devrait être faite lors de la Conférence de 1992 sur le développement durable, et portera sur l'état actuel des efforts nationaux, principalement en ce qui a trait aux mesures visant à améliorer l'utilisation rationnelle de l'eau.

Lignes de conduite en matière de qualité de l'eau : Ces mesures devraient également se concentrer sur les écosystèmes et reconnaître que les eaux de surface et les eaux souterraines non polluées sont la pierre angulaire du développement durable des ressources aquatiques du globe et le but de l'équité à long terme en matière d'utilisation des eaux, au fil des générations.

7. Les installations d'approvisionnement en eau potable salubre devraient être construites ou améliorées partout dans le monde et devraient tenir compte explicitement des augmentations possibles de la fréquence et de la gravité des sécheresses et des inondations.

8. Les conventions et les protocoles actuels en matière de polluants à base de soufre et d'azote devraient être adoptés à l'échelle mondiale et devraient être élargis de façon à comprendre les métaux toxiques à l'état de traces et les polluants organiques chroniques. De tels accords devraient être basés sur les charges critiques admissibles de polluants.

RECHERCHE

Les décisions prises dans le vaste domaine des ressources en eau ont des répercussions critiques sur la société. Elles sont difficiles à renverser et leurs effets durent des dizaines d'années. L'ère actuelle des changements globaux exige donc une connaissance approfondie de l'hydrologie et des processus connexes, et renforce le besoin urgent d'efforts accrus en matière de surveillance, aussi bien au niveau national qu'international.

RECOMMANDATIONS

9. La recherche en ce qui a trait à une mise en valeur et à un approvisionnement rationnels des ressources en eau devrait d'abord viser une meilleure compréhension des rapports entre le climat, l'hydrologie, les sols et les biotes. Cette connaissance est la condition essentielle à l'élaboration de fonctions de transfert avec lesquelles nous pourrons projeter les changements importants de l'atmosphère sur les processus hydrologiques et pédologiques. Ces fonctions servent de blocs de construction pour les modèles qui transforment l'information obtenue à l'aide des modèles de circulation générale en prévisions spécifiques relatives aux impacts régionaux du changement atmosphérique global.

10. L'élaboration de ces fonctions de transfert pose un défi nouveau et urgent pour la science de l'hydrologie et ses disciplines connexes. Il faut particulièrement dévier l'attention de l'échelle locale traditionnelle pour la fixer sur les questions d'ordre planétaire en matière de circulation et de distribution des eaux, là où le progrès est nécessaire pour l'application de mesures de mise en valeur durable. Les hydrologistes devraient s'impliquer plus à fond dans les programmes scientifiques interdisciplinaires et internationaux, existants et prévus, comme le PIGB et le GEWEX.

11. Il faudrait accélérer la recherche sur les processus écologiques des écosystèmes aquatiques critiques, touchés par le changement climatique et les pluies acides et toxiques. En règle générale, des différences de climat de 10 °C entre deux endroits sont associées à des différences multipliées par trois au niveau du taux des processus de l'écosystème. Le changement climatique peut toucher un système donné, dans le temps, de la même façon selon le processus impliqué. Cette question mérite une étude interdisciplinaire plus approfondie. Les méthodes de remise en état des lacs et des rivières doivent également être étudiées plus à fond.

12. La recherche en général contribuera également à la mise au point de méthodes opérationnelles nouvelles et améliorées pour évaluer la vulnérabilité des ressources en eau au changement atmosphérique dans diverses régions du globe. Ces méthodes seront essentielles pour une juste répartition régionale des ressources humaines et financières.

RÉSUMÉ

Il est unanimement reconnu que, malgré certaines incertitudes prévisionnelles, le changement climatique global et le transport à grande distance des polluants diminueront la fiabilité des approvisionnements en eau, augmenteront la vulnérabilité aux sécheresses et aux inondations, porteront atteinte à l'intégrité des écosystèmes aquatiques et augmenteront la possibilité de conflits sociaux partout dans le monde. Actuellement, nous sommes mal préparés pour formuler des plans d'action qui nous permettraient de maitriser ces changements pour le bien de l'humanité à long terme.

Pour pouvoir atténuer ces répercussions prévues, il importe, de toute urgence, d'améliorer l'utilisation rationnelle des eaux et d'accroitre la souplesse des systèmes actuels et projetés d'aménagement des ressources en eau par rapport à la variabilité du climat aussi bien actuelle que prévue.

Pour réduire "les pluies toxiques", nous recommandons que les conventions actuelles sur les pluies acides (SO_x et NO_x) soient appliquées à l'échelle mondiale et modifiées de façon à inclure les polluants organiques toxiques et les métaux à l'état de trace.

Pour pourvoir éliminer certaines incertitudes, des programmes intégrés de surveillance et de recherche sont nécessaires de toute urgence (1) pour idenfier les régions critiques et les bassins fluviaux où les changements apportés aux processus hydrologiques et à la demande en eau causeront de graves problèmes; (2) pour comprendre et modéliser de façon quantitative les impacts hydrologiques, écologiques et socio-économiques du changement climatique régional; et (3) pour améliorer les méthodes d'évaluation de la vulnérabilité des systèmes de ressources en eau.

L'adoption d'une stratégie de mise en valeur soutenue face aux problèmes actuels et futurs en ce qui a trait à l'eau nous permettra d'adhérer sans réserve au principe global de l'équité d'une région à l'autre et d'une génération à l'autre. La coopération internationale, le transfert technologique ouvert, la participation réelle du public et des programmes efficaces d'information sont essentiels.

RESSOURCES TERRESTRES

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INTRODUCTION

Le Groupe accepte que l'augmentation des concentrations atmosphériques des GES, le dépôt accru de composés acidifiants ainsi que l'augmentation des rayons ultraviolets due aux changements dans la couche d'ozone stratosphérique entraineront de plus en plus de changements climatiques globaux et auront des effets néfastes nets sur les écosystèmes terrestres et côtiers, leur répartition spatiale, leur productivité primaire et leur diversité génétique. Il devient de plus en plus évident que tout cela aura des conséquences à long terme sur le développement durable de notre société.

Notre but à long terme doit consister à stopper les changements environnementaux néfastes et à restaurer la stabilité des écosystèmes terrestres. Une stratégie visant à atteindre un tel objectif doit faire appel à un ralentissement significatif du changement climatique, actuellement de 0,3 °C par décennie, au cours des prochaines années. Cette stratégie devrait chercher à stopper l'augmentation des GES atmosphériques au cours des cinquante prochaines années. Ces objectifs doivent être atteints si nous voulons éviter les changements globaux inacceptables au niveau des ressources terrestres de notre planète.

Les objectifs susmentionnés sous-entendent la cessation de l'utilisation de CFC et une réduction de 50% des émissions de CO_2. Pour atteindre ce dernier objectif, il est essentiel de mettre un terme au déboisement actuel et de préserver le réservoir terrestre de carbone. Il faut souligner qu'un réchauffement des températures augmentera les quantités de CO_2 dans l'atmosphère à la suite de l'augmentation de la respiration et de la décomposition du carbone contenu dans la tourbe et le sol.

Le Groupe a également remarqué que les marécages de palétuviers sont les régions les plus productives du monde et, comme les autres écosystèmes côtiers importants, sont sérieusement menacés par la possibilité d'une hausse du niveau de la mer.

RECOMMANDATIONS

1. Un Fonds international devrait être créé spécialement pour l'aide au développement et à la recherche en ce qui a trait aux aspects des ressources terrestres en fonction du changement climatique énumérés ci-après.

2. Le réservoir terrestre de carbone devrait être maintenu et augmenté grâce à un aménagement et une protection avisés des forêts tropicales et tempérées et de leurs sols, de la toundra et des marécages qui représentent les principaux réservoirs de carbone.

   Le déboisement des forêts tropicales mérite une attention particulière, c'est pourquoi tous les gouvernements et tous les organismes devraient intensifier leur appui politique et financier aux programmes nationaux et internationaux existants qui cherchent à contrôler le déboisement et à encourager une utilisation durable des ressources forestières tropicales.

   Un programme, le Plan d'action des forêts tropicales, a été approuvé par les gouvernements, les organismes internationaux et non gouvernementaux et constitue la plaque tournante de toutes ces activités. Voici les mesures prioritaires dans le domaine de la foresterie en ce qui a trait au changement climatique :

a) Étudier les causes de l'appauvrissement global qui forcent les ruraux démunis à être les instruments de la destruction des forêts. Les mesures nécessaires engloberaient des réformes agraires, des mesures d'établissement des prix agricoles, et l'accès au crédit et à l'assistance technique. Ces mesures comprendraient également la maximisation des revenus et des possibilités d'emploi pour les pauvres des régions rurales dans des activitiés reliées à la foresterie.

b) Encourager une productivité agricole accrue et appliquer une planification efficace de l'utilisation des terres pour le transfert méthodique des terres de la foresterie à l'agriculture seulement lorsque ces terres sont appropriées à une production durable, réduisant ainsi la nécessité d'empiéter sans cesse sur les forêts qui restent pour l'expansion de l'agriculture de subsistance.

c) Intensifier les efforts visant à mettre au point un approvisionnement et une utilisation plus efficaces du bois combustible et favoriser d'autres sources énergétiques pour les deux milliards et demi de personnes qui vivent dans les pays en voie de développement et qui, d'ici l'an 2000, se serviront encore de ce combustible pour le chauffage et la cuisson. Une utilisation plus efficace de l'énergie permettra en particulier de réduire les besoins en énergie ainsi que les émissions de CO_2.

d) Coopérer avec des institutions financières et les organismes d'assistance de façon à ce que les avantages externes de l'établissement et du maintien des forêts en tant que réservoirs de carbone soient dorénavant inclus dans la planification de l'aménagement forestier. D'autres avantages externes, comme le maintien du matériel génétique, ainsi que la conservation des sols et de l'eau, doivent également être incorporés.

e) Fournir de plus grandes ressources financières pour la recherche fondamentale et la recherche appliquée en matière de forêt tropicale ainsi que pour les études précédant l'établissement de lignes de conduites afin de corriger les pratiques qui encouragent actuellement le déboisement dans bien des pays en voie de développement. Les efforts en matière d'éducation, de formation et de vulgarisation doivent également être accrus.

f) Poursuivre des études sur la nécessité et la faisabilité de l'établissement d'une institution financière grâce à laquelle la dette pourrait être appliquée à des projets de reboisement, l'aménagement de parcs nationaux et de réserves fauniques, la création de centres de conservation et autres activités environnementales nécessaires.

3. L'élaboration de pratiques d'utilisation durable des terres doit être encouragée. L'accent doit être placé sur l'agroforesterie, le reboisement des terres déjà éclaircies; le reboisement des bassins hydrographiques déjà endommagés et de ceux dont l'équilibre hydrologique est menacé; la production de variétés culturales à haut rendement, résistantes à la sécheresse; et la mise au point de systèmes de récolte appropriés aux conditions climatiques défavorables, dans le cadre d'une stratégie d'adaptation aux changements climatiques; l'élaboration de pratiques d'aménagement efficaces entraînant la mise au point de méthodes de traitement et d'enfouissement sous terre des déchets solides afin

de minimiser les effets néfastes sur l'atmosphère; et les conditions et les lignes de conduites qui touchent l'utilisation, le peuplement et le mode d'occupation des terres.

4. L'identification des terres agricoles les plus productives doit être une priorité de façon à ce que le système de mise en réserve des terres soit appliqué pour rendre ces régions prioritaires et, ainsi, prévenir la perte de productivité due aux conditions atmosphériques défavorables et à la montée du niveau de la mer.

5. Il faut sensibiliser davantage le public aux questions posées par le changement atmosphérique relativement à une utilisation rationnelle durable des terres grâce à la mise sur pied d'un groupe de travail international sous l'égide du PNUE, avec la collaboration de groupes d'intérêt professionnels et locaux.

6. Les programmes actuels qui s'attaquent à l'impact des dépôts acides et autres matières toxiques sur les ressources terrestres doivent être élargis de façon à tenir compte de la dimension planétaire de l'action de ces polluants.

Bon nombre des objectifs qui sont incorporés dans ces recommandations reprennent certaines opinions qui relèvent de la sagesse économique traditionnelle. Un développement durable nécessite un engagement vis-à-vis de la protection des biens et des services environnementaux, y compris les ressources terrestres, et cet engagement doit être étayé par une théorie d'un système économique durable qui peut être mise en pratique rapidement.

RESSOURCES CÔTIÈRES ET MARINES

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INTRODUCTION

Les océans, qui couvrent 70% de la surface du globe, constituent une composante majeure du système climatique. Les principaux points à considérer sont les suivants:

i) La circulation océanique joue un rôle primordial dans la détermination, à l'échelle globale, des flux thermiques et de régime des pluies.

ii) Les interactions air-mer conditionnent l'impact à long terme des changements atmosphériques sur les milieux marins et côtiers.

iii) Le biote marin, surtout le phytoplancton, atténue le changement climatique par son action sur les concentrations atmosphériques de CO_2. Même si nous devons encore approfondir l'étude de ces interactions, il est d'ores et déjà évident que toute modification des composantes océaniques et biotiques aura un très large éventail d'effets immédiats et à long terme.

La production végétale dans les océans (30 à 50 Gt/a) est à peu près équivalente à la production terrestre annuelle, mais de 10 à 30% de la substance végétale marine produite est déposée par sédimentation. Ce flux de carbone réagit rapidement aux changements de la circulation océanique et dépasse la production annuelle de CO_2 résultant du déboisement et du brûlage des combustibles fossiles; il représente donc un élément clé dans l'apparition des nouvelles tendances observées dans notre climat planétaire.

De plus, le réchauffement des océans dû à l'effet de serre produira des effets cumulatifs avec le changement du niveau de la mer et la modification des trajectoires de tempêtes et du régime des pluies dans les régions du globe les plus densément peuplées, comme les zones côtières, où ces phénomènes causeront de lourdes pertes humaines et financières.
Une hausse des températures de l'air au-dessus des glaciers et du pack polaire contribuera à prolonger la saison estivale et à étendre la superficie des zones d'eau libre; elle entrainera le fractionnement d'un plus grand nombre d'icebergs et leur dérive en quantité appréciable vers les routes maritimes. Le transport maritime le long des côtes de l'Arctique canadien, dans les pays scandinaves et en URSS sera donc facilité.

PÊCHES

Un léger réchauffement global des océans modifierait modérément, et peut-être positivement, la production mondiale de poissons, qui représente un cinquième de la consommation de protéines animales par les sociétés (à l'exclusion du lait et des oeufs). En particulier, les modes régionaux de production et la variabilité des stocks aux fluctuations naturelles, comme les sardines et les anchois, pourraient changer sensiblement. De plus, si le réchauffement est assez important pour modifier de façon significative les modes de circulation générale dans les océans, le déplacement possible du territoire de ces stocks, aurait un impact sur l'économie tant à l'échelle nationale que locale.

Dans les zones côtières, la réduction des aleviniers et d'autres aires d'élevage, causée par la montée prévue du niveau de la mer, nuira à la productivité d'espèces très appréciées, comme les crevettes et les poissons anadromes, et aux rendements de l'aquaculture extensive. Selon les variations du régime des pluies, le débit des rivières augmentera ou diminuera les rendements susmentionnés.

Les polluants transportés dans l'atmosphère, comme les nitrates, les BPC et les PAN, sont nocifs pour les ressources vivantes marines et d'eau douce. La nocivité de ces substances variera en fonction des taux d'émissions.

ZONES CÔTIÈRES

Actuellement, un tiers de la population humaine mondiale vit dans les zones côtières où se concentrent les activités économiques importantes et les grandes villes.

Les marécages, les mangroves et les forêts sont aujourd'hui soumises à de fortes contraintes. À l'état naturel, les marécages s'adaptent à la hausse du niveau de la mer par un recul vers l'intérieur. Ce déplacement naturel sera toutefois combattu par les utilisateurs et les propriétaires actuels des terres. En conséquence, les marécages et les mangroves seront réduits, et les terres utilisées pour l'agriculture et l'aquaculture, perdues. L'intrusion du sel nuira à la productivité. Les ouvrages hydrauliques se dégraderont. De plus, on observera une plus forte vulnérabilité aux vagues de tempête et aux perturbations des écosystèmes. Les îles de sable et les récifs de coraux habités seront menacés.

Les décideurs à titre privé et collectif réagissent plus facilement à des désastres isolés qu'à de lents changements cumulatifs. La hausse du niveau de la mer est un processus lent et à long terme, mais cumulatif. En conséquence, on n'envisagera probablement pas de mesures correctrices avant que la hausse prévue n'ait causé de graves inondations entraînant des pertes humaines et des dommages à la propriété et aux infrastructures.

On s'attend à ce que les pays en voie de développement soient plus durement touchés parce que leurs populations dépendent plus étroitement des écosystèmes naturels et que leurs moyens d'action sont inférieurs à ceux des pays industrialisés. De nombreux problèmes liés à l'utilisation collective des ressources naturelles sont déjà graves. Bon nombre de sociétés n'ont jamais réussi à utiliser de façon optimale leurs ressources limitées et accessibles à tous, ou à faire coexister les économies modernes (qui ont tendance à favoriser les initiatives individuelles et les échanges) et les économies et les cultures traditionnelles (basées sur l'exploitation collective des ressources naturelles vivantes). De telles interactions entre les deux types d'économie et de culture surviennent tant dans les pays industrialisés que dans les pays en voie de développement.

RECOMMANDATIONS

1. Pour pouvoir déterminer le rôle de des océans dans l'accroissement de la concentration de CO_2 dans l'atmosphère, il faut améliorer rapidement la précision de l'estimation des flux de carbone dans l'océan, d'au moins un ordre de grandeur.

2. Jusqu'à récemment, les sciences halieutiques n'ont pas prêté suffisamment d'attention à la variabilité des stocks de poissons et aux interrelations entre leur abondance et leurs milieux physiques et biologiques. En conséquence, l'évaluation et la surveillance des effets des modifications atmosphériques sur la productivité des ressources halieutiques, et l'amélioration des stratégies de gestion des pêches à moyen et à long terme, ne sont possibles que si l'on connaît le rôle des facteurs naturels et des activités humaines dans la productivité et la variabilité des ressources marines et côtières.

3. Afin de prendre les mesures qui s'imposent face à une telle variabilité, il sera nécessaire de surveiller les modifications de la biomasse du phytoplancton à plusieurs endroits clés dans le monde.

4. De plus, il faut accroître la souplesse des industries et des localités tributaires des ressources marines. Pour ce faire, il faut réduire les volumes excessifs de prises, élaborer des plans compensatoires, améliorer les stratégies de commercialisation, appuyer les stratégies communautaires de développement durable, et ainsi de suite.

5. On doit accorder une importance encore plus grande à l'élaboration et à la mise en application de dispositions institutionnelles et légales adaptées à une utilisation et à une préservation souple et durable des ressources halieutiques, ainsi qu'à la gestion de leur exploitation. Ces travaux doivent être le fruit d'une collaboration entre des groupes susceptibles d'être touchés par l'exploitation d'une telle ressource.

6. Afin d'atténuer les effets dommageables d'une hausse du niveau de la mer dans les régions littorales, les autorités et les organismes régionaux, nationaux et locaux doivent entreprendre et appuyer la préparation d'une évaluation des impacts, en tenant compte des risques sur les plans humain, économique et écologique, et en s'assurant de la valeur des systèmes institutionnels et légaux.

7. Les gouvernements doivent élaborer, pour les basses terres littorales, des projets d'analyse et de planification visant à quantifier les risques de hausse du niveau de la mer, et à déterminer les avantages et les contraintes de la localisation de nouvelles exploitations à l'intérieur des terres.

8. On doit présenter dans le cadre de programmes éducatifs les résultats d'études d'impacts propres au site, qui serviront à illustrer la nécessité d'appuyer les mesures visant à réduire les émissions de gaz responsables de l'effet de serre.

9. L'essor de la navigation dans l'Arctique et ailleurs exigera une surveillance intensifiée des routes maritimes par les services nationaux d'hydrographie et de prévisions des glaces.

FORMES D'AVENIR ET PRÉVISION

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INTRODUCTION

Pour conserver l'espoir de faire face au changement futur, nous devons acquérir et exploiter la connaissance du passé et développer l'aptitude à prévoir les formes éventuelles d'avenir. Nul modèle ne saurait à lui seul traiter des incertitudes de la prévision, des détails nécessaires aux décisions, ainsi que des répercussions sociales, techniques et écologiques du changement. Il convient donc de recourir à diverses techniques pour obtenir des résultats utiles.

Non seulement nous devons améliorer nos méthodes de prévision et poursuivre nos efforts d'intégration des modèles de cause à effet, mais nous devons également renforcer notre aptitude à communiquer et à signaler les implications à une culture plus étendue de sorte qu'on puisse prendre des mesures individuelles et collectives d'une façon pertinente et avertie. Du fait des conséquences mondiales, il faudra des modifications institutionnelles et d'attitude. Il est tout aussi nécessaire de prendre des mesures touchant les questions interdépendantes de la croissance démographique, de l'utilisation et de l'épuisement des ressources, ainsi que des inégalités techniques; ces mesures doivent respecter l'environnement.

GÉNÉRALITÉS

Les modèles, les méthodes de prévision et les formes d'avenir sont des outils essentiels de prévision à des époques de profonds changements qualitatifs, bien que certaines solutions puissent voir le jour à la suite d'événements imprévus susceptibles de surpasser la capacité d'adaptation des particuliers, des institutions et des nations. Si les modèles, les méthodes de prévision et les formes d'avenir doivent être un outil efficace, il faut faire preuve d'éclectisme. Nul modèle, processus ou concept ne saurait à lui seul traiter correctement toutes les données nécessaires aux processus décisionnels, les interactions spacio-temporelles qu'exige le réalisme, ainsi que les fonctions déterminantes sociales, technologiques et écologiques. Néanmoins, les méthodes et approches individuelles ont leur propre force en tant que partie intégrante de l'ensemble. Les méthodes de simulation quantitative sont essentielles à l'étude de l'interaction entre les systèmes physiques. Les approches semi-quantitatives ou qualitatives sont plus appropriées pour estimer les effets. Les techniques de projection qui s'appuient sur la spéculation et la supposition s'appliquent à la construction de scénarios d'avenir d'option de politique.

La Conférence sur l'atmosphère en évolution a fait connaitre les rapports les plus récents sur la destruction de la couche d'ozone de la planète par les chlorofluorocarbones (CFC). La prévision des effets d'une réduction de cette barrière protectrice sur la santé de l'homme et sur les cultures a débouché sur l'élaboration du Protocole de Montréal, dont le but est de réduire l'utilisation et l'émission de chloro-et fluorohydrocarbones pour prévenir l'érosion supplémentaire de cette couche. Cependant, des relevés scientifiques plus récents indiquent qu'il faudra peut-être réduire encore plus les émissions comparativement aux normes visées par le Protocole. Ainsi, comme ce cas le démontre, lorsque l'environnement est exposé à des menaces planétaires bien définies suscitant un véritable consensus entre scientifiques, gouvernements et secteur privé, il est possible de formuler une solution internationale efficace même s'il survient des événements soudains et surprenants.

La perspective d'un réchauffement planétaire est une question plus vaste et plus complexe que la destruction de la couche d'ozone par les CFC. En dépit des incertitudes dans la prévision du changement climatique futur, il est unanimement admis que les changements potentiels sont graves et qu'ils auront très probablement des conséquences économiques et sociales importantes. Cette incertitude ne pourra être réduite que par un perfectionnement des méthodes de prévision du changement climatique, et de son impact. Cependant, nous devons entreprendre dès maintenant l'élaboration détaillée des futurs possibles et des options politiques susceptibles d'atténuer nos problèmes. Après la mise au point d'une méthode de prévision du changement climatique, il faut établir des options futures basées sur la coopération internationale. Nous devons tenir compte des facteurs socio-économiques comme les contraintes démographiques et la répartition et l'utilisation inégales des ressources, ainsi que des aspects purement techniques de la gestion des GES. Nous devons prendre des mesures destinées à transformer l'environnement futur, de façon à promouvoir de saines politiques économiques, énergétiques et environnementales, fondées essentiellement sur le principe d'un "développement durable".

Les questions de politiques multisectorielles, comme celles qui sont posées par l'évolution climatique, doivent être traitées tant à l'échelle nationale qu'à l'échelle internationale. L'analyse et les mesures internationales, qui s'appuient sur une prévision avisée et une planification anticipée à l'échelle nationale, sont la condition essentielle qui permettront de faire face à ces problèmes futurs.

RECOMMANDATIONS

1. Il faut considérer le changement climatique comme une variable dans la planification économique, hydrologique, agricole et socio-économique à long terme. On doit déterminer le degré de vulnérabilité de ces secteurs et d'autres au changement à l'échelle régionale, nationale et internationale, et trouver les solutions appropriées.

2. Il faut identifier et évaluer les changements majeurs qui peuvent survenir dans les systèmes biologiques, énergétiques, économiques, socioculturels à la suite du changement climatique, de façon à pouvoir définir, estimer, évaluer et mettre en application des stratégies intégrées de prévention. Pour atteindre cet objectif, les gouvernements doivent examiner leur structure organisationnelle pour que la prévision de problèmes qui concernent plusieurs services, ministères ou organismes soit traitée de façon appropriée et non pas jetée aux oubliettes. Il faut donc, tout au moins, créer une capacité intégrée de prévision et d'anticipation pour les gouvernements et d'autres organismes, les mécanismes appropriés d'une telle entreprise devant être établis sans retard.

3. Les organisations internationales concernées doivent examiner leur rôle actuel dans le traitement des questions liées au changement climatique, et mettre au point des structures et des méthodes permettant de recueillir, de partager et d'étudier les données et l'information à l'échelle internationale.

4. Les instituts de recherche qui produisent des prévisions sur les changements climatiques planétaires et régionaux futurs, et leurs impacts associés, devraient s'assurer de bien identifier les sources d'incertitude dans leurs évaluations et indiquer les limites de confiance de leurs prévisions.

5. Les prévisionnistes et d'autres chercheurs dans diverses spécialités secondaires doivent se familiariser de plus en plus avec les concepts et les méthodes de leurs collègues dans d'autres disciplines. Ils pourront alors fournir une information qui servira aux efforts internationaux en vue de prévoir le changement climatique et identifier les forces derrière ces transformations, y compris les incidences environnementales et sociales qui en découlent. Il leur sera enfin possible d'élaborer, dans le cadre de lignes de conduite, des solutions de rechange, qui pourraient modifier la distribution de ces impacts.

CONCLUSION

Les civilisations passées et contemporaines, y compris la nôtre, ont exercé traditionnellement des formes de contrôle scientifique, économique, politique et militaire, mais ces dernières n'étaient pas conçues pour maîtriser l'ampleur ou la puissance des changements de comportement qui semblent se produire dans nos environnements sociaux, démographiques et naturels.

POLITIQUES ET INCERTITUDE

Président : K.M. Meyer-Abich

Rapporteur : R.W. Slater

Membres :

M. Adam	W. Mittler
G. Bangay	J. Piette
R. Bierbaum	R. Pomerance
L. Bjoerkbom	N.J. Quinn
A.D. Bryce	J. Risbey
C. Caccia	M. Sahnoun
D. Cook	H.S. Sandhu
F.L. De Alba	L. Sayn-Wittgenstein
W. Giles	M. Smith
P.R. Jutro	C. Starrs
J. Langer	J. Topping, Jr.
W.J. Maunder	K. Von Moltke
M.B. McElroy	L. Whitby
R. Milko	G.J.R. Wolters

GÉNÉRALITÉS

Le dossier scientifique qui nous a été soumis nous a convaincus que l'état des connaissances justifie maintenant une intervention politique. Les données climatologiques transposées en termes politiques ont révélé une tendance alarmante et des risques considérables dans les développements économiques actuels. Nous avons été favorablement impressionnés par la confirmation massive des prévisions faites depuis le début des années 1970. Ainsi, les conclusions du rapport Brundtland, selon lesquelles le développement économique sous sa forme actuelle n'est pas durable et qu'il pourrait entraîner de graves conflits, sont confirmées.

Les incertitudes qui existent encore dans l'analyse scientifique n'invalident aucunement la conclusion réelle qui préconise la prise de décisions politiques dès maintenant. Des étapes subséquentes dans le processus décisionnel nécessiteront une information plus détaillée sur les développements régionaux ainsi que sur les effets économiques et sociaux du changement atmosphérique. Cette information doit se fonder sur des études complémentaires tant en sciences naturelles qu'en sciences sociales.

RECOMMANDATIONS

1. On doit faire avancer les programmes de recherche sur la chimie de l'atmosphère à l'échelle planétaire, ainsi que d'autres études dans les secteurs agricole, économique, juridique, politique, social et sanitaire, qui visent particulièrement les conséquences du changement climatique (prévention, compensation et adaptation).

   Il existe cependant des incertitudes de nature politique qui exigent un examen plus attentif. La question fondamentale est de savoir si le système politique, tant à l'échelle mondiale qu'à l'échelle nationale, pourra chasser efficacement la menace atmosphérique. Comme solution à ces incertitudes nous proposons ce qui suit:

2. Nous recommandons que les principaux pays responsables des menaces actuelles prennent l'initiative en vue de corriger la situation. Il s'agit, bien entendu, des pays industrialisés. Comme l'a déclaré Madame

Brundtland: "Nous, dans le Nord, nous avons une responsabilité particulière." Fort heureusement, les pays industrialisés sont aussi ceux qui sont techniquement et économiquement en mesure de trouver des solutions. La responsabilité de ces pays implique la fermeture des installations qui compromettent un développement durable ainsi que le refus de transférer ces installations dans d'autres pays.

3. Jusqu'à présent, les politiques environnementales n'ont été qu'une réussite partielle. En prenant des risques climatiques, l'homme a définitivement dépassé les limites d'un développement économique durable sans danger pour l'environnement. La destruction environnementale a provoqué un débat sur les valeurs fondamentales. Le système politique doit se sensibiliser à ce débat. Les pays industrialisés doivent commencer dès maintenant à rétablir l'intégrité de l'environnement en faisant du changement atmosphérique le point central d'une innovation écologique de l'économie industrielle.

4. Pour atteindre cet objectif, il ne sera plus suffisant de stabiliser les émissions aux taux actuels; elles devront être réduites. Le simple gel des émissions actuelles serait insuffisant si l'on veut garantir la survie de l'homme et de toutes les autres formes de vie sur la planète. Pour ce faire, nous recommandons que:

- le Protocole de Montréal soit ratifié aussitôt que possible;
- les autres pays signent cette Convention;
- les gaz responsables de la destruction de la couche d'ozone, qui n'ont pas encore été cités, soient inclus;
- le Protocole soit modifié, après ratification, de façon à ce qu'une nouvelle version prescrive l'abandon graduel des CFC pour atteindre une utilisation zéro au milieu des années 1990 (selon l'exemple suédois);
- les émissions de CO_2 soient réduites de 10 à 20 % à la fin du siècle;
- le Protocole provisoire sur le NO_X, en vertu de la CEE, qui est une première initiative judicieuse, soit ratifié le plus rapidement possible.

5. Ces cibles et ces échéanciers en matière de réduction d'émissions devraient être l'objet d'un traité international entre les nations qui doivent prendre l'initiative dans ce domaine. Ces dernières devraient inviter toutes les autres à se joindre à elles afin de faire progresser un développement économique durable sans danger pour l'environnement. Dans ce cas, la Convention de Vienne peut servir de modèle ou de guide pour l'élaboration d'une convention ou d'une loi sur l'atmosphère.

6. La menace atmosphérique confirme le fait que la politique environnementale n'est fondamentalement plus en opposition avec les objectifs économiques à long terme. En particulier, on peut citer les intérêts convergents de l'environnement et de secteurs comme le progrès technologique soutenu, l'énergie, les réseaux de transport, l'agriculture, la santé humaine, le consommateurisme ainsi que la sécurité nationale et internationale. Étant donné qu'une telle convergence aide le système politique à accorder à la question atmosphérique toute la priorité qu'elle requiert, nous recommandons que cette priorité soit adoptée sans délai.

7. Un processus décisionnel ouvert pourrait également servir de mécanisme producteur de décisions par ailleurs impopulaires. Ce qu'il convient de faire en premier lieu est de sensibiliser davantage le public et d'influencer le comportement des consommateurs, et de promouvoir ainsi des décisions peut-être impopulaires. Nous recommandons un débat démocratique sur les mesures à employer pour combattre la menace atmosphérique. Les organisations non gouvernementales devraient jouer un rôle déterminant dans la poursuite de ce débat.

8. Il est évident que l'impact des pays en voie de développement sur le changement atmosphérique ne doit pas être négligé. Nous recommandons que les pays industrialisés aident ces pays à faire face à la destruction environnementale. Il faut élaborer des approches régionales pour mettre un terme au déboisement et promouvoir le reboisement. Il faut établir un fonds international servant à financer des mesures adéquates, un transfert technologique ainsi que les études nécessaires. On pourrait, par exemple, créer ce fonds avec l'établissement d'une taxe sur le pétrole, une possibilité que nous avons examinée.

9. Nous espérons que les institutions internationales ainsi que les gouvernements nationaux répondront favorablement à l'appel de la Commission mondiale sur l'environnement et le développement. Nous proposons un examen du système international actuel afin de déterminer son efficacité.

INDUSTRIE, COMMERCE ET INVESTISSEMENT

Président : P. Winsemius

Rapporteur : R. Dobell

Membres :

C. Bird	L. Kuleshnyk
M. Brennan	J. MacNeill
F. Feldmann	J. Potton
W.C. Ferguson	H.W. Quinn
B. Fritsch	A. Roncerel-Bonin
M. Ginsburg	J. Seeliger
D. Gregory	R. Srubar
D. Ireland	J. Thompson
H.J. Karpe	P.F. Van Es

GÉNÉRALITÉS

Il est, à l'heure actuelle, parfaitement évident que nous sommes confrontés à d'énormes problèmes en matière de changement atmosphérique, comme le réchauffement climatique, la destruction de la couche d'ozone et les pluies acides, dont l'ampleur exige des moyens d'action extraordinaires. Le secteur privé, les gouvernements et, même les familles ne peuvent plus échapper maintenant à la nécessité d'une action concertée.

Les impacts directs du changement climatique sur l'activité économique et les structures sociales, qui ont été largement débattus en termes généraux, comprennent une probabilité accrue de phénomènes climatiques extrêmes, la possibilité d'une désorganisation massive des systèmes de production, du commerce et des structures de la population, et enfin, des effets négatifs majeurs en matière de répartition des revenus et des richesses.

Néanmoins, étant donné les taux de changement observés, il est probable que l'on puisse absorber les impacts directs du changement climatique sur les activités industrielles et économiques en ayant recours aux processus décisionnels normaux en usage dans le secteur privé, au moins dans le cas des grandes entreprises et des pays industrialisés qui ont une capacité d'adaptation supérieure. On entrevoit cependant des problèmes majeurs pour les entités plus vulnérables, comme les petites entreprises et les pays en voie de développement qui, dans bien des cas, ont beaucoup moins d'options d'adaptation.

Cependant, le point capital est la plus grande portée des coûts sociaux généraux de la désorganisation de l'activité économique comparativement aux impacts directs du changement climatique. Les investissements publics dans les mouvements de population et les infrastructures sociales seront probablement énormes.

On doit donc considérer comme inévitable l'adoption de mesures correctrices sociales et politiques en vue d'atténuer le changement climatique et d'adapter la planète aux coûts sociaux prévus des tendances irréductibles. Grâce à ces mesures correctrices anticipées, les impacts indirects sur les activités économiques et sociales se manifesteront plus rapidement et auront plus d'ampleur que les impacts directs correspondants déjà décrits.

Un bref examen des scénarios "d'émissions réduites" révèle la nature extrêmement exigente des ajustements qui sont nécessaires pour ralentir simplement les processus actuels de réchauffement climatique ou de destruction de la couche d'ozone. Des études complémentaires des contributions industrielles à ces phénomènes désignent des cibles particulières comme la production énergétique, l'industrie lourde, le transport et l'agriculture.

Il est clair qu'un vaste ensemble de mesures destinées à promouvoir les économies d'énergie, le transfert technologique et les technologies de remplacement sera nécessaire pour préparer la voie à un développement durable, mais il est tout aussi évident que ce programme sera probablement insuffisant pour garantir sa réalisation.

En conséquence, le Groupe conclut qu'il faut absolument engager une action extraordinaire par le biais d'une série de mesures importantes comprenant notamment les points suivants:

RECOMMANDATIONS

1. Les pays industrialisés de l'Ouest devraient créer et financer en grande partie un Fonds mondial de l'atmosphère pour mobiliser des fonds massifs destinés à appuyer:

   - la mise au point de technologies et d'applications à faible consommation d'énergie;
   - un meilleur accès aux technologies écologiques actuelles et nouvelles;
   - le transfert des technologies appropriées aux pays en voie de développement afin d'assurer une industrialisation caractérisée par une utilisation plus efficace des combustibles;
   - un échange d'information à l'échelle internationale.

   L'exploitation d'un tel fonds, qui pourrait être assortie de limites mondiales appropriées sur les émissions, serait financée par une taxe sur l'utilisation de combustibles fossiles (de l'ordre de 1% ou plus).

2. L'industrie devrait améliorer les mécanismes destinés à incorporer les considérations environnementales à son processus interne de prise de décisions. À cet effet, elle pourrait recourir aux moyens suivants:
   - examens réguliers des résultats environnementaux à communiquer aux conseils d'administration ou aux actionnaires;
   - codes de déontologie environnementale pour les entreprises;
   - participation active de l'industrie à la mise en application d'initiatives de développement durable, et à des programmes de recherche-développement orientés vers l'intégration de l'économie et de l'environnement.

3. On devrait créer au plus haut niveau une tribune multipartite internationale à laquelle participeraient tous les principaux intéressés sur le plan environnemental, c'est-à-dire les dirigeants commerciaux et politiques, les scientifiques et les chefs communautaires, dont les discussions seraient soumises aux délibérations des chefs de gouvernement.

Cette tribune devrait aborder de toute urgence les questions suivantes:

i) Les mécanismes permettant de créer d'ici 1992 le Fonds mondial de l'atmosphère.

ii) L'accélération des efforts de recherche-développement dans le cadre d'un programme adaptatif pour la création de technologies et de produits écologiques, conformes aux objectifs d'économie d'énergie, d'élimination des CFC dans le commerce et la production industrielle, et de réduction des émissions de CO_2. Ces efforts de R et D doivent s'accompagner d'une campagne intensifiée d'information et de sensibilisation du public axée sur les consommateurs, les politiciens, ainsi que les groupes cibles de l'industrie.

iii) L'élimination des barrières institutionnelles qui retardent l'adoption des technologies à faibles émissions par les industries et les foyers individuels.

iv) L'amélioration de l'information du marché pour orienter la consommation vers des produits écologiquement sains. Les effets négatifs de l'étiquetage des produits et les limites éventuelles du commerce devraient être compensés par des formes tangibles d'encouragement, comme les initiatives massives de "dette de développement" préconisées dans un autre passage de la présente Déclaration de la conférence. En vertu d'un vaste programme de protection des forêts tropicales contre les mauvaises décisions prises en matière d'utilisation des terres, on devrait établir des normes d'étiquetage qui décourageraient la consommation de produits résultant d'une l'exploitation dommageable des forêts tropicales ombrophiles.

QUESTIONS GÉOPOLITIQUES

Président : H. Cleveland

Rapporteurs : N. Desai
P. Gleick

Membres :

R.E. Benedick	J. MacNeill
B. Bertie	D. McDermott
K. Bush	W.R. Moomaw
J.M.F. Bustani	R. Morgenstern
C.D. Campbell	R.J.D. Page
A. Chisholm	A. Polansky
H. Coward	D. Runnalls
J. Ferretti	G. Saint-Jacques
J. Firor	E. Salim
F. Hampson	K. Subramahnyan
F. Kinnelly	O. Ullsten
C.I. Jackson	Zhou Xiuji
M. Lemayer	

GÉNÉRALITÉS

Bien que les problèmes atmosphériques nécessitent une coordination internationale des efforts, nous devrions cependant inciter les organisations gouvernementales et non gouvernementales à passer promptement à l'action, tout en cherchant à conclure une entente internationale plus globale. Ce double processus devrait entrainer de nouvelles normes de comportement, comme les limites imposées à l'émission des gaz qui emmagasinent la chaleur, ainsi que la reconnaissance du fait que l'atmosphère représente le patrimoine mondial le plus intimement lié aux formes d'avenir de l'homme.

Ces promptes mesures peuvent reposer sur les possibilités qui s'offrent de mieux utiliser l'énergie dans chaque pays. Elles devraient s'accompagner d'examens rigoureux et diversifiés des sources d'énergie de substitution. Ces processus feront intervenir de grandes réductions de l'utilisation des combustibles fossiles et des transferts de technologie et de ressources au Tiers-Monde.

On ne peut aujourd'hui prévoir avec exactitude quelles seront les régions particulières du globe, ni les secteurs de l'économie, qui seront les premiers éprouvés ou les plus durement touchés par une atmosphère en mutation rapide. Toutefois, l'ampleur et la variété des répercussions éventuelles seront telles qu'il est de l'intérêt de tous les peuples, selon nous, d'unir leurs efforts sans délai pour ralentir les changements et négocier la conclusion d'une entente internationale sur le partage des responsabilités en matière de préservation du climat et de l'atmosphère.

Les variations climatiques aggraveront les tensions internationales, accroîtront les risques de conflit et intensifieront la discrimination interne et les inégalités quant aux ressources. Tous souffriront des effets de l'atmosphère en mutation, mais il existe des différences importantes dans la gravité des impacts et dans la responsabilité en matière de changements. Bien que les principaux responsables de l'émission des GES soient les pays industrialisés, ce sont les pays en voie de développement qui seront le plus durement touchés par les changements climatiques. Ces problèmes seront considérablement exacerbés par les taux sans précédent de croissance démographique. Les pays en voie de développement sont ceux qui ont le moins de ressources pour s'adapter aux impacts ou les atténuer.

La lutte contre les changements climatiques exige non seulement le remplacement des approches conflictuelles par un esprit de collaboration en matière de "sécurité non militaire", mais elle est liée également à l'avenir du désarmement et de la limitation des armes. Par exemple, si l'énergie nucléaire doit contribuer à réduire les émissions de GES, le public doit être assuré qu'il se dirige vers un avenir exempt d'armes nucléaires.

Les nations du monde doivent reconnaitre que l'atmosphère est un patrimoine commun et qu'il doit être traité comme tel. Dans le cas d'un bien détenu en commun:

- la souveraineté n'est pas "cédée", mais "partagée";
- les participants ont des droits d'usage (comparables à des servitudes) et non des droits de propriété ou d'appropriation;
- les participants se partagent également l'entretien et la gestion de la propriété. Cette obligation comprend la protection de la diversité;
- l'utilisation individuelle est sujette en principe au consentement de tous, et les décisions nécessitent un consensus.

RECOMMANDATIONS

1. Bien que des efforts internationaux coordonnés soient nécessaires (concrétisés, par exemple, par Le Droit de l'atmosphère), nous devons aussi compter sur les interventions à titre privé et collectif, ainsi que gouvernementales et non gouvernementales. Nous devons entreprendre tout ce qui est possible dès maintenant, sans attendre une entente internationale globale. Des normes particulières doivent être établies pour réduire les émissions des GES, et pour atténuer les impacts climatiques.

2. La totalité des coûts et des avantages des interventions nécessaires pour protéger le patrimoine commun doit être partagée d'une façon que les participants considèrent comme "équitable". Cette "équité" dépend du mode de vie à l'intérieur des sociétés ainsi que des rapports entre les pays. Par exemple, les lignes de conduite et les pratiques énergétiques devront être différents dans des pays à divers stades de développement ou caractérisés par un mode de vie distinct. Les pays en voie de développement auront besoin de plus d'énergie. En plus, la transition vers un avenir énergétique différent nécessitera des investissements dans le rendement énergétique et les combustibles non fossiles. Afin de garantir la réalisation de ce scénario, la communauté planétaire doit établir des mécanismes facilitant un transfert sans heurt des ressources et des technologies pertinentes des pays industrialisés aux pays en voie de développement.

3. Une "convention-cadre" traitant de l'évolution climatique ne devrait pas s'appuyer seulement sur des données scientifiques, mais aussi sur des considérations stratégiques et politiques ainsi que sur un esprit de communauté planétaire.

4. Les institutions et les dispositions nécessaires pour formuler cette convention-cadre doivent être flexibles et équitables:

   - Les normes sont établies par tous les participants à l'échelle internationale, mais les systèmes ne sont pas centralisés ("un système à deux niveaux").
   - Toutes les fonctions ne nécessitent pas le même degré de participation. Pour certains systèmes de gestion ou certaines responsabilités (par ex., les sauvegardes contre le nucléaire ou une limitation de la combustion du charbon), un "consortium des principaux intéressés" peut constituer la meilleure approche.
   - On doit réserver un rôle explicite aux initiatives et aux interven-

tions non gouvernementales, ou qui sont le fruit de la collaboration des secteurs privé et public.
- Pour gérer le patrimoine commun, à savoir l'observation et la dissémination des données ainsi que l'acheminement des réactions, il faudra avoir recours à des technologies de pointe dans le domaine de l'information.
- Le moyen le plus efficace de financer la recherche sur le patrimoine, et de le gérer consiste en des revenus "automatiques". Ces derniers peuvent comprendre des dispositions semblables à celles des assurances, basées sur le partage des risques, des droits imposés à des activités (comme l'utilisation de combustibles fossiles) qui utilisent le patrimoine, des droits de permis, ou d'autres dispositions similaires.

5. Les mesures à prendre pour prévenir les changements dommageables de l'atmosphère -- ralentissement de l'émission de polluants et stabilisation ultérieure de la composition de l'atmosphère -- doivent prendre une ampleur internationale. En tant que telles, elles nous confrontent à des besoins mondiaux de longue date: la stabilisation de la population mondiale, l'atténuation des tensions militaires et le désarmement, ainsi que la diminution de la disparité des richesses, de la consommation et des débouchés au sein des pays et parmi eux. Dans notre démarche visant à atteindre ces objectifs historiques, nous renforcerons notre aptitude à ralentir ou à éliminer les changements dommageables de l'atmosphère. Si nous négligeons les problèmes de l'atmosphère, nous ne ferons qu'accroître les tensions et compromettre notre aptitude à améliorer l'économie de tous les pays. Peut-être que les impératifs nouvellement reconnus de collaboration en matière de graves problèmes climatiques offriront d'autres façons d'envisager les anciens problèmes.

QUESTIONS JURIDIQUES

Président : J.A. Beesley

Rapporteur : A. Adede

Membres :

P. Bakken	C. Morton
R.D. Bojkov	M. Pietarinen
G.V. Buxton	K. Ramakrishna
I. Courage	R. Robinson
J. Goffman	S. Shrybman
A. Kessel	J.R. Spradley
M. Kostuch	H. Strauss
F. Mathys	J. Young
A.S. Miller	S. Zwerver

INTRODUCTION

Le groupe juridique insiste sur le fait qu'il existe un besoin urgent d'élaborer, d'une façon progressiste et à partir des données scientifiques de pointe, un droit international de l'environnement pour protéger l'atmosphère. Bien qu'il y ait déjà un important ensemble de lois internationales sur l'environnement, le régime juridique touchant expressément l'atmosphère est assez fragmenté et incomplet.

Dans son débat sur la meilleure façon d'élaborer un régime juridique nécessaire pour résoudre les problèmes liés à la gestion des risques environnementaux découlant des utilisations agricoles, chimiques et énergétiques qui ont des effets nocifs sur l'atmosphère, le groupe s'est appuyé sur un certain nombre de considérations.

RECOMMANDATIONS

1. Le régime juridique conçu pour la protection de l'atmosphère devrait tenir compte des précédents qui existent en cette matière, en les adaptant au besoin pour tenter de résoudre les problèmes particuliers de l'atmosphère qui pourraient nécessiter l'établissement de nouveaux principes, règlements ou cadres institutionnels. On prend en considération les précédents qui font jurisprudence internationale comme la trilogie des cas : Fonderie de Trail, Canal de Corfou et Lac Lanoux, qui ont établi le principe selon lequel les États ont l'obligation de prévenir les dommages transfrontaliers; les dommages environnementaux pourraient être illégaux; et les États victimes ont légalement le droit d'insister sur la prévention et la réduction de tels dommages. Le Groupe a également tenu compte du Principe 21 de la Déclaration de 1972 de la Conférence des Nations Unies sur le milieu humain; de la Convention de la CEE de 1979 sur la pollution transfrontalière de l'atmosphère à grande distance et des protocoles connexes; de la Partie XII de la Convention des Nations Unies de 1982 sur le Droit de la mer; et de la Convention de Vienne de 1985 pour la protection de la couche d'ozone et de son Protocole de Montréal de 1987 (considéré comme un modèle).

2. En conséquence, on devrait s'efforcer d'élaborer une convention générale ou convention-cadre qui se prêterait à l'établissement d'ententes ou de protocoles particuliers stipulant des normes internationales pour la protection de l'atmosphère, et d'encourager les États à promulguer des lois nationales pertinentes. À cet égard, on devrait accepter l'invitation du Premier ministre du Canada qui propose de tenir une assemblée de juristes et de décideurs au début de 1989 à Ottawa. L'élaboration d'une telle convention ne devrait pas retarder, entre-temps, une entente portant sur une activité particulière, comme par exemple le déboisement, ou nuire à des initiatives nationales en vue de promulguer ou de renforcer des lois pertinentes.

3. En élaborant la convention générale ou convention-cadre, on doit tenir compte de l'éventail de moyens disponibles à l'échelle planétaire, nationale, régionale ou bilatérale pour résoudre les problèmes atmosphériques qui sont de nature transfrontalière ou planétaire.

4. L'élaboration complémentaire d'une convention internationale pour la protection de l'atmosphère serait facilitée par la réunion régulière de représentants nationaux d'un haut niveau. Un groupe de travail intergouvernemental approprié pourrait établir un échéancier précis en vue de mettre au point de nouveaux instruments pour la protection de l'atmosphère, sur la base de stratégies à court, à moyen et à long terme.

5. Lorsqu'on élabore divers instruments juridiques, il faut accorder la priorité à la question de conformité, non seulement par le biais du concept de responsabilité, mais aussi par des mécanismes d'incitation qui, entre autres, tiennent compte des intérêts particuliers des pays en voie de développement.

6. Une convention-cadre devrait prévoir la coordination d'activités scientifiques et de recherche technologique, le transfert de la technologie,

l'échange d'information, l'élaboration de régimes et de plans nationaux d'aménagement, ainsi que les besoins particuliers des pays en voie de développement. À cet égard, on a proposé de préférence l'utilisation des installations actuelles d'organisations internationales appropriées sous l'égide des Nations Unies.

PROGRAMMES INTÉGRÉS

Président : T. Malone

Rapporteur : I. Burton

Membres :

F.W.B. Baker	I. Lang
C.E. Berridge	J.A.W. McCulloch
V. Boldirev	G. Pearman
Ph. Bourdeau	M. Permut
R. Cushman	R. Price
M.R. Dence	E.F. Roots
D. Fisk	C.J.E. Schuurmans
D. Fowle	Yu. Sedunov
E. Gibbs	J. Stone
R. Gualtieri	R.T. Watson
F.A. Koomanoff	

GÉNÉRALITÉS

Les changements atmosphériques provoqués par l'intervention de l'homme sont considérés comme l'une des plus grandes menaces pour l'humanité. La capacité de lutter contre cette menace dépendra non seulement de l'avancement des connaissances, mais aussi de l'intégration de l'information et de la collaboration internationale.

Les institutions qui produisent et disséminent les connaissances ne sont pas toujours reliées adéquatement les unes aux autres, et les programmes de recherche et d'intervention ont tendance à être fragmentés, parfois inconsistants et caractérisés par une absence d'intercommunication et pas des objectifs qui ne sont pas toujours compatibles. En conséquence, il faut mieux intégrer les connaissances et accroître la coopération dans les secteurs de la recherche et de l'intervention à l'intérieur des institutions et entre celles-ci. Un programme amélioré et plus cohérent est nécessaire pour bien comprendre les processus qui changent l'atmosphère et leurs conséquences socio-économiques.

Il est encourageant de constater que le Programme climatologique mondial et le Programme sur l'homme et la biosphère, qui sont des entreprises permanentes, ont des objectifs bien définis dans ce domaine, et que de nouvelles initiatives d'envergure comme le Programme international géosphère - biosphère, le Programme des réactions humaines au changement climatique mondial, et la Commission intergouvernementale sur l'évolution planétaire voient le jour.

De tels efforts multidisciplinaires et interdisciplinaires, tant à l'échelle nationale qu'internationale, nécessitent un soutien plus massif et soutenu pour pouvoir supporter les énormes pressions actuelles.

Il est également réconfortant de savoir que, à une époque où la gravité des problèmes de l'atmosphère en mutation est reconnue, on assiste à une renaissance des bio-géosciences dans un nouveau cadre intégré de science planétaire, grâce auquel, pour la première fois, il devient possible d'étudier les phénomènes globaux dans une perspective holistique. Cette démarche intellectuelle ne fait pas encore appel massivement aux sciences humaines, mais on peut d'ores et déjà déceler des signes de convergence.

RECOMMANDATIONS

1. Les gouvernements doivent renouveler leur engagement face aux programmes interdisciplinaires et en assurer le financement adéquat.

2. Un progrès encourageant dans le domaine qui nous intéresse est la convergence des sciences naturelles avec les sciences sociales et humaines vers un objectif qui est la création et la clarification des options de politique à l'échelle régionale, nationale et internationale. Cette évolution doit être encouragée et accélérée avec toute la force possible. Les processus de convergence et d'intégration seront facilités par l'élaboration de cadres conceptuels, créés et partagés dans une communauté de scientifiques engagés dans des programmes de recherche interdisciplinaire à l'échelle nationale et internationale. De tels cadres pourraient englober la recherche scientifique, l'évaluation des lignes de conduite et la capacité institutionnelle à prendre les mesures appropriées.

3. On propose que les scientifiques engagés dans les programmes de recherche interdisciplinaire s'impliquent dans l'élaboration de cadres globaux appropriés, à l'échelle nationale et internationale, ces derniers devant servir à faciliter l'identification de lacunes en recherche et de domaines impliquant une intervention commune.

4. Toutes les organisations pertinentes doivent évaluer leur propre capacité à relever les défis posés par l'atmosphère en mutation et la sécurité planétaire par des moyens qui peuvent être totalement intégrés à d'autres contributions. Le projet d'examen, à l'échelle internationale, de telles évaluations, doit être débattu à la Conférence mondiale sur le climat de 1990, en qualité de contribution aux préparations de la Conférence sur le milieu humain de 1992. Les résultats d'une évaluation de la capacité de recherche à l'échelle mondiale, et d'exploitation de programmes intégrés, effectuée par un groupe indépendant d'un haut niveau, devraient être présentés à cette Conférence.

5. Lors de l'élaboration d'un programme intégré, il faut prêter une attention particulière à l'identification de secteurs critiques qui pourraient justifier une intervention urgente comme i) des variations

plausibles inattendues des extrêmes de température en raison de leur importance pour les écosystèmes, des changements possibles dans la répartition et la quantité des précipitations, et d'autres effets du réchauffement global, comme une hausse du niveau de la mer; ii) la vulnérabilité et l'adaptabilite de la structure des écosystèmes et leur impact sur la biodiversité; ainsi, les changements dans les zones climatiques et les habitats pourraient provoquer des contraintes environnementales excédant la capacité de certaines organisations et niveaux trophiques à réagir, et conduire à une grave perturbation des écosytèmes, accompagnée d'une réduction radicale de la composition des espèces et d'une perte de la diversité génétique; et iii) l'adaptation des paysages agricoles, forestiers et aménagés par l'homme au changement des conditions, avec le besoin correspondant de s'assurer que les cultures alimentaires et les arbres forestiers soient adaptés aux variations prévues des conditions.

6. On peut aussi donner une forte impulsion à l'intégration en créant des systèmes de surveillance et d'information constituant une base commune d'harmonisation des données sur l'atmosphère en mutation, sur les changements qui surviennent dans les écosystèmes terrestres et marins, et sur les activités socio-économiques. Ces systèmes doivent s'appuyer sur ceux que l'on possède déjà et répondre aux besoins des programmes de recherche.

7. Afin d'améliorer notre compréhension de l'importance et de l'urgence des changements atmosphériques, il faut mettre au point un vaste programme diversifié d'information et d'éducation du public. La sensibilisation aux problèmes environnementaux et à leur importance pour toutes les activités humaines devrait être une composante des programmes d'éducation à tous les niveaux, tant dans les pays en voie de développement que dans les pays industrialisés. Les organismes pour l'environnement naturel devraient, en collaboration avec des organisations internationales comme l'UNESCO, jouer un rôle de chef de file et veiller à ce que l'information environnementale appropriée soit mise à la disposition des autorités éducationnelles. En ce qui concerne l'éducation supérieure, on devrait viser à surmonter les problèmes liés au maintien d'une haute compétence scientifique, tout en assurant l'exploitation de vastes programmes de recherche interdisciplinaire sur les problèmes environnementaux.

8. On ne doit pas négliger l'exploitation d'un programme intégré visant à informer les medias et les organisations non gouvernementales, qui peuvent jouer un rôle clé dans l'éducation d'un vaste public ainsi que dans l'apparition, dans tous les pays, d'un public informé capable d'influer sur les politiques nationales et internationales.

THE CHANGING ATMOSPHERE

Jill Jaeger
The Beijer Institute, Stockholm, Sweden

"The rate of change is outstripping the ability of scientific disciplines and our current capabilities to assess and advise" (Our Common Future).

FOREWORD[1]

When the century began, neither human numbers nor technology had the power to radically alter planetary systems. As the century closes, not only do vastly increased human numbers and their activities have the power, but major, unintended changes are occurring in the atmosphere, in soils, in waters, among plants and animals, and in the relationships among all of these. **(Our Common Future; World Commission on Environment and Development, 1987)**

This background document is about changes in the atmosphere. Unintended changes therein are of such a magnitude, and their effects so imminent, that they must now be placed high on policy agendas. The document focusses on climate change. Climate is so pervasive that its changes have implications for virtually every endeavour. We now have the capacity to critically alter climate, and may have already done so by our use of the atmosphere as the dumping ground for gaseous and particulate waste and by the altered use of lands. But more. Emissions to the atmosphere are now endangering the protective ozone layer, altering the earth's ecosystems and productivity, and negatively impacting on the environment and human health. The resulting situation, as this century draws to an end, poses a serious challenge to the global community.

This document has been prepared by a scientist, Dr. Jill Jaeger, who has been engaged in climate research. It summarizes the scientific knowledge and perception of concern, and attempts to "pass the torch" over to policy-makers and their advisors who have the responsibility to see that action is taken by identifying the impacts of change and proposing policy initiatives. The report draws heavily on a series of international meetings dealing with greenhouse gases and their effects. Notable among these are the 1985 World Climate Programme's International Conference on the Assessment of the Role of Carbon Dioxide and other Greenhouse Gases in Climate Variations and Associated Impacts and also the Beijer Institute workshops held in 1987 in Villach and Bellagio. A summary of the discussions and recommendations of the workshops entitled "Developing Policies for Responding to Climate Change" has been published in the World Climate Programme Impact Studies series and will be made available to Conference participants. Over 90 scientists from 28 countries participated in the 1985 World Climate Programme Conference. The Beijer Institute workshops were attended by about 64 scientists and senior policy-makers and advisors from 16 countries.

[1] G.A. McKay, Conference Secretary

The message is clear. There is a strong likelihood of global warming that could increase the sea-level, greatly alter agroecosystems and water resources, and generally challenge traditional ways of life. Some of the projected rates of change are outside our planning experience. Our ability to predict these effects is inadequate, as is our ability to cope should present projections be realized. Moreover, the use of the atmosphere as a chemical waste disposal system threatens both natural resources and human health. Sound policies to protect atmospheric imperatives must be developed and implemented if we are to leave a legacy comparable to that which we received.

The report is intended as background reading for the Conference. It should help to achieve a common understanding of atmospheric concerns that give rise to the policy discussions in the Conference Working Groups, and thereby facilitate communication and a Conference focus.

1. INTRODUCTION

In numerous ways human activities are changing the face of the earth. These changes are taking place on various time- and space-scales. For example, for hundreds of years forest cover has been removed to make land for agriculture. The total area that has been affected in this way is large and in tropical areas deforestation continues at a rate estimated to be between 9 and 24.5 million hectares per year. Another example is the land-use changes due to urbanization: emissions of dust and gases into the urban atmosphere, the release of heat and other factors lead to the well-known phenomenon of the urban heat island. These are just a few examples of the ways that human activities have been changing the earth. Collectively, they and other alterations of the planet have led to serious concern over our stewardship. Lester Brown in Building a Sustainable Society said, "Since World War II, 'national security' has acquired an overwhelmingly military character ... Yet the threats to security may now arise less from the relationship of nation to nation and more from the relationship of humanity to nature ... The erosion of soils, the deterioration of the earth's basic biological systems, and the depletion of oil reserves now threaten the security of countries everywhere ...."

The atmosphere is unique in its function as a life-support system. It interacts strongly, but systemically with the environmental component - for example, the oceans, land surface, biota and ice and snow cover, which collectively shape our climate and are considered to form the "climate system". Concern has been expressed about the scale of the observed and predicted changes of the atmosphere as a result of human activities that are changing that system.

Interest in the possible effects of human activities on climate has increased dramatically in the last 25 years. Following the 1970 Study of Critical Environmental Problems (SCEP), the Study of Man's Impact on Climate (SMIC) was carried out in 1971. This study provided an authoritative assessment of the state of understanding of the possible impacts of human activities on regional and global climate. Since then an increasing number of individual, national and international assessments have been made. In 1979 the World Climate Conference in Geneva led to the establishment of the World Climate Programme, sponsored by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP) and the International Council of Scientific Unions (ICSU). The World Climate Programme has many research projects and the ways that climate can and will be affected by human activities are of major importance.

It becomes increasingly obvious, however, that if we are to respond appropriately to the changes that are occurring, scientific matters cannot be considered in isolation - it is necessary to bring together the expertise of the scientists, technical experts and policy-makers. The United Nation's World Commission on Environment and Development (1987) showed how important such interactions can be and it is hoped that the 1988 World Conference on the Changing Atmosphere in Toronto will further promote such interactions and thus pave the way for concerted international action to deal with the web of environmental and social issues. The call for action is urgent but is made with the knowledge that appropriate responses are possible and should be given high priority.

2. REASONS FOR CONCERN

There are, of course, several reasons for the present concern about the changing atmosphere. Firstly, there is a feeling that events are becoming "out of control". The emissions of greenhouse gases (GHG) into the atmosphere, for example, are increasing in some cases quite rapidly. Figure 1 shows the estimates of the emissions of carbon dioxide (CO_2) and chlorofluorocarbons (CFCs) during recent decades. These and many other environmental changes have been accelerating, especially during the past 30 years. In addition, many of the changes in the atmosphere, climate or environment are irreversible. Even if we stopped the emissions of CO_2 into the atmosphere today, it would take hundreds of years for the atmospheric concentration of CO_2 to return to its pre-industrial level and in the meantime climate changes will continue to occur. Likewise, a return to the climatic and ecological conditions of the time before deforestation took place is virtually impossible. One of the main reasons for this irreversibility is the complexity of the climate system. Even if the changes due to human activities initially affect only one part of the climate system, such as the atmosphere, biota or ocean, there are many interactions between these different parts.

Another reason for concern is the level of potential losses. For instance, it has been estimated that the global warming induced by greenhouse gases will accelerate the present sea-level rise giving a rise of probably about 30 cm and possibly as much as 1.5 m by the middle of the next century. Such a rise of sea-level would cause increased erosion of beaches and coastal margins, land-use changes in coastal areas, wetland loss, changes in the frequency and severity of flooding, and damage to coastal structures, port facilities, and water management systems. Obviously, such potential changes involve high costs to society. For example, the cost of maintaining beaches on the east coast of the United States has been estimated between 10 and 100 billion dollars (US) (Jaeger, 1988). Likewise, other changes, such as the depletion of stratospheric ozone or transboundary pollution would involve large potential losses.

Basically there are two strategies for responding to climate change: limitation and adaptation. Although there was a generally expressed opinion at the beginning of the 1980s that adaptation would be politically more feasible than controlling the causes of climate change, in recent years more attention has been focussed on strategies to limit the changes. The costs of limitation strategies would be investment costs that could become net positive investments, e.g., improvements in energy end-use efficiency that could pay for themselves in a few years. Costs of adaptation, in contrast, would in

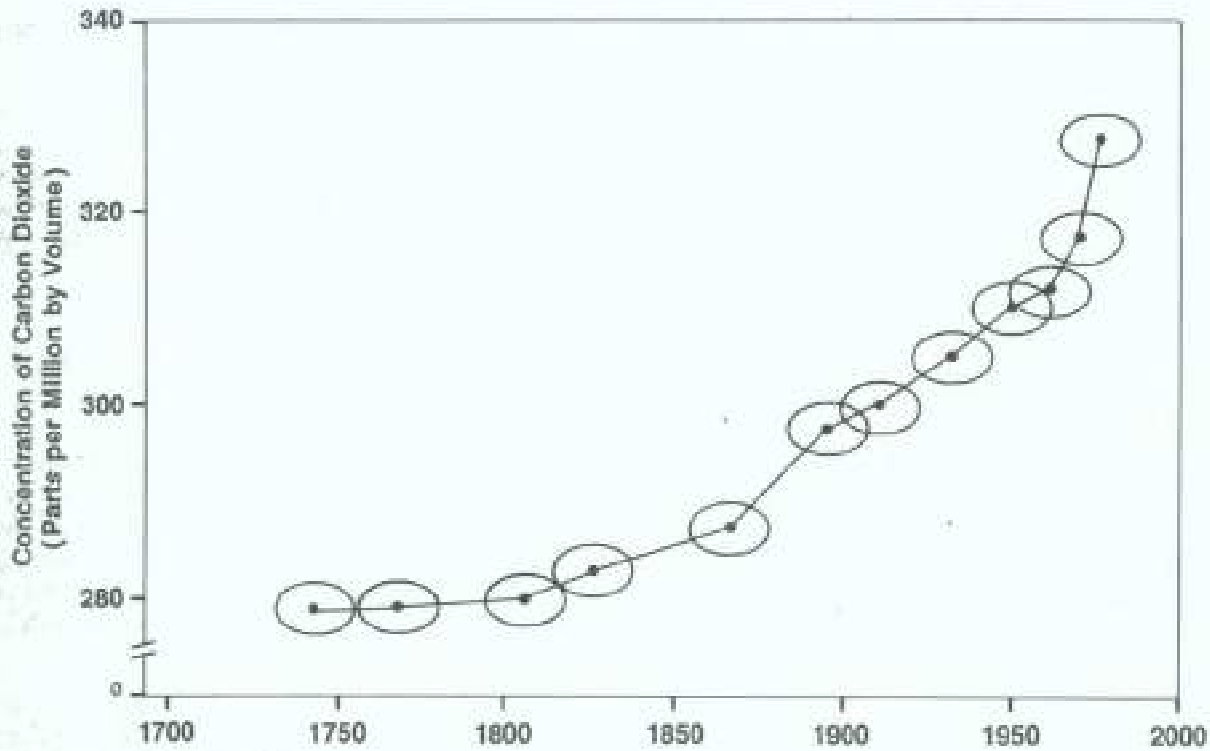

Figure 1a.
CO_2 concentrations measured in glacier ice formed during the last 200 years (Neftel et al., 1985).

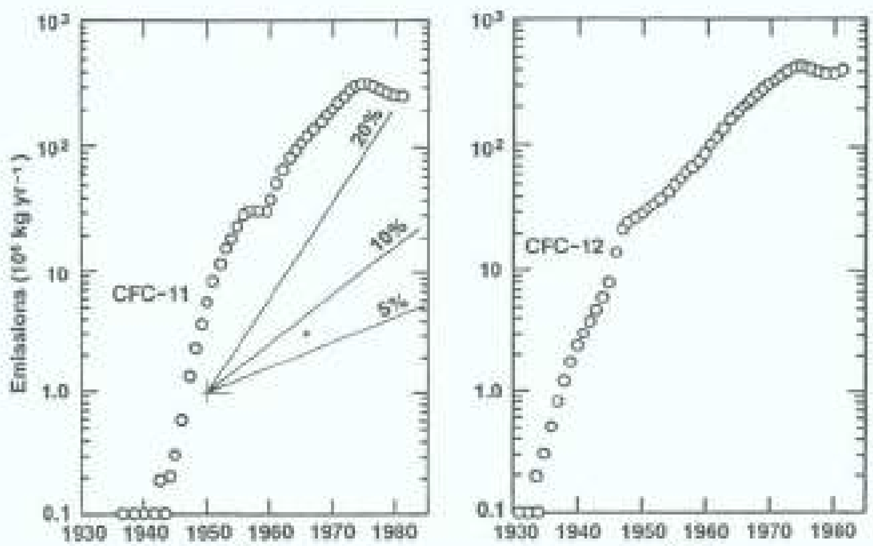

Figure 1b.
Historical emissions of CFC-11 and CFC-12 (Bolle et al., 1986).

many cases involve bills to repair damage. Questions of equity, compensation, spreading the cost of remedial technologies, etc., also arise.

Since effective policy implementation generally takes a very long time, concern is increasing that by the time policy has been agreed upon and implemented internationally, the changes to the atmosphere will already have occurred and have serious implications for environment and society. Moreover, the atmosphere is "a global commons" - a shared resource - and many of the misuses of the atmosphere are felt far away in space and time.

3. CHANGING THE ATMOSPHERE

3.1 The Greenhouse Effect

A number of trace gases in the atmosphere, the most important of which are water vapour, ozone (O_3) and carbon dioxide (CO_2), nitrous oxide, methane, and chlorofluorocarbons (CFCs), are referred to collectively as the greenhouse gases (GHGs), since they exert a "greenhouse effect" by trapping thermal energy in the earth's atmosphere. When the atmospheric concentration of a greenhouse gas is increased, the result is a warming of the earth's surface and the lower atmosphere.

At a conference convened by UNEP, WMO and ICSU in Villach, Austria, in 1985 (World Climate Programme, 1986), scientists agreed that "As a result of the increasing concentrations of greenhouse gases ... in the first half of the next century a rise of global mean temperature could occur which is greater than any in man's history".

3.1.1 Observed and Projected Changes of Greenhouse Gas Concentrations

The concentration of atmospheric CO_2 has increased from a value of 275 $\pm$ 10 ppmv in 1850 (Bolin, 1986) to 343 $\pm$ 1 ppmv in 1984, an increase of about 25% (Figure 1a). The main sources of the CO_2 increase are fossil-fuel burning, deforestation and land-use changes. The atmospheric concentration of CH_4 has been increasing at a rate of about 1%/year during the last 10 years. This increase is most likely related to human activities, primarily agriculture (Bolle et al., 1986). The N_2O concentration was increasing at about 0.2%/year in the 1970s, probably as a result of agriculture, fossil-fuel and biomass burning. At the beginning of 1980 it was estimated that the concentrations of two CFCs (F11 and F12) that attack stratospheric ozone were increasing at about 6%/ year (Bolle et al., 1986) (Figure 1b). The CFCs are produced for a variety of uses such as solvents, refrigerator fluids and spray-can propellants. The concentration of tropospheric (ground-level) ozone is increasing as a result of photochemical processes, with the present rate of increase estimated to be 1-2%/year.

3.1.2 Possible Effects on Global Climate

Numerous studies have been made in recent years of the possible climate changes as a result of increasing GHG concentrations. Computer models show that a doubling of the atmospheric CO_2 concentration increases the global mean equilibrium surface temperature by 1.5-4.5°C.

Figure 2 shows three scenarios of global mean surface temperature changes derived by a group of experts at the Villach Workshop in 1987 (Jaeger, 1988). The scenarios suggest that the continuation of the present increasing trends in GHG emissions could readily lead to mean-value temperature and rates of global temperature changes over the next half century that are well above those experienced within the last one hundred years, possibly exceeding them on average by an order of magnitude.

The figure shows scenarios of globally averaged temperature change in response to continued emissions of atmospheric GHGs. The middle curve reflects a scenario of continued present trends of emissions and a moderate climate sensitivity. There is a chance of 5:10 that the actual path of climate change will be below the middle curve. The upper curve reflects a scenario of accelerated greenhouse gas emissions and a relatively higher climate sensitivity. The lower curve reflects a scenario of curtailed emissions and a relatively lower climate sensitivity. In the professional judgment of the Villach 1987 experts group, there is a 9:10 chance that the actual future pattern of global temperature change induced by greenhouse gases will lie within the bounds set by the upper and lower curves. The ceiling of 5°C on the temperature graph has been imposed because of the dubious relevance of present climate models in simulating the response to a global warming higher than around 5°C. These results are based on results of the Villach Workshop (Jaeger, 1988) and three emission scenarios (high buildup, slow buildup and base cases) from Mintzer (1987).

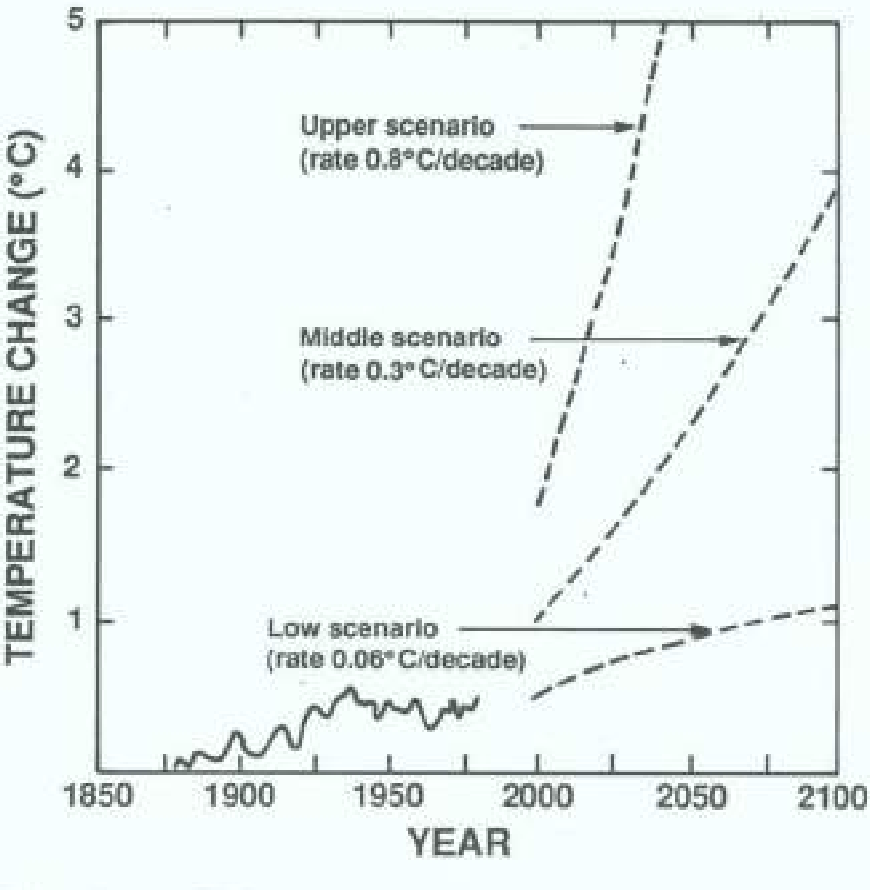

Figure 2.
Scenarios of global temperature change due to continuing greenhouse gas emissions.

3.1.3 Potential Changes of Regional Climate

Although there is general agreement about the magnitude of the effect of a CO_2 concentration doubling on the globally averaged equilibrium surface temperature, the effects on regional distributions of such climate elements as temperature and precipitation are more difficult to estimate using available models. On the basis of model results, a few statements about regional climate changes can be made (see Table 1): The largest temperature increases in a warming world would likely occur during winter in the high latitudes of the Northern Hemisphere, where changes could be 2-2.5 times greater and faster than the globally averaged annual values. On the other hand, changes in the low latitudes will probably be somewhat smaller and slower than the globally averaged changes.

Estimates of regional precipitation changes are very uncertain. Model studies suggest that changes could include enhanced winter snowfall in the high latitudes, intensified rainfall in those zones of the low latitudes that are presently rainy, and perhaps a decrease in summer rainfall in the mid-latitudes.

3.1.4 Observed Temperature Changes in the Last 100 Years

Figure 3 shows the observed globally averaged mean surface temperature variations since 1861 (Jones et al., 1986). The temperature increased by about 0.5°C between 1880 and 1985. Wigley et al. (1986) suggest that the transient warming to date due to changes in greenhouse gas concentrations should be in the range 0.3-1.1°C, given all model uncertainties. However, although the observed temperature increase is consistent with the projected temperature increase, the observed increase cannot be ascribed in a scientifically rigorous manner to the changes in greenhouse gases alone. A recent comparison (Wigley and Raper, 1987) suggests that the observed temperature change is small compared with the change predicted by climate models.

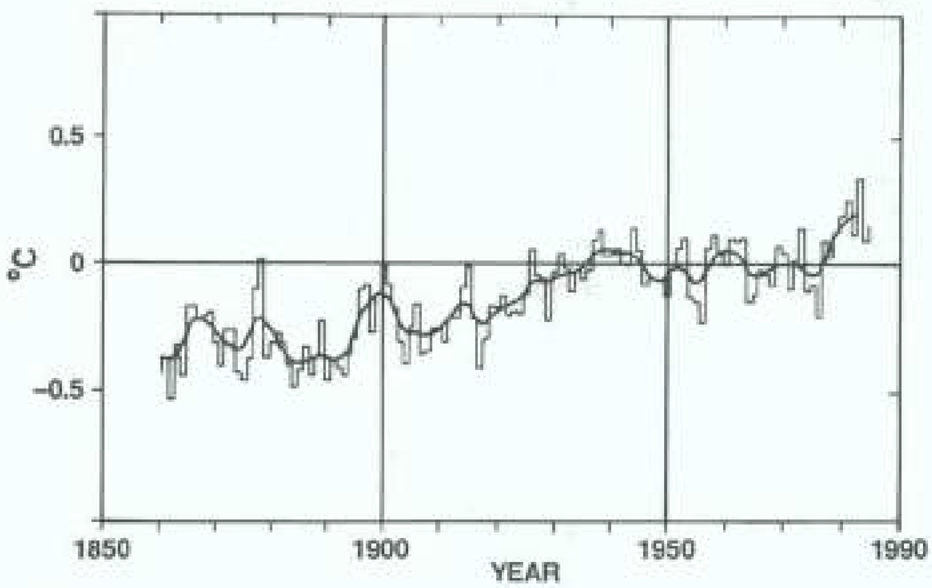

Figure 3.
Global annual mean surface temperature change. The smooth curve shows the 10-year Gaussian filtered values (Jones et al., 1986).

3.2 Decreasing Stratospheric Ozone

The observed changes in the concentrations of ozone at various levels in the atmosphere have received much attention in recent years, especially because ozone is known to prevent the most dangerous ultraviolet radiation wavelengths from reaching the earth's surface.

Ozone, although it is only a minor constituent of the earth's atmosphere, is very important to human society, since it is the one gas in the atmosphere that prevents harmful solar ultraviolet radiation from reaching the surface of the earth. A decrease in the total column amount of ozone would have adverse effects on human health (skin cancer, eye damage, suppression of the immune response system) and on the productivity of terrestrial and aquatic ecosystems. In addition, changes in the vertical distribution of ozone could modify the atmospheric temperature structure, which could lead to changes in the atmospheric circulation and thus to climate changes.

3.2.1 The Destruction of Ozone in the Stratosphere

Methane, nitrous oxide, CFCs and halons are precursors to oxides that can catalyze the destruction of ozone in the stratosphere via a series of chemical reactions. Carbon monoxide and carbon dioxide can affect ozone directly. CO_2 also has an indirect effect, since it controls to a large extent the temperature structure of the stratosphere and this is important in controlling rates at which the hydrogen, nitrogen, chlorine and bromine oxides destroy ozone. The increases in these trace gases that can affect the ozone concentrations in the atmosphere are a result of the combustion of fossil fuels and land-use practices. The source of CFCs and halons is industrial production. CFCs are used for propellants, refrigerants and foam-blowing agents, and halons are used for fire extinguishers. One major aspect of the ozone issue is that the atmospheric lifetimes of nitrous oxide and CFCs are very long, so that full recovery of the system would take several tens to hundreds of years after the emission of these gases is terminated. The CFCs take several years to travel from the earth's surface to the heights at which they can affect the ozone layer. This means that there is a delay between the release and the effects.

3.2.2 Projected Changes of Ozone Amount in the Stratosphere

As in the case of the effects of the greenhouse gases, numerical models are used to predict changes in the amount of ozone in the atmospheric column, in the vertical distribution of ozone and in the temperature. The results of model calculations suggest that if the atmospheric concentrations of CO_2, CH_4 and N_2O continue to increase at their current rates for the next 100 years and CFC emissions continue to grow at 3%/year, there would be a reduction of the globally averaged overhead column ozone amount of about 60% by the year 2040. In contrast, the calculations show that a true global freeze of the emissions of all bromine- and chlorine-containing chemicals at or below projected 1990 levels would give global column ozone depletions of less than 1% by the year 2015 and less thereafter.

It must be noted, however, that even when the predicted column ozone changes are small, as in the case of a true global freeze, so that there is little change in the amount of ultraviolet radiation reaching the earth's surface, large changes in the vertical distribution of ozone are predicted to have some effects on climate.

3.2.3 Global Ozone Trends

Measurements of ozone concentrations over the past few decades show that they have been increasing in the lower atmosphere owing to increased hydrocarbon and nitrogen oxide emissions, and decreasing higher up in the stratosphere. Ground-based observations show that column ozone generally increased by about 3% from 1960 to the early 1970s, remained constant throughout the 1970s and decreased since then by about 4%. Other data also suggest a significant decrease in the global column content of ozone since the late 1970s.

3.2.4 Antarctic Ozone Changes

Data from Halley Bay in Antarctica have recently indicated a considerable decrease (more than 50%) in the total column content of ozone above the Antarctic during the spring period (late August to mid-November) since 1957, with most of the decrease occurring since the mid-1970s. The ozone decrease extends from the South Pole to about 45°S. Ozone changes of the same magnitude have not been observed in the Arctic, although there is some evidence of less extensive depletions.

Measurements show that the chemical composition of the lower stratosphere over Antarctica is significantly altered compared with that expected from theoretical considerations and compared with that elsewhere on earth. Preliminary results of the 1987 measurements suggest that both chemical and meteorological mechanisms perturbed the abundance of ozone in 1987. At the Conference on The Changing Atmosphere, Watson concluded that before the chemical and meteorological processes are better understood, the global implications of the Antarctic phenomena cannot be assessed. In the context of the implications of "The Changing Atmosphere", however, it is important to note that "the Antarctic ozone phenomena vividly demonstrate that the environment does not always change slowly, linearly, or predictably in response to a perturbation" (Watson, 1988).

3.3 <u>Transboundary Pollution</u>

Ever since the early 1970s, transboundary air pollution has been an issue that has received national and international attention. At the United Nations Conference on the Human Environment in Stockholm in 1972 the problem of air pollution was discussed for the first time at such an international political level. What appeared to be a limited problem at that time is now considered to be a serious environmental problem facing Europe and parts of North America. Attention was first given to the transport of sulphur compounds, and subsequently nitrogen oxides and hydrocarbons have been included in evaluations.

3.3.1 Atmospheric Transport of Sulphur

Sulphur leaves chimneys as a gas, sulphur dioxide (SO_2). The amounts of sulphur released when fossil fuels are burned depend on their sulphur content. Since the typical residence time of SO_2 in the atmosphere is on the order of one to two days, SO_2 emissions are often deposited quite a distance from their source. In Europe, for instance, this means that the SO_2 emissions from one country are often deposited in another country. Dry and wet removal processes, i.e., precipitation and fallout of dry particles, control the atmospheric residence time of sulphur. Their relative contributions to deposition vary: dry deposition is more important close to the high densities of sulphur emissions and wet deposition in more remote areas. Since sulphur dioxide is converted to sulphuric acid in the atmosphere and the acid condenses to form droplets, rain-water becomes acidified in the regions affected. Unaffected rain-water has a pH of 5-6. In Europe and parts of North America and China the pH of rain is now between 4 and 4.5 and sometimes is as low as 3 (Persson, 1988).

3.3.2 Other Pollutants

In addition to sulphur, other pollutants enter the atmosphere as a result of human activities and are transported over long distances before being deposited. Of particular concern are the nitrogen oxides and hydrocarbons.

Flue gases resulting from combustion mainly contain the gas nitric oxide (NO), which reacts with oxygen to produce nitrogen dioxide (NO_2). The stable end-product to this reaction is nitric acid, which can exist in gaseous form in the atmosphere (Persson, 1988). In contrast to sulphur, which is mostly emitted from tall chimneys, a large proportion of the nitrogen oxides and hydrocarbons are released at ground level from road traffic. Since the nitrogen oxides have to be converted into nitric acid before they can be effectively deposited, the nitrogen oxides are usually deposited a long distance from their source. Nitrogen oxides and hydrocarbons are a prerequisite for the formation of photochemical oxidants, the most important of which is ozone (Persson, 1988).

Ammonia (NH_3) is emitted in areas of intense livestock farming. It is generally deposited closer to the source than the sulphur and nitrogen oxides. Ammonia neutralizes acid precipitation but in the soil, ammonium ions are converted into nitrate ions, and hydrogen ions are released resulting in soil acidification.

Ozone, formed by photochemical reactions in the atmosphere, is also transported across boundaries. During particular episodes, ozone concentrations of more than 100 ppb may be found at the same time in various places throughout northern Europe, compared with background levels of between about 15 to 40 ppb. Even small increases in the surface ozone concentration are known to have harmful effects on plants and human beings

Other substances that are being transported over boundaries are toxic chlorinated hydrocarbons. The cause of the emissions of dioxins is sources of combustion, e.g., incinerators and motor vehicles. In addition, metals like mercury and cadmium are found deposited thousands of kilometres from the emission source. The transport of radioactive substances after the Chernobyl accident demonstrated dramatically the existence of the phenomenon of long-range transport.

One further example of an atmospheric disturbance resulting from the long-distance transport of pollutant is the occurrence of Arctic haze. The Arctic haze contains large amounts of anthropogenic components like carbon soot and sulphuric acid. The concentrations of Arctic haze are greatest between December and April because south-north air-mass movements are stronger and more frequent at this time and the pollutants are less readily removed owing to the lack of precipitation and the stability of the Arctic atmosphere.

3.4 Common Factors Contributing to the Changing Atmosphere

There are strong links between the major issues of the changing atmosphere. For example, there are two strong links between the greenhouse gas warming and the decrease of stratospheric ozone: first, tropospheric ozone acts as a greenhouse gas; second, the gases that are predicted to modify the stratospheric ozone concentration are greenhouse gases (carbon monoxide, methane, nitrous oxide and chlorofluorocarbons). The greenhouse gas warming and transboundary pollution issues are linked by the common source (fossil-fuel combustion) of gases, SO_2 and CO_2 in particular. Decreased energy use thereby reduces all types of emissions. Furthermore, energy use is linked to land-use changes and investments, such as deforestation in the humid tropics. The issues they pose are complex and involve large uncertainties. They all contribute to long-term global problems and will be difficult to reverse. These links suggest the need to consider the issues together when priorities are being set for policy.

The previous paragraphs have described the increasing rates of emissions of greenhouse gases into the atmosphere, and of emissions of other pollutants and toxic materials, and have indicated that these, along with deforestation can critically influence the role of the atmosphere as our "life-support system". That results primarily because climate is altered on global and regional scales, and the atmosphere transports noxious materials. This reduction in the carrying capacity of the earth is occurring simultaneously with a rapid increase in global population, and with it concurrent increases in demands for food, water, energy and land. These changes could further increase not only the emission of gases and particles into the atmosphere but also large-scale changes of land use. Now is the time to initiate rational controls on atmospheric change. The cost of inaction is too great.

3.5 Land-Use Alterations and Climate

As a result of land use, human activities have altered large areas of the earth's surface. There are basically three ways in which changes in the characteristics of the land surface can influence the climate. First, the reflectivity of the surface can be changed and this changes the amount of solar energy absorbed at the surface. Second, the roughness of the surface can be changed and this affects the transfers of energy, moisture and momentum into the atmosphere. Third, the surface wetness can be changed, affecting the evaporation from the surface. Human activities that lead to such changes include deforestation for agricultural purposes, energy use, urbanization, irrigation and creation of artificial lakes.

3.5.1 Deforestation

The clearing of forests for agricultural purposes has been practised for many centuries. In the tropics, for example, slash and burn agriculture has long been used to clear the land. Estimates suggest that some 40% of the African Equatorial forest has been converted to savanna over the past few thousand years, and half of the remaining forest has been altered (Sagan et al., 1979). In recent years, the effects of shifting cultivation have been overtaken by the wholesale removal of forests mainly for commercial purposes. The loss of total tropical forest is estimated to be between 9 and 24.5 million hectares per year (Henderson-Sellers, 1987). In the Mediterranean area and in China, early civilizations destroyed the temperate forests; the forest areas of North America and Europe have been reduced mainly during the past one thousand years, and some reforestation is occurring today.

3.5.2 Overgrazing and Desertification

Bryson and Baerreis (1967) suggested that overgrazing was the cause of the expansion of the Rajasthan Desert in India. The basic suggestion was that overgrazing leads to a lack of vegetation and thus to an increased amount of dust in the atmosphere. It was postulated that this dust changes the rate of heating of the atmosphere, leading to decreased rainfall. Hare's (1983) review indicated that increases in albedo due to overgrazing or unwise cultivation in arid areas can cause a decrease in the rainfall amount. Sagan et al. (1979) also concluded that human influences have played a major role in desertification and pointed out that although most damage in arid lands is due to overgrazing, another problem is salinization by irrigation projects. Overgrazing has also been suggested as one of the factors in the protracted Sahel drought.

4. ENVIRONMENTAL AND SOCIO-ECONOMIC CONSEQUENCES

4.1 The Effects of GHG-Induced Climatic Change

In recent years attention has turned to the potential effects of climate changes on society and ecosystems. At the 1985 Villach Conference, the effects on agriculture and forests received particular attention. Other studies (e.g., CDAC, 1983) have also considered this topic. At the Villach Workshop in 1987 the participants considered the effects of climate changes on broad latitudinal zones and on coastal areas.

In considering the effects of climate changes on coastal areas the participants pointed out that half of humanity inhabits coastal areas. The global warming as a result of increasing concentrations of the greenhouse gases would accelerate the present sea-level rise resulting in a rise of as much as 1.5 m by the middle of the next century as a result of the thermal expansion of seawater and the melting of land ice. The effects of sea-level rise will include erosion of beaches and coastal margins; land-use changes; wetland loss; changes in the frequency and severity of flooding; damage to port facilities and coastal structures; and damage to water management systems.

In the middle latitude regions between 30 and 60 degrees latitude, the amount of warming as a result of the greenhouse gases will be somewhat greater than the global average warming. The participants at Villach in 1987 considered the effects of climate change on agriculture, water resources, soils and human concerns and concluded that available technologies reduced the threat on managed resources. The main deleterious effects of change would be in poorly managed ecosystems that would be exposed to rates of climate change for which they are poorly adapted. Forest dieback could occur, and biotic preserves and natural areas would be threatened. Two aspects of the anticipated climate changes were felt to be of major importance:

- Future climate changes are likely to be more rapid than changes in the past.
- In the absence of measures to avert them, the climate changes are expected to persist indefinitely into the future.

If the rate of increase of temperature is as fast as that implied by the High Scenario in Figure 2, forest dieback would start to occur between the years 2000 and 2050. On the other hand, if the temperature increases at the rate given by the Low Scenario in Figure 3, no major effects on forests in the middle-latitude regions would occur before the year 2100.

With regard to agriculture in the middle latitudes it is certain that a GHG-induced warming would cause intra-regional shifts in productivity. For all but the most rapid warming (i.e., the upper scenario shown in Figure 2), adaptation based on agricultural research should permit the maintenance of global food supplies. However, there would be local disruptions. For the faster rates of warming, agricultural adaptations may be out of step temporally with effects of climate change, generating erratic reductions in food availability. Taken alone, climate warming would have probably little net effect on agriculture in the mid-latitude band; productivity in the lower-latitude zone of the band might be reduced because of increased evapotranspiration, whereas the higher latitudes of the band would benefit from the longer growing season. Agriculture is dependent on the availability of fertile soils. Shifts of crops due to GHG-induced climate changes may be affected positively or negatively by this factor. There are also major uncertainties about changes in precipitation and evapotranspiration, so that it is not possible to predict at this stage whether the net effects of change will be positive or negative for specific regions except that irrigated agriculture in semi-arid areas in the mid-latitudes will probably be adversely affected by the warming.

In the semi-arid tropical regions climate variability is already a problem and future climate changes could worsen the current critical problems of the semi-arid tropics. The climate changes that might occur by the middle of the next century as a result of the increasing concentrations of GHGs include increases of regional temperatures on the order of 0.3-5°C; a tendency for a decrease in precipitation rate in one or more seasons; and a reduction of soil moisture availability. The major effects are expected to be on food availability, water availability, fuelwood availability, human settlement, and unmanaged ecosystems. The temperature increases, precipitation pattern changes and CO_2 concentration changes would alter the agricultural production potential within a region that is already highly sensitive to the effects of climate and is often marginal for agriculture. Productivity changes would aggravate current difficulties in meeting basic nutritional needs. In addition, resource degradation through increased desertification could occur.

Over the next half century it is expected that the addition of greenhouse gases will warm the humid tropical regions by 0.3-5°C. This warming will be accompanied by changes in the precipitation distribution. Major effects of climate changes would result from rising water levels along coasts and in rivers as a result of increasing sea-level and an increase of tropical storm surges. In addition, the changing spatial and temporal distributions of temperature and precipitation would have effects on industry, settlement, agriculture, grazing land, fisheries and forests.

In the high-latitude regions the mean winter temperature could increase by 0.8°C to considerably more than 5°C by the middle of the next century as a result of greenhouse gas increases. The climate changes would have the following important effects:

- a withdrawal of summer pack-ice
- increased cloudiness and precipitation
- the slow disappearance of permafrost
- changes in the tundra and the northern limit of the boreal forest

Such changes could have important effects in high-latitude regions. For example, the possible changes of sea ice would provide opportunities for the increased use of the Northeast and Northwest passages. Some of the difficulties of offshore oil development could be reduced, but onshore development could become more difficult and expensive in areas of melting permafrost. With warming, agricultural opportunities should improve, but only over limited areas because of the lack of suitable soils in high-latitude regions. Rapid shifts in growth conditions could cause the dislocation or disruption of ecosystems as well as the movement of the limits of agriculture and forestry northwards. Nordic regions are important in the global carbon cycle and a climate warming could result in a substantial increase of methane emissions from tundra, thus increasing the emissions of GHGs into the atmosphere. In addition, if permafrost retreats in the boreal soils region and the soils dry out, then CO_2 would be released into the atmosphere, again amplifying the greenhouse effect.

4.2 The Effects of Transboundary Pollution

Soil acidification is an important link between air pollution and damage to the terrestrial and aquatic environment. Soil acidification involves a decrease in the acid neutralization capacity of the soil and occurs when the rate of acid input exceeds the weathering rate.

In Europe, soils have been acidified over large areas within the last 30-60 years. The changes in the soil affect vegetation, groundwater and surface water. Some of the soil changes may be irreversible.

Lake acidification is a well documented problem in many mountainous and forested regions of Europe. For example, in Sweden it has been estimated that acidification affects 15,000 of 85,000 lakes larger than one hectare in area and seriously affects 1,800 of these (Alcamo et al., 1987). Lake acidification results from acidic runoff that is inadequately buffered by soils in the lake's catchment. The extent of lake acidification also depends on the amount of snowmelt, the flow paths of runoff, the lake chemistry and other physical and chemical processes. Ecological changes resulting from lake acidification, e.g., failing fish reproduction, have become increasingly evident in Europe and North America.

Evidence of groundwater acidification in Europe comes from both wells and surface water fed by groundwater. The impact of acid deposition on groundwater is usually first noticed as an increasing water hardness. In some areas acidification could increase the mobility of metals, which are leached out of the ground into the groundwater.

Forest dieback has been observed in central Europe since the 1970s. In addition to the dependence on local conditions, the following environmental stresses may be important: soil acidification; direct leaf damage due to acid deposition; direct damage due to elevated concentrations of SO_2, ozone and other pollutants; and nitrogen overfertilization. Climate factors and natural stresses also could play a role in some circumstances.

4.3 Other Effects of the Changing Atmosphere

As pointed out, a decrease in the total column amount of ozone would have adverse effects on human health (skin cancer, eye damage and suppression of the immune response system) and on the productivity of terrestrial and aquatic ecosystems. The marine environment could undergo dramatic changes because of the sensitivity of single-cell marine organisms to ultraviolet radiation. Plant and animal life could also be affected by an increased occurrence of smogs as a result of higher temperatures and increased low-level ozone concentrations. A further documented effect of ultraviolet radiation is the degradation of many common synthetic materials. Higher ultraviolet radiation levels as a result of the reduction of stratospheric ozone would lead to damage of many of the plastics currently used in the building industry and elsewhere; the costs of preventing such damage have been estimated to be considerable. In addition, changes in the vertical distribution of stratospheric ozone could modify the atmospheric temperature structure, which could lead to changes in the atmospheric circulation and thus to climate changes.

The consequences of deforestation and land-use changes have not been assessed to the extent of those associated with the greenhouse gases, ozone depletion and transboundary pollution. Certainly on a regional scale, deforestation and land-use changes result in changes of climate, particularly in the absorption of solar radiation and in the amount of precipitation, and such changes would affect agricultural productivity.

Climate changes on the local, regional and global scales will have direct effects on ecosystems and agriculture. In addition, global warming will have a first-order effect on sea-level. These effects will cause secondary effects, for example, on the economy, trade and security. Although attempts have been made to quantify such effects, the uncertainties associated with the whole chain of events are so large that it is not possible at present to make detailed projections of the potential changes. It is, however, very important to note that effects on the economy, trade, etc., should be expected.

5. RESPONDING TO CHANGE

5.1 Policy Responses for the GHG Issue

Strategies for responding to climate change can be divided into two categories: Adaptation strategies that adjust the environment or the ways of using it to reduce the consequences of a changing climate; limitation strategies that control or stop the growth of the GHG concentrations in the atmosphere and limit the climate change. A prudent response to climate change should consider both limitation and adaptation strategies and involve consideration of compensation, i.e., how costs related to loss and technological fixes should be distributed. Even if a very concerted effort were made now to implement limitation strategies, some adaptation would still be necessary because of the climate changes resulting from the greenhouse gases that have already been emitted into the atmosphere.

Both adaptation and limitation strategies would involve large expenditures. For example, it has been estimated that partial adaptation to the increases in sea-level that will probably occur during the next 50 years as a result of GHGs already emitted could involve a global expenditure of $30-300 billion (US) over a planning and construction time of twenty to forty years for coastal maintenance measures.

Clearly there is an urgent need to examine the strategies for adaptation to and the limitation of climate change and to develop a methodology of comparing the costs of different strategies. There are many actions in the long term that will be required in order to ensure appropriate responses are made to climate changes. Immediate steps that should be taken are:

1) The Protocol on Substances that Deplete the Ozone Layer should be approved and implemented without delay.

2) Governments should immediately begin to re-examine their energy policies with the goals of achieving a high energy end-use efficiency, reducing multiple forms of air pollution and reducing CO_2 emissions.

3) Measures to reduce deforestation and increase reforestation should be taken.

4) Areas vulnerable to sea-level rise should be identified and planning for installations near the sea should allow for the risks of sea-level flooding.

5) Policy research, monitoring of climate change, and scientific research should be directed towards improving the understanding of the greenhouse effect and of the options for dealing with it.

6) Various institutional arrangements should be made to ensure that the necessary preparations are made and actions are taken. In addition, there is a need for increased awareness world-wide of the nature of the problem and of the necessity of adopting measures to tackle it.

5.2 Policy Responses to Reduce Depletion of the Stratospheric Ozone

Increasing concern about changes in the ozone concentrations in the atmosphere has led to a series of actions to safeguard the ozone layer. In 1977, UNEP convened a meeting of experts to draft a World Plan of Action on the Ozone Layer. Continued concern led to the creation of a working group of legal and technical experts to frame a Convention for the Protection of the Ozone Layer, which was adopted in Vienna by 21 states and the European Economic Community in March 1985. Several more states have since signed the convention. The 21 articles of the convention pledge the parties to protect human health and the environment from the effects of ozone depletion. In September 1987 the Protocol on Substances that Deplete the Ozone Layer was agreed to in Montréal Canada, and is presently awaiting ratification before it can be implemented.

In response to concern about the ozone layer several countries have regulated the production or use of CFCs. For example, the United States banned the use of CFCs as aerosol propellants in 1978, and Canada followed soon after with a ban on CFCs in major uses. A 1980 EEC Council decision required EEC members not to increase the production capacity of CFCs and to achieve a 30% reduction of CFC use in aerosols by the end of 1981 compared with 1976 levels.

5.3 Policy Responses to Reduce the Long-Range Transport of Air Pollutants

In recent years evidence has accumulated about soil, lake and groundwater acidification and forest dieback resulting from the long-range transport of pollutants, in particular, sulphur and nitrogen compounds. Although the cause-and-effect linkages are more clearly demonstrated for the long-range transport of air pollutants than for greenhouse warming and ozone depletion, policy has been limited by discussions of cost-benefit analysis, economic viability of strategies and other details. However, concern about air pollution led to the signing of a Convention on Long-Range Transboundary Air Pollution by 34 states and the European Economic Community in November 1979. The Convention had the form of a framework agreement, recognizing the problems of air pollution and the responsibility of the signatories for solving them. The Convention came into force in March 1983 after the requisite number of states had ratified it. A Protocol on Sulphur Emissions was signed in July 1985 and came into force in September 1987. The signatories undertake to reduce national emissions of sulphur dioxide - or their transboundary fluxes - by at least 30% by 1993 at the latest (with 1980 emission levels as the basis).

5.4 Common Aspects of Policy Response

The effects of the changes in the atmosphere are of major concern for humanity, e.g., sea-level changes, health effects and forest dieback. For this reason, in regard to ozone changes and transboundary pollution, nations have signed conventions recognizing the problems and their responsibility for solving them. In connection with the conventions, protocols are now being worked out to specify strategies to limit the problems.

Both the ozone and greenhouse gas issues are global questions that have policy implications different from those of other environmental problems. In addition, strong links between these two issues suggest that they should be considered together in terms of a complex of trace gas-climate issues.

In each case it is clear that if we decide to wait for more certainty before implementing policy, then we must accept the risk of having to deal with larger rates of change in the greenhouse gases, ozone depletion and acid deposition than if actions were taken today.

6. THE ATMOSPHERE AND GLOBAL STEWARDSHIP

6.1 The Policy Challenge

6.1.1 What Has Been Done?

As discussed in the previous section, policy steps have been taken in the cases of stratospheric ozone depletion and long-range transport of pollution. For greenhouse warming and for deforestation, the last two decades have seen an increasing scientific awareness of the magnitude of the problem. In 1985 the scientific community suggested, after a detailed review of the greenhouse gas problem, that scientists and policy-makers should begin to collaborate to explore the effectiveness of alternative policies and adjustments. This collaboration was begun at the workshop in Bellagio in 1987 and was continued at the World Conference on the Changing Atmosphere in 1988.

6.1.2 What Should Be Done?

In order to respond prudently to the challenges of the changing atmosphere, two kinds of action are necessary. Firstly, there is a need to increase awareness of the problems and the ways that they could be solved. In doing this, care has to be taken that a balanced account of the problems is given, without exaggeration or sensationalism. Experience has shown that national or international action on such problems has only been taken after awareness of the issue had indeed increased to a substantial level. In the case of the long-range transport of air pollutants, the phenomenon of forest dieback ("Waldsterben"), especially in central Europe, stimulated action. Similarly, the discovery of the Antarctic "ozone hole" focussed attention on the stratospheric ozone problem in the media.

Secondly, after awareness of the problems of the changing atmosphere has been increased, action can be taken on agreements, conventions and protocols. Although conventions have already been signed to protect the ozone layer and to limit long-range transboundary air pollution, there is still a need for scientific reviews of protocols and appropriate tightening of the regulations to reduce emissions to an acceptable level. Ultimately, because of the global character of the atmosphere, a law of the atmosphere may be warranted. Such a law could incorporate and build on other conventions and protocols such as the 1987 Montréal ozone protocol.

6.1.3 A Strategy for Action

There are obviously many long-term actions that will be required in order to ensure appropriate responses to the changing atmosphere. These actions will be taken at a number of different levels. At the level of the individual, decisions will be made, for example, about the heating system in a house, the crop to be planted in a particular field, or the number of trees to be felled, and if public education about the issues that have been discussed above is effective and governmental support is appropriate, then individual decisions could be made that are compatible with the concern expressed for these issues. Appropriate community support systems and infrastructures must be in place for this to be realized.

At the national level, action will also be necessary. On the one hand, governments should examine existing policies, e.g., energy policy and forest policy, and adjust them to reduce the rates at which the atmosphere is being changed. In addition, governmental support for research and development of alternative technologies must be greatly intensified. Corporations, banks, the investment community and non-government organizations must also include consideration of the atmosphere in their planning and operational agendas.

Countries should also act to see that appropriate international instruments and organizations are in place for the design and implementation of agreements, conventions and protocols to coordinate activities and to overcome existing knowledge and information gaps. In addition, banks, industry, regional organizations and similar international groupings should become involved in the development of policies for responding to changes in the atmosphere. In many cases decisions are being made today on the assumption that conditions will be the same as those in the recent past. This assumption is not true and appropriate awareness-building would help put decisions on a sounder basis. Active collaboration between scientists and decision-makers from international organizations (including industry) would help in the development of appropriate policy responses.

6.2 The Challenge to Science

All of the issues discussed in this report are scientifically complex. In all cases there are uncertainties, some of which will be difficult or impossible to reduce. Despite the complexity and uncertainties, scientists can give useful information to policy-makers, especially when the nature of the uncertainties and of the certainties are clearly specified. Moreover, increased collaboration between scientists and policy-makers would ensure that scientific research is really directed towards answering the questions that policy-makers are likely to ask.

6.3 The Need for Leadership

It is clear that human activities are leading to major changes in the atmosphere. Such changes, especially if the rate at which they are occurring continues to increase, will have major effects on environment and society. Most of these effects will have serious adverse consequences. For this reason, a coordinated international response is necessary. This response will require strong leadership, sincere cooperation, and unfailing support. The call for action is urgent and the challenges to policy-makers and to scientists must not be ignored.

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Table 1. Regional scenarios for climate change.

Region[1]	Temperature Change[2] (as a multiple of global average change) Summer	Winter	Precipitation Change[3]
High latitudes (60-90°)	0.5-0.7X	2.0-2.4X	Enhanced in winter
Mid latitudes (30-60°)	0.8-1.0X	1.2-1.4X	Possibly reduced in summer
Low latitudes (0-30°)	0.9-0.7X	0.9-0.7X	Enhanced in zones with heavy rainfall today

[1] The figures in this table are taken from computer modelling results for the Northern Hemisphere. Low-latitude trends are likely to be similar for the Southern Hemisphere. The mid-latitudes of the Southern Hemisphere may differ somewhat owing to their relatively small land mass. The high latitudes of the Southern Hemisphere could respond much differently than Arctic areas because the Antarctic surface lies at high altitudes and is land-based.

[2] The regional temperature changes are presented here as multiples of the globally and annually averaged temperature changes. Thus, for example, if one supposes that the globally averaged annual temperature change for the year 2040 was 2.0°C, then Table 1 says that high-latitude winter temperatures in the same year would rise by 4.0 to 4.6°C. Similarly, a rate of change in the global mean temperature of 0.3°C per decade would give a mean rate of change in the high-latitude winter temperatures of 0.6 to 0.7°C per decade.

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

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

L'ATMOSPHÈRE EN ÉVOLUTION

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"La vitesse du changement dépasse les capacités des disciplines scientifiques ainsi que nos possibilités actuelles en matière d'évaluation et de recommandation" (Notre avenir à tous)

AVANT-PROPOS *

Au début du siècle, la race humaine, ni par son nombre ni par sa technologie, n'avait le pouvoir de modifier radicalement les systèmes planétaires. Le siècle arrive à sa fin et non seulement la population mondiale, par son explosion et par son activité, a-t-elle acquis ce pouvoir, mais ce sont en outre des changements majeurs et involontaires que subissent l'atmosphère, les sols, les eaux, la végétation et les animaux, de même que les rapports entre tous ces éléments. **(Notre avenir à tous - Commission mondiale sur l'environnement et le développement, 1987)**

Ce document de base porte sur les changements dans l'atmosphère. Les changements atmosphériques involontaires sont d'une telle ampleur et leurs répercussions sont si imminentes qu'il faut leur accorder immédiatement la première place à l'ordre du jour politique. L'auteur met l'accent sur le changement climatique. Le climat joue un rôle prédominant et les modifications qu'il subit peuvent se faire sentir dans presque tous les domaines. Nous avons maintenant la capacité de le perturber gravement et il se peut que nous y soyons arrivés par notre utilisation de l'atmosphère comme dépotoir de déchets gazeux et de polluants particulaires et par les changements de plus en plus marqués qui caractérisent l'utilisation des sols. Mais il y a plus. Les émissions dans l'atmosphère menacent maintenant la couche protectrice d'ozone, modifient les écosystèmes et la productivité terrestres et entraînent des effets nocifs sur l'environnement et la santé humaine. La situation qui en résulte, alors que le siècle tire à sa fin, impose des exigences et présente un défi de taille.

Le présent rapport a été rédigé par une scientifique, Madame Jill Jaeger, qui a participé aux activités de recherche climatologique. L'auteure résume les connaissances et les préoccupations du point de vue scientifique. Elle tente de "passer le flambeau" aux décideurs et à leurs conseillers à qui il incombe de veiller à ce que des mesures soient prises en définissant les conséquences du changement et en proposant des politiques. Ce document s'appuie fortement sur une série de conférences internationales sur les gaz à effet de serre (GES) et leurs effets. Parmi celles-ci il faut mentionner le Congrès international du Programme climatologique mondial (PCC) de 1985

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sur l'évaluation de rôle du dioxyde de carbone et des autres GES sur les variations climatiques et leurs résultats, ainsi que les colloques parainés par l'Institut Beijer à Villach et Bellagio en 1987. Un résumé des débats et des recommandations en a été publié dans la série d'études des incidences du climat du PCC sous le titre "Developing Policies for Responding to Climate Change"; les participants pourront se procurer le résumé lors du Congrès. Plus de 90 scientifiques provenant de 28 pays ont participé à la Conférence du PCC de 1985. Les colloques de l'Institut Beijer réunissaient environ 64 scientifiques et des décideurs et conseillers supérieurs de 16 nations.

Le message est clair. Un réchauffement mondial peut vraisemblablement se produire et causer la hausse du niveau des océans, modifier considérablement les agroécosystèmes et les ressources en eau et enfin, compromettre les modes de vie traditionnels. La vitesse des changements prévus dépasse nos possibilités de planification et elle est irréversible. Notre capacité de prévoir les conséquences est limitée, tout comme notre capacité de faire face à la situation si les prévisions actuelles se réalisaient. De plus, l'utilisation de l'atmosphère comme système d'élimination des déchets chimiques menace la productivité de nos ressources et la santé humaine. Nous devons élaborer et appliquer des mesures solides pour protéger l'atmosphère si nous voulons laisser aux générations futures un héritage semblable à celui qui nous a été donné.

Le rapport est un document à lire avant la Conférence sur l'atmosphère en évolution. Il devrait permettre aux participants d'acquérir une compréhension commune des problèmes atmosphériques qui donneront lieu aux discussions sur les mesures à prendre au sein des groupes de travail de la Conférence et par conséquent, il devrait faciliter la communication et servir à fixer l'orientation de la Conférence.

1. INTRODUCTION

Par de nombreuses façons, les activités humaines changent la face de la terre. Les changements se produisent à diverses échelles temporelles et spaciales. Par exemple, depuis des centaines d'années, le couvert forestier doit faire place aux terres agricoles. La surface totale qui a été ainsi perturbée est considérable et, dans les régions tropicales, le déboisement se poursuit à un rythme qui se situe entre 9 et 24,5 millions d'hectares par an. Les changements attribuables à l'urbanisation sont un autre exemple : la libération de poussières et de gaz dans l'atmosphère urbain, les caractéristiques de surface, le dégagement de chaleur et d'autres changements donnent lieu au phénomène connu de l'ilot thermique urbain. Il ne s'agit là que de quelques exemples des changements que les activités humaines exercent sur la Terre. Collectivement, ces changements et d'autres perturbations que subit la planète nous font réfléchir sérieusement à notre responsabilité. Dans "Building a Sustainable Society", Lester Brown déclare : "Depuis la Seconde Guerre mondiale, la "sécurité nationale" revêt un caractère exagérément militaire... pourtant, les menaces à la sécurité résultent moins des rapports entre les nations que des rapports entre l'humanité et la nature... L'érosion des sols, la dégradation des systèmes biologiques fondamentaux de la Terre et l'épuisement des réserves de pétrole mettent présentement en danger la sécurité de tous les pays..."

L'atmosphère est unique en ce qu'elle permet le maintien de la vie. Il existe une interdépendance serrée et systématique entre l'atmosphère et les composantes environnementales; par exemple, les océans, la surface terrestre, le biote et la couverture de glace et de neige qui, par leur action conjuguée, façonnent notre climat et que l'on considère comme les éléments du "système climatique". On s'inquiète de l'ampleur que prennent les changements atmosphériques observés et prévus, provoqués par les activités humaines et qui influent sur ce système.

Les effets possibles des activités humaines sur le climat suscitent un intérêt qui s'est accru de façon spectaculaire au cours des vingt-cinq dernières années. L'étude de 1970 intitulée "Study of Critical Environmental Problems" (SCEP) a été suivie en 1971 par l'étude "Study of Man's Impact on Climate" (SMIC). Cette dernière a présenté une évaluation approfondie de l'état des connaissances actuelles concernant les répercussions possibles des activités humaines sur le climat régional et mondial. Depuis, on a procédé à des évaluations individuelles, nationales et internationales de plus en plus nombreuses. En 1979, la Conférence climatique mondiale tenue à Genève a mené à la création du Programme climatique mondial (PCM) parrainé par l'Organisation météorologique mondiale (OMM), le Programme des Nations Unies pour l'environnement (PNUE) et le Conseil international des unions scientifiques (CIUS). De nombreux projets de recherche sont effectués dans le cadre du PCM et l'on accorde une importance capitale aux répercussions présentes et futures que peuvent avoir les activités humaines sur le climat.

Cependant, il est de plus en plus évident que si nous devons réagir de façon appropriée aux changements qui se produisent, les aspects scientifiques ne peuvent pas être considérés isolément - il faut réunir les compétences des chercheurs, des techniciens et des décideurs. La Commission mondiale sur l'environnement et le développement (1987) des Nations Unies a montré l'importance de ces interventions collectives et on espère que la Conférence mondiale sur l'atmosphère en évolution, à Toronto en 1988, favorisera davantage ces rapprochements et servira de toile de fond aux mesures internationales concertées visant à résoudre les nombreux et complexes problèmes environnementaux et sociaux. La mobilisation des forces s'impose; nous savons que les mesures appropriées existent et qu'il faut leur donner la priorité.

2. CAUSES D'INQUIÉTUDE

Nous avons bien sûr de nombreuses raisons de nous préoccuper des changements atmosphériques. Premièrement, nous avons l'impression de perdre le contrôle de la situation. La libération des GES dans l'atmosphère, par exemple, augmente très rapidement dans certains cas. La figure 1 montre les émissions estimées de dioxyde de carbone (CO_2) et de chlorofluorocarbones (CFC) au cours des dernières décennies. Ces manifestations et de nombreux autres changements environnementaux se sont accélérés au cours des trente dernières années. De plus, bon nombre de ces changements atmosphériques climatiques ou environnementaux sont irréversibles. Même si nous arrêtons aujourd'hui toute émission de CO_2 dans l'atmosphère, il faudrait des centaines d'années pour que les concentrations de GES retrouvent leur niveau préindustriel et, dans l'intervalle, des changements climatiques continueront de se produire. De même, le retour aux conditions climatiques et écologiques qui existaient avant le déboisement est pratiquement impossible. L'une des principales raisons de cette irréversibilité est la complexité du système climatique. Bien que les changements anthropiques ne perturbent initialement qu'un élément du système climatique, comme l'atmosphère, le biote ou les océans, les actions réciproques de ces différents éléments sont nombreuses.

L'ampleur des pertes possibles est aussi une cause de préoccupations. Par exemple, on a établi que le réchauffement mondial causé par les GES accélérera la montée actuelle des océans qui atteindra probablement 30 cm et peut-être 1,5 m d'ici le milieu du siècle prochain. Une telle hausse du niveau des océans accentuerait l'érosion des plages et des bordures littorales, les changements de l'utilisation des sols dans les régions côtières, la disparition des marécages, les changements dans la fréquence et la gravité des inondations et les dégats causés aux structures côtières, aux installations portuaires et aux systèmes de gestion des eaux. Il est certain que ces changements coûteraient très cher à la socité. Par exemple, on prévoit que le coût d'entretien des plages sur la côte Est des États-Unis sera de l'ordre de 10 à 100 milliards de dollars US (Jaeger, 1988). De même, d'autres changements tels que la diminution de l'ozone stratosphérique ou la pollution transfrontière pourraient entrainer des pertes considérables.

Il existe fondamentalement deux stratégies à adopter en réaction au changement climatique : la limitation et l'adaptation. Bien qu'au début des années 1980, on ait été généralement d'avis que les stratégies d'adaptation seraient politiquement plus réalisables que celles de lutte contre les causes du changement climatique, on a, au cours des dernières années, accordé plus d'attention aux stratégies de limitation. Les coûts des stratégies de limitation seraient les coûts des investissements qui pourraient entrainer des bénéfices nets, par exemple, les améliorations de l'efficacité dans le domaine énergétique pourraient devenir rentables en quelques années. Par contre, les coûts de l'adaptation correspondraient dans de nombreux cas à la réparation des dégâts. Des questions d'équité, d'indemnité, de répartition du coût des techniques de correction, etc. se posent aussi.

Puisque la mise en oeuvre efficace de mesures prend généralement beaucoup de temps, on craint de plus en plus qu'au moment où ces mesures auront été acceptées et appliquées à l'échelle internationale, l'atmosphère aura déjà subi les changements prévus, ce qui entrainera des répercussions graves sur l'environnement et la société. En outre, l'atmosphère est un "patrimoine mondial" - une ressource partagée dont le mauvais usage se fera sentir loin dans le temps et dans l'espace.

3. CHANGEMENTS DANS L'ATMOSPHÈRE

3.1 L'effet de serre

Certains gaz à l'état de trace dont les plus importants sont la vapeur d'eau, l'ozone (O_3) et le dioxyde de carbone (CO_2), l'oxyde nitreux (N_2O), le méthane (CH_4) et les chlorofluorocarbones (CFC) sont désignés par le terme collectif de gaz à effet de serre (GES), étant donné qu'ils produisent un "effet de serre" en retenant l'énergie thermique dans l'atmosphère de la terre. Lorsque la concentration dans l'atmosphère d'un GES augmente, il en résulte un réchauffement de la surface de la terre et de la couche inférieure de l'atmosphère.

Au cours du congrès tenu en 1985 à Villach, en Autriche, (Programme climatologique mondial, 1986) et organisé par le PNUE, l'OMM et le CIUS, les savants ont déclaré unanimement : "L'accroissement de la concentration de GES ... au cours de la première partie du siècle prochain pourrait entrainer une hausse de la température moyenne mondiale d'une importance encore jamais enregistrée dans l'histoire de l'humanité".

3.1.1 Changements observés et prévus de la concentration des GES

La concentration de CO_2 dans l'atmosphère est passé de 275± 10 ppmv en 1850 (Bolin, 1986) à 343 ± 1 ppmv en 1984, soit une augmentation de 25 % environ (figure 1a). L'utilisation des combustibles fossiles, le déboisement et les changements dans l'utilisation des terres sont les principales causes de l'augmentation de la concentration de CO_2. La concentration de CH_4 dans l'atmosphère a augmenté à un taux d'environ 1 % par an au cours des dix dernières années. Cette augmentation est très probablement liée aux activités humaines, principalement l'agriculture (Bolle et coll., 1986). La concentration de N_2O a augmenté de 0,2 % par an environ au cours des années 1970 et l'agriculture, l'utilisation des combustibles fossiles et la combustion de la biomasse en sont probablement la cause. Au début des années 1980 on a établi à environ 6 % par an l'augmentation de la concentration des deux types de CFC (CFC-11 et CFC-12) qui s'attaquent à l'ozone stratosphérique (Bolle et coll., 1986) (figure 1b). Les CFC sont des gaz de fabrication industrielle utilisés à diverses fins, par exemple, comme solvants, fluides frigorifères et agents propulseurs. Les processus photochimiques contribuent à l'augmentation de la concentration d'ozone troposphérique (niveau du sol) qui se situe entre 1 et 2 % par an.

3.1.2 Répercussions possibles sur le climat mondial

Les changements climatiques possibles causés par l'augmentation de la concentration des GES ont fait l'objet de nombreuses études au cours des dernières années. Les modèles informatiques montrent que le doublement de la concentration de CO_2 dans l'atmosphère ferait augmenter de 1,5 à 4,5 °C la moyenne mondiale de la température d'équilibre en surface.

La figure 2 représente les scénarios du changement de la moyenne mondiale de la température en surface élaborés par un groupe d'experts au colloque de Villach en 1987 (Jaeger, 1988). Selon ces scénarios, le maintien des tendances actuelles de la libération des GES entrainerait, au cours des cinquante prochaines années, des températures moyennes et des taux de changement de température mondiale considérablement supérieurs à ceux enregistrés au cours des cent dernières années, les dépassant même en moyenne de dix fois leur valeur.

La figure illustre les scénarios du changement de la moyenne mondiale de la température qui pourrait se produire en réaction à la libération continue de GES dans l'atmosphère. La courbe du milieu représente le scénario selon lequel les tendances actuelles de la libération se poursuivent et l'incidence climatique est modérée. Il y a cinq chances sur dix que le tracé réel du changement climatique se trouve au-dessous de la courbe du milieu. La courbe supérieure représente le scénario selon lequel la libération des GES s'accélère et l'incidence climatique est relativement élevée. La courbe inférieure représente le scénario selon lequel la libération des GES est réduite et l'incidence climatique relativement faible. Selon le jugement des spécialistes du groupe de Villach 1987, il y a neuf chances sur dix que le régime réel du changement climatique causé par les GES tombe dans les limites établies par la courbe supérieure et la courbe inférieure. On a limité la variation de température à 5 °C en ordonnée parce que les modèles climatiques actuels ne peuvent simuler de façon fiable la réaction à un réchauffement mondial supérieur à environ 5 °C. Ces observations sont fondées sur les résultats du colloque de Villach (Jaeger, 1988) et sur les trois scénarios (accumulation forte et accumulation lente et cas de référence) proposés par Mintzer (1987).

3.1.3 Changements climatiques régionaux possibles

Bien que l'on reconnaisse généralement l'ampleur des répercussions d'une concentration doublée de CO_2 sur la moyenne mondiale de la température d'équilibre en surface, les effets sur les répartitions régionales des éléments climatiques, comme la température et les précipitations, sont plus difficiles à évaluer à l'aide des modèles actuels. D'après les résultats fournis par les modèles, on peut faire quelques observations sur les changements climatiques régionaux (tableau 1) : l'accroissement de température le plus marqué dans un monde en réchauffement se produirait vraisemblablement en hiver, sous les hautes latitudes de l'hémisphère Nord. Dans ces régions, l'ampleur et la vitesse des changements pourraient être de deux fois à deux fois et demie supérieurs aux moyennes annuelles mondiales. Par contre, l'ampleur et la vitesse des changements de la température sous les basses latitudes seraient vraisemblablement inférieurs aux moyennes mondiales.

Les prévisions des variations des précipitations régionales sont très incertaines. Les études laissent entrevoir que ces changements pourraient comprendre un accroissement des chutes de neige en hiver sous les hautes latitudes, un accroissement des chutes de pluie sous les basses latitudes pluvieuses à l'heure actuelle et peut-être une diminution des précipitations en été sous les latitudes moyennes.

3.1.4 Changements de température observés au cours des cent dernières années

La figure 3 présente la moyenne mondiale des variations de la température en surface observées depuis 1861 (Jones et coll., 1986). Entre 1880 et 1985, la température a augmenté de 0,5 °C environ. Selon Wigley et coll., (1986), le réchauffement passager jusqu'à ce jour attribuable aux changements de la concentration des GES devrait se situer entre 0,3 et 1,1 °C, compte tenu de toutes les imprécisions des modèles. Cependant, bien que l'augmentation de température observée corresponde à l'augmentation de température prévue, on ne peut, avec une rigueur scientifique, attribuer l'augmentation observée uniquement aux changements dans la libération des GES. Une étude comparative récente (Wigley et Raper, 1987) semble indiquer que le changement de température observé est faible par rapport au changement prévu par les modèles climatiques.

Tableau 1. Scénarios régionaux du changement climatique

Région[1]	Changement de la température[2] (multiple de la moyenne mondiale) Été	Hiver	Changement des précipitations[3]
Hautes latitudes (60-90 degrés)	de 0,5 à 0,7x	de 2 à 2,4x	Augmentation en hiver
Latitudes moyennes (30-60 degrés)	de 0,8 à 1x	de 1,2 à 1,4x	Réduction possible en été
Basses latitudes (0-30 degrés)	de 0,9 à 0,7x	de 0,9 à 0,7x	Augmentation là où la pluviosité actuelle est élevée

[1] Les chiffres donnés dans ce tableau proviennent des résultats de la modélisation de l'hémisphère Nord. Sous les basses latitudes, les tendances seront vraisemblablement analogues dans l'hémisphère Sud. Sous les latitudes moyennes, on constatera peut-être des changements quelque peu différents dans l'hémisphère Sud en raison de l'étendue relativement petite des terres émergées. Sous les hautes latitudes de l'hémisphère Sud, l'incidence pourrait être très différente de ce que l'on prévoit pour l'Arctique en raison de la haute altitude de l'Antarctique et de la présence de terres sous les glaces.

[2] Les changements de température régionaux indiqués ici sont des multiples des moyennes annuelles mondiales des changements de température. Par conséquent si on suppose par exemple que la moyenne annuelle du changement mondial de température pour l'année 2040 atteindrait 2 °C, le tableau 1 indique que la température en hiver sous les hautes latitudes pourrait s'élever cette même année de 4 à 4,6 °C. De même, un taux de changement de la température moyenne mondiale de 0,3 °C par décennie correspondrait à un taux de changement sous les hautes latitudes des températures en hiver de 0,6 à 0,7 °C par décennie.

Les chiffres s'appliquant aux températures particulières que donne le tableau ci-dessus proviennent de deux modèles de la circulation générale de l'atmosphère terrestre, modèles que l'on a choisis pour représenter l'éventail de résultats que fournissent les études scientifiques actuelles les plus poussées. En particulier, la première valeur de chaque fourchette des multiples de température est tirée des modèles de J. Hansen et de ses collègues qui travaillent à la NASA. Quant à la seconde valeur, elle provient des travaux de G. Manabe et de ses collègues des laboratoires de la National Oceanographic and Atmospheric Administration des États-Unis, à Princeton.

[3] Les précipitations constituent la propriété climatique la plus difficile à modéliser ou à prévoir. Les évaluations qualitatives que l'on donne ici reposent néanmoins sur un certain nombre d'études. On s'est servi en particulier de l'étude récente de Mitchell et ses collègues du Bureau météorologique britannique. Il faut remarquer que l'accroissement de la vitesse moyenne de l'évaporation mondiale suivrait exactement l'accroissement de l'intensité des précipitations mondiales.

3.2 Diminution de l'ozone stratosphérique

Au cours des dernières années, on a observé attentivement la fluctuation de la concentration de l'ozone à divers niveaux dans l'atmosphère, surtout parce que l'on sait que l'ozone empêche la plupart des ondes dangereuses du rayonnement ultraviolet d'atteindre la surface de la terre.

Bien qu'il ne soit qu'un composant secondaire de l'atmosphère terrestre, l'ozone est très important pour la société puisque c'est le seul gaz de l'atmosphère qui empêche les rayons ultraviolets dangereux du soleil d'atteindre la surface de la terre. Une diminution de la quantité totale d'ozone dans la colonne atmosphérique aurait des répercussions négatives sur la santé de l'être humain (cancer de la peau, troubles de vision, arrêt des fonctions du système immunitaire) et sur la productivité des écosystèmes terrestres et aquatiques. En outre, des changements de la distribution verticale de l'ozone pourraient modifier la structure des températures atmosphériques et entrainer ainsi des changements de la circulation atmosphérique et donc des changements climatiques.

3.2.1 Destruction de l'ozone dans la stratosphère

Le méthane, l'oxyde nitreux, les CFC et les haloalcanes sont les précurseurs des oxydes qui peuvent catalyser la destruction de l'ozone dans la stratosphère par un ensemble de réactions chimiques. Le monoxyde de carbone et le gaz carbonique peuvent influer directement sur l'ozone. Le CO_2 peut également avoir un effet indirect puisqu'il règle en grande partie la structure des températures de la stratosphère, ce qui a une influence importante sur la vitesse à laquelle l'hydrogène, l'azote et les oxydes de chlore et de brome détruisent l'ozone. L'augmentation de ces gaz à l'état de trace qui peuvent faire fluctuer la concentration d'ozone dans l'atmosphère est attribuable à l'utilisation des combustibles fossiles et aux méthodes d'utilisation des terres. Les CFC et les haloalcanes proviennent des activités industrielles. Les CFC sont utilisés en tant que propulseurs, fluides frigorifères et agents moussants tandis que les haloalcanes sont utilisés en tant qu'extincteurs d'incendie. L'un des principaux aspects de la question de l'ozone est que la vie atmosphérique de l'oxyde nitreux et des CFC est très longue et, par conséquent, un rétablissement complet du système prendrait plusieurs dizaines ou centaines d'années à partir du moment où ces gaz ne sont plus émis. Les CFC mettent plusieurs années pour voyager de la surface de la terre aux altitudes auxquelles ils peuvent nuire à la couche d'ozone. Ainsi, les effets se font sentir à retardement par rapport au moment de l'émission.

3.2.2 Changements prévus de la quantité d'ozone dans la stratosphère

Tout comme pour les incidences des GES, on utilise des modèles numériques pour prévoir les changements de la quantité d'ozone dans la colonne atmosphérique, de la distribution verticale de l'ozone et des températures. Selon les résultats des calculs des modèles, si les concentrations atmosphériques de CO_2, de CH_4 et de N_2O continuent d'augmenter à leur taux actuel au cours des cent prochaines années et si les émissions de CFC continuent de croître à un taux de 3 % par an, il y aura une réduction de la quantité d'ozone suspendue dans la colonne atmosphérique d'environ 60 % en moyenne dans le monde d'ici l'an 2040. Par contre, les calculs indiquent qu'un vrai gel mondial des émissions de tous les produits chimiques contenant du brome et du chlore aux quantités prévues pour 1990 ou au-dessous de celles-ci entrainerait un épuisement global de l'ozone dans la colonne atmosphérique de moins de 1 % d'ici l'an 2015 et encore moins par la suite.

Cependant, il est à noter que même si les changements prévus de l'ozone dans la colonne atmosphérique ne sont que faibles, comme dans le cas d'un vrai gel mondial, de façon à ce que la quantité de rayons ultraviolets qui atteignent la surface de la terre ne change que très peu, on prévoit des changements considérables de la distribution verticale de l'ozone et des répercussions éventuelles sur le climat.

3.2.3 Tendances de l'ozone dans le monde

Les mesures effectuées au cours des dernières décennies indiquent que la concentration d'ozone a augmenté dans la basse atmosphère en raison d'une augmentation des émissions d'oxyde d'hydrocarbure et d'oxyde d'azote et qu'elle a diminué plus haut dans la stratosphère. Selon des observations effectuées depuis la surface, la concentration d'ozone dans la colonne a augmenté d'environ 3 % de 1960 au début des années 1970, est restée constante tout au long des années 1970 et a depuis diminué d'environ 4 %. Selon d'autres données, la teneur mondiale d'ozone dans la colonne a diminué de façon considérable depuis la fin des années 1970.

3.2.4 Changement de l'ozone dans l'Antarctique

Selon des données récentes provenant d'Halley Bay dans l'Antarctique, la teneur totale d'ozone dans la colonne au-dessus de l'Antarctique diminue considérablement (de plus de 50 %), au cours du printemps (fin août-mi-novembre) depuis 1957, et cette diminution s'est produite en grande partie depuis le milieu des années 1970. La diminution de l'ozone s'étend du pôle Sud à environ 45° de latitude S. Nous n'avons pas observé dans l'Arctique des changements d'ozone de la même ampleur. On dispose de certaines preuves qui indiquent un épuisement moins important.

Selon certaines mesures, la composition chimique de la stratosphère inférieure de l'Antarctique diffère beaucoup de ce qu'on prévoyait théoriquement et de ce qu'elle est ailleurs sur la terre. Selon les résultats préliminaires des mesures de 1987, ce sont des mécanismes chimiques et météorologiques qui ont perturbé la concentration d'ozone en 1987. Au cours de la Conférence de 1988 qui se tiendra à Toronto, Watson formulera la conclusion suivante : tant que nous ne comprendrons pas davantage les procédés chimiques et météorologiques, nous ne pourrons pas évaluer les conséquences mondiales des phénomènes de l'Antarctique. Dans le contexte des incidences de "l'atmosphère en évolution", il est cependant important de noter que "les phénomènes de l'ozone dans l'Antarctique sont une preuve éclatante que les incidences d'une pertubation sur l'environnement ne sont pas toujours lents, linéaires ou prévisibles" (Watson, 1988).

3.3 Pollution transfrontière

Depuis le début des années 1970, la pollution atmosphérique transfrontière est une question étudiée tant sur le plan national que sur le plan international. Le problème de la pollution de l'atmosphère fut analysé pour la première fois au niveau politique international lors de la Conférence des Nations Unies sur l'environnement humain tenue à Stockholm en 1972. Ce qui semblait être un problème limité à cette époque est considéré maintenant comme un grave problème environnemental auquel se heurtent l'Europe et certaines parties de l'Amérique du Nord. On s'est d'abord penché sur le transport des composés dérivés du soufre, puis on a inclu dans les évaluations les oxydes d'azote et les hydrocarbures.

3.3.1 Transport atmosphérique du soufre

Le soufre se dégage des cheminées sous forme de gaz, l'anhydride sulfureux (SO_2). Les quantités de soufre qui se dégagent au moment de l'utilisation des combustibles fossiles dépendent de la teneur en soufre du combustible. Puisque la durée de séjour typique du SO_2 dans l'atmosphère est de l'ordre de un à deux jours, le SO_2 émis se dépose souvent à une grande distance de la source. En Europe, par exemple, cela signifie que le SO_2 émis dans un pays se dépose souvent dans un autre pays. Les procédés de déposition par voies sèche et humide, par exemple les précipitations et les retombées sèches de particules, déterminent la durée de séjour du soufre dans l'atmosphère. Leur contribution relative aux dépôts varie : les dépôts secs sont plus importants s'ils se produisent près des hautes densités de soufre émis et les dépôts humides, dans des régions plus éloignées. Puisque l'anhydride sulfureux se convertit en acide sulfurique dans l'atmosphère et que l'acide se condense pour former des gouttelettes, l'eau de pluie s'acidifie dans les régions touchées. L'eau de pluie non perturbée a un pH de 5 à 6. En Europe et dans certaines parties de l'Amérique du Nord et de la Chine, le pH de la pluie se situe maintenant entre 4 et 4,5 et parfois il descend jusqu'à 3 (Persson, 1988).

3.3.2 Autres polluants

Outre le soufre, d'autres polluants entrent dans l'atmosphère en raison des activités de l'être humain et sont transportés sur de grandes distances avant de se déposer. On se préoccupe davantage des oxydes d'azote et des hydrocarbures.

Les gaz de carneau qui se dégagent de la combustion contiennent principalement de l'oxyde nitrique (NO), qui réagit avec l'oxygène pour produire du dioxyde d'azote (NO_2). Le produit final stable de cette réaction est l'acide nitrique qui peut exister sous forme gazeuse dans l'atmosphère (Persson, 1988). Par opposition au soufre, qui est en grande partie émis des grandes cheminées, une proportion élevée des oxydes d'azote et des hydrocarbures est émise au niveau du sol, provenant de la circulation routière. Puisque les oxydes d'azote doivent être convertis en acide nitrique avant de ne pouvoir réellement se déposer, ils se déposent généralement à une grande distance de leur source. Les oxydes d'azote et les hydrocarbures sont essentiels à la formation d'oxydants photochimiques, dont le plus important est l'ozone (Persson, 1988).

L'ammoniac (NH_3) est émis dans des régions où l'élevage du bétail est intense. Il se dépose généralement plus près de la source que le soufre et les oxydes d'azote. L'ammoniac neutralise les précipitations acides, mais dans le sol, les ions ammonium sont convertis en ions nitrate, ce qui provoque une émission d'ions hydrogène qui engendre l'acidification des sols.

L'ozone, formé par des réactions photochimiques dans l'atmosphère, est également transporté au-delà des frontières. Au cours d'épisodes précis, les concentrations d'ozone de plus de 100 ppb peuvent se trouver au même moment dans tout le nord de l'Europe. La concentration de fond se situe généralement entre 15 et 40 ppb. Même les augmentations légères de la concentration de l'ozone à la surface de la terre influent négativement sur les plantes et les êtres humains.

Les hydrocarbures chlorés sont d'autres substances toxiques transportées au-delà des frontières. Les émissions de dioxines sont attribuables à la combustion, par exemple dans les incinérateurs et les véhicules motorisés. En outre, on trouve des dépôts de certains métaux comme le mercure et le cadmium à des milliers de kilomètres de la source d'émission. Le transport des substances radioactives après l'accident de Tchernobyl a prouvé de façon spectaculaire l'existence du phénomène du transport à grande distance.

Voici encore un exemple d'une perturbation atmosphérique attribuable au transport à grande distance des polluants, soit la manifestion de la brume arctique. La brume arctique contient de grandes quantités de composants anthropiques comme la suie et l'acide sulfurique. Les concentrations de la brume arctique sont à leur plus fort entre décembre et avril car les courants atmosphériques du sud au nord sont plus forts et plus fréquents au cours de cette période et les polluants se déposent moins facilement en raison du manque de précipitations et de la stabilité de l'atmosphère arctique.

3.4 Facteurs communs qui contribuent aux changements atmosphériques

Les principales questions qui se rapportent à l'évolution de l'atmosphère sont formement liées. Par exemple, il existe deux grands liens entre le réchauffement dû aux GES et la diminution de l'ozone dans la stratosphere : premièrement, l'ozone de la troposphère réagit comme un GES; deuxièmement, les gaz qui sont censés modifier les concentrations d'ozone dans la stratosphère sont des GES (monoxyde de carbone, méthane, oxyde nitreux et chlorofluorocarbones). Les questions qui portent sur le réchauffement dû aux GES et sur la pollution transfrontière sont liées car ce sont des gaz de même source (utilisation des combustibles fossiles), le SO_2 et le CO_2 surtout, qui contribuent aux problèmes. En utilisant moins d'énergie, on réduit ainsi tous les types d'émission. En outre, l'utilisation de l'énergie est liée aux changements et aux investissements qui se rapportent à l'utilisation des terres, par exemple le déboisement dans les régions tropicales humides. Les émissions de gaz soulèvent des questions complexes et de grandes incertitudes. Elles contribuent toutes aux problèmes mondiaux à long terme et leurs effets seront difficiles à renverser. D'après les liens établis, on peut conclure qu'il faudrait analyser l'ensemble de ces questions lorsqu'on fixera des priorités afin d'élaborer des lignes de conduite et de prendre des mesures.

Les paragraphes précédents montrent les taux croissants des émissions des GES dans l'atmosphère et d'autres polluants et matières toxiques. Ces émissions et le déboisement peuvent gravement influencer le rôle de l'atmosphère comme "système de survie". Il en est ainsi surtout en raison des changements climatiques à l'échelle mondiale et régionale et du transport atmosphérique des matières nocives. Cette réduction de la capacité de tolérance de la terre se produit simultanément avec une augmentation rapide de la population mondiale et des augmentations proportionnelles de la demande en aliments, en eau, en énergie et en terres. Ces changements pourraient augmenter davantage les émissions de gaz et de particules dans l'atmosphère et provoquer des changements à grande échelle quant à l'utilisation des terres. Il est temps d'appliquer des mesures de lutte rationnelles en ce qui concerne les changements atmosphériques. Notre inaction est trop onéreuse.

3.5 Modifications dues à l'utilisation des terres et climat

En utilisant les terres, les êtres humains ont modifié de grandes régions de la surface de la planète. Les changements des caractéristiques de la surface peuvent influencer le climat de trois façons fondamentales. Premièrement, le pouvoir de réflexion de la surface peut changer et influencer la quantité d'énergie solaire absorbée à la surface. Deuxièmement, les inégalités de la surface peuvent changer et ainsi influer sur les transferts d'énergie, sur l'humidité et sur les mouvements dans l'atmosphère. Troisièmement, l'humidité de la surface peut changer et influer sur l'évaporation à la surface. Les activités humaines qui mènent à ces changements comprennent le déboisement à des fins agricoles, l'utilisation de l'énergie, l'aménagement urbain, l'irrigation et la création de lacs artificiels.

3.5.1 Déboisement

Le déboisement des forêts à des fins agricoles se fait depuis de nombreux siècles. Dans les tropiques, par exemple, le débroussaillement et les brûlis ont longtemps été utilisés pour déboiser les terres. Selon les estimations, environ 40 % des forêts équatoriales de l'Afrique ont été convertis en savanes au cours des quelques derniers milliers d'années et la moitié des forêts qui demeurent ont changé (Sagan et coll., 1979). Au cours des dernières années, les effets des cultures itinérantes ont été dépassés par le déboisement en gros des forêts, principalement à des fins commerciales. La perte totale en forêts tropicales est estimée à entre 9 et 24,5 millions d'hectares par an (Henderson-Sellers, 1987). Dans la région de la Méditerranée et en Chine, les premières civilisations ont détruit les forêts tempérées tandis qu'en Amérique du Nord et en Europe, on les a détruites principalement au cours des mille dernières années. Aujourd'hui, on mène certaines activités de reboisement.

3.5.2 Surpâturage et désertification

Selon Bryson et Baerreis (1967), le surpâturage était la cause de l'expansion du désert du Rājasthān en Inde. Ces auteurs se fondaient sur le fait que le surpâturage mène à un manque de végétation et ainsi accroît la quantité de poussière dans l'atmosphère. Ils ont postulé que cette poussière modifie le taux de réchauffement de l'atmosphère et diminue ainsi les précipitations. Selon l'étude de Hare (1983), les augmentations de l'albédo attribuables au surpâturage ou à de mauvaises méthodes agricoles en régions arides peuvent réduire la quantité de précipitations. Sagan et coll. (1979) ont conclu également que les influences de l'être humain ont joué un rôle principal dans la désertification et ils ont souligné que même si la plupart des dommages causés aux terres arides sont attribuables au surpâturage, la salinisation entraînée par les ouvrages d'irrigation constitue aussi un problème. Le surpâturage est également considéré comme l'un des facteurs qui ont provoqué la sécheresse persistante dans le Sahel.

4. CONSÉQUENCES ENVIRONNEMENTALES ET SOCIO-ÉCONOMIQUES

4.1 Effets du changement climatique attribuable aux GES

On se préoccupe beaucoup depuis quelques années des effets possibles des changements climatiques sur la société et les écosystèmes. Les effets de ces changements sur l'agriculture et les forêts ont fait l'objet d'une attention particulière à la Conférence de Villach, tenue en 1985. D'autres études (CDAC, 1983) ont également porté sur le même sujet. Les participants au colloque de Villach en 1987 se sont pour leur part intéressés aux effets des changements climatiques sur de grandes zones latitudinales ainsi que sur les régions côtières.

S'intéressant aux effets des changements climatiques sur les <u>régions côtières</u>, les participants ont souligné que la moitié de la population du globe habite le long des côtes. Le réchauffement mondial causé par une augmentation des concentrations de GES accélérera la montée actuelle des océans qui atteindra jusqu'à 1,5 m d'ici le milieu du siècle prochain et ce, en raison de l'expansion thermique des eaux océaniques et de la fonte des glaces terrestres. Cette montée des océans provoquera notamment l'érosion des plages et des bordures littorales, des changements dans l'utilisation des sols, la disparition de marécages, des changements dans la fréquence et la gravité des inondations, des dégâts touchant les structures côtières, ainsi que des dégâts touchant les systèmes de gestion des eaux.

Dans les régions des latitudes moyennes, soit celles qui sont situées entre 30 et 60 degrés de latitude, le réchauffement attribuable aux GES sera légèrement supérieur au réchauffement moyen du globe. Les participants réunis à Villach en 1987 ont étudié les effets du changement climatique sur l'agriculture, les ressources en eau, les sols et diverses activités humaines et ils en sont arrivés à la conclusion que les ressources exploitées étaient moins menacées que les autres en raison des technologies existantes. Les répercussions les plus importantes devraient toucher les écosystèmes relativement peu exploités qui seront exposés à un taux de changement climatique pour lequel ils sont mal préparés. On pourrait assister à la dégénérescence des forêts, et les réserves biotiques de même que les milieux naturels seraient menacés. Deux aspects des changements climatiques prévus sont particulièrement importants :

- les changements climatiques à venir seront probablement beaucoup plus rapides que ceux qui ont eu lieu par le passé;
- en l'absence de mesures visant à les contrecarrer, les changements climatiques devraient, selon les prévisions, persister indéfiniment.

Si les températures augmentent aussi rapidement qu'on le prévoit dans le scénario du changement maximal (figure 2), la dégénérescence des forêts pourrait survenir entre l'an 2000 et l'an 2050. Par contre, si la hausse des températures est conforme au scénario du changement minimal (figure 3), la dégénérescence des forêts dans les régions des latitudes moyennes ne se produira pas avant l'an 2100.

En ce qui a trait à l'agriculture dans les régions des latitudes moyennes, il est certain que le réchauffement dû aux GES entrainera une redistribution de la productivité au sein des régions. Dans tous les scénarios sauf celui du réchauffement le plus rapide (scénario supérieur, figure 2), l'adaptation fondée sur la recherche en agriculture devrait permettre le maintien des ressources vivrières de la planète. On peut néanmoins s'attendre à certaines perturbations à l'échelle locale. Si le réchauffement correspond au scénario le plus rapide, l'adaptation de l'agriculture pourrait marquer un retard par rapport aux effets du changement climatique, ce qui engendrerait des réductions irrégulières de la disponibilité alimentaire. Le réchauffement climatique seul n'aurait probablement qu'un effet net négligeable sur l'agriculture dans la ceinture des latitudes moyennes. En effet, les latitudes les plus basses de la ceinture risquent de connaitre des problèmes de productivité en raison de l'évapotranspiration accrue tandis que les latitudes les plus élevées pourront augmenter leur productivité grâce à la saison de croissance prolongée. L'agriculture est tributaire de la présence de sols fertiles. Ce facteur peut avoir un effet positif ou négatif sur la redistribution des cultures causée par les changements climatiques dus aux GES. Il existe aussi des incertitudes importantes en ce qui concerne les changements concernant les précipitations et l'évapotranspiration. Il est donc impossible de prévoir, pour le moment, si les effets nets du changement seront positifs ou négatifs pour des régions données, si ce n'est que les zones semi-arides des latitudes moyennes où l'on pratique l'irrigation seront probablement désavantagées par le réchauffement.

Dans les <u>régions tropicales semi-arides</u>, la variabilité climatique constitue déjà un problème et les changements climatiques à venir risquent d'aggraver les problèmes critiques que connaissent actuellement ces régions. Les changements climatiques qui pourraient survenir d'ici au milieu du siècle prochain en raison des concentrations accrues de GES comprennent notamment des augmentations de la température régionale de l'ordre de 0,3 °C à 5 °C, une tendance à la baisse de l'intensité des précipitations au cours d'une ou de plusieurs saisons et enfin, une diminution de l'humidité du sol. On prévoit que les plus grands effets seront ressentis dans les domaines de la production alimentaire, des ressources en eau, des ressources en bois de chauffage, des établissements humains et des écosystèmes naturels. Les augmentations de la température, les variations du régime des précipitations et les variations de la concentration du CO_2 risquent de modifier le potentiel de la production agricole dans une région qui est déjà très sensible aux effets du climat et souvent marginale du point de vue agricole. Il est déjà difficile à l'heure actuelle de répondre aux besoins alimentaires et cette situation risque de s'aggraver en raison des changements de productivité. La désertification accrue risque également d'entrainer une diminution des ressources.

Au cours des cinquante prochaines années, on prévoit que l'augmentation des concentrations de GES donnera lieu à des hausses de température de l'ordre de 0,3 °C à 5 °C dans les <u>régions tropicales humides</u>. Ce réchauffement sera accompagné de changements dans la répartition des précipitations. Les principaux effets des changements climatiques se traduiront par des niveaux d'eau plus élevés le long des côtes et dans les cours d'eau en raison de la montée des océans ainsi que de plus fréquentes marées de tempêtes tropicales. La variation de la répartition spatiale et temporelle des températures et des précipitations aura également des répercussions sur l'industrie, les établissements humains, l'agriculture, les pâturages, la pêche et les forêts.

Dans les <u>régions des hautes latitudes</u>, la moyenne des températures hivernales pourrait connaitre une augmentation allant de 0,8 °C à beaucoup plus de 5 °C d'ici le milieu du siècle prochain en raison de la présence accrue de GES. Les effets les plus importants des changements climatiques dans ces régions seraient les suivants :

- retrait de la banquise estivale;
- augmentation de la nébulosité et de la précipitation;
- lente disparition du pergélisol;
- changements de la toundra et de la bordure nord de la forêt boréale.

Ces différents changements pourraient avoir d'importantes répercussions dans les régions des hautes latitudes. Par exemple, les changements éventuels de la superficie des glaces en mer ouvrent la possibilité d'une utilisation accrue des passages du nord-est et du nord-ouest. L'aménagement de puits pétroliers en mer pourrait être facilité, mais l'exploitation sur terre serait cependant rendue plus difficile et plus onéreuse dans les régions où il y aurait fonte du pergélisol. Le réchauffement pourrait améliorer les débouchés agricoles, mais seulement dans un petit nombre de régions où les sols sont fertiles. Les modifications rapides des conditions de croissance risquent d'entrainer la dislocation des écosystèmes ainsi qu'un déplacement vers le nord des limites de l'agriculture et de la sylviculture. Les régions du Nord jouent un rôle essentiel dans le cycle mondial du carbone et le réchauffement climatique risque d'entrainer une augmentation substantielle des émissions de méthane provenant de la toundra et, par conséquent, une augmentation des émissions de GES dans l'atmosphère. De plus, si le pergélisol disparait des régions boréales et que les sols s'assèchent, cela provoquera un rejet de CO_2 dans l'atmosphère et amplifiera l'effet de serre.

4.2 Effets de la pollution transfrontière

L'acidification des sols constitue un lien important entre la pollution atmosphérique et la détérioration des milieux terrestres et aquatiques. Ce phénomène, qui désigne la diminution du pouvoir de neutralisation de l'acide que possèdent les sols, survient lorsque le taux des dépôts acides dépasse celui de l'élimination.

L'acidification des sols est largement répandue en Europe depuis 30 à 60 ans. Ces changements du sol, dont certains peuvent être irréversibles, ont des répercussions sur la végétation, les eaux souterraines et les eaux de surface.

L'acidification des lacs est un problème bien connu dans de nombreuses régions montagneuses et boisées d'Europe. Ainsi, en Suède, on a estimé que 15 000 des 85 000 lacs de plus d'un hectare étaient affectés par l'acidification, dont 1 800 très gravement (Alcamo et coll., 1987). Un lac s'acidifie lorsque le sol de son bassin versant n'est pas en mesure de neutraliser les eaux de ruissellement acides. L'acidification des lacs dépend aussi de la quantité de neige fondue, des trajectoires empruntées par le ruissellement, de la chimie des lacs ainsi que de divers autres processus physiques et chimiques. Les changements d'ordre écologique qui sont attribuables à l'acidification des lacs, dont le faible taux de reproduction des poissons, se font de plus en plus sentir en Europe et en Amérique du Nord.

On peut conclure à l'acidification des eaux souterraines en Europe à partir de l'eau des puits et de l'eau de surface qui sont alimentées par des sources souterraines. L'augmentation de la dureté de l'eau est en général la première conséquence des dépôts acides sur les eaux souterraines. Dans certaines régions, l'acidification peut augmenter la mobilité des métaux contenus dans le sol et ceux-ci sont alors entraînés dans les eaux souterraines.

On assiste depuis le début des années 1970 à la dégénérescence des forêts de l'Europe centrale. Outre les conditions locales, les contraintes environnementales suivantes peuvent jouer un rôle important dans cette dégénérescence : l'acidification des sols; la détérioration directe des feuilles des arbres en raison des dépôts acides; les dommages directs causés par les concentrations élevées de SO_2, d'ozone et d'autres polluants; ainsi que la fertilisation excessive au moyen de l'azote. Des facteurs climatiques et des contraintes naturelles peuvent aussi contribuer à la dégénérescence de forêts dans certaines circonstances particulières.

4.3 Autres effets de l'atmosphère en évolution

Comme on l'a déjà signalé, la diminution de la quantité d'ozone dans la colonne totale porterait atteinte à la santé publique (cancer de la peau, troubles de la vue, disparition du mécanisme de réponse immunitaire) ainsi qu'à la productivité des écosystèmes terrestres et aquatiques. Le milieu marin pourrait subir lui aussi des changements considérables en raison de la sensibilité des organismes unicellulaires au rayonnement ultraviolet. Les plantes et les animaux seraient également affectés par un smog plus fréquent, attribuable à des températures plus élevées ainsi qu'à de plus fortes concentrations d'ozone à basse altitude. La dégradation d'un grand nombre de substances synthétiques courantes constitue un autre effet démontré du rayonnement ultraviolet. Un rayonnement plus intense en raison de la diminution de la couche d'ozone dans la stratosphère provoquerait la détérioration de bon nombre de plastiques actuellement utilisés dans l'industrie de la construction ainsi que dans d'autres domaines et il en coûterait très cher, selong les estimations, pour empêcher cette détérioration. De plus, la variation de la répartition verticale de l'ozone dans la stratosphère pourrait modifier la structure de la température atmosphérique, ce qui donnerait lieu à des changements de la circulation de l'atmosphère et, par conséquent, à des changements climatiques.

Les conséquences du déboisement et des changements apportés dans l'utilisation des terres n'ont pas été évaluées de façon aussi approfondie que celles des gaz à effet de serre, de l'appauvrissement en ozone ainsi que de la pollution transfrontière. Il est certain qu'à l'échelle régionale, le déboisement et l'exploitation différente du sol se traduisent par des changements de climat, notamment en ce qui a trait à l'absorption du rayonnement solaire et au volume des précipitations, et ces changements ne peuvent qu'avoir des répercussions sur la productivité agricole.

Les changements climatiques qui surviennent à l'échelle locale, régionale et mondiale auront des effets directs sur les écosystèmes et l'agriculture. Le réchauffement mondial aura également un effet important sur le niveau des mers. Ces différents effets seront accompagnés d'effets secondaires touchant notamment l'économie, le commerce et la sécurité. Même si on a déjà essayé d'évaluer quantitativement ces effets, les incertitudes qui se rattachent à la chaîne globale d'événements sont si grandes qu'il est impossible d'estimer pour le moment avec précision les changements qui pourraient se produire. Il est cependant très important de s'attendre à des effets sur l'économie, le commerce, etc.

5. RÉACTIONS AU CHANGEMENT

5.1 Réactions d'ordre politique au problème des GES

Les stratégies à adopter en réponse au changement climatique se répartissent en deux catégories : les stratégies d'adaptation, d'une part, qui préconisent l'adaptation de l'environnement ou des façons de l'utiliser afin de réduire les conséquences du changement climatique, et les stratégies de limitation, d'autre part, qui luttent contre l'augmentation de la concentration des GES dans l'atmosphère ou qui enrayent cette augmentation et, par conséquent, limitent le changement climatique. La prudence veut que pour faire face au changement climatique, on envisage des stratégies aussi bien de limitation que d'adaptation et que l'on tienne également compte de l'indemnisation qui s'impose (mode de répartition du coût des pertes subies ainsi que des solutions d'ordre technologique). Même si l'on assistait maintenant à un grand effort concerté en faveur de l'application de stratégies de limitation, il faudrait quand même penser à une certaine adaptation en raison des changements climatiques causés par les GES qui ont déjà été libérés dans l'atmosphère.

Les stratégies d'adaptation aussi bien que de limitation entraîneront de grandes dépenses. Ainsi, on a établi que l'adaptation partielle à la montée des océans, qui aura probablement lieu au cours des cinquante prochaines années en raison des GES rejetés dans l'atmosphère jusque-là, nécessitera un investissement mondial de 30 à 300 milliards de dollars US sur une période de planification et de construction variant de 20 à 40 ans pour la protection du littoral.

Il est nécessaire d'examiner sans délai les stratégies d'adaptation au changement climatique et les stratégies visant à limiter ce changement; il faut aussi élaborer des méthodes permettant de comparer le coût des différentes stratégies. De nombreuses mesures à long terme devront être mises en oeuvre si l'on veut réagir adéquatement aux changements climatiques. Les mesures ci-après devraient être prises immédiatement :

1) Le Protocole sur les substances qui détruisent la couche d'ozone devrait être approuvé et mis en vigueur sans délai.

2) Les gouvernements devraient immédiatement commencer à réexaminer leurs politiques en matière d'énergie en vue d'en arriver à une efficacité finale plus élevée, de réduire les multiples formes de pollution atmosphérique et de réduire aussi les émissions de CO_2.

3) Des mesures devraient être prises pour restreindre le déboisement et accroître le reboisement.

4) On devrait déterminer les zones qui risquent de subir les effets de la montée des océans et tenir compte des risques d'inondation dans la planification des nouvelles installations à proximité des océans.

5) La recherche de mesures, la surveillance du changement climatique et la recherche scientifique devraient viser une meilleure compréhension de l'effet de serre ainsi que des options qui existent à cet égard.

6) Les organismes visés devraient se préparer au changement climatique et prendre les dispositions qui s'imposent. Il faudrait également sensibiliser davantage la population mondiale à la nature du problème ainsi qu'à la nécessité de recourir à diverses mesures pour le résoudre.

5.2 Lignes de conduite visant à réduire l'appauvrissement de la stratosphère en ozone

Les préoccupations de plus en plus grandes au sujet des changements de la concentration d'ozone dans l'atmosphère ont donné lieu à une série de mesures visant à protéger la couche d'ozone. En 1977, le PNUE a organisé une réunion d'experts chargés d'établir un plan d'action mondial concernant la couche d'ozone. Un groupe de travail composé d'experts juridiques et techniques a ensuite eu pour tâche de mettre au point une Convention sur la protection de la couche d'ozone, qui a été adoptée à Vienne par 21 pays ainsi que la Communauté économique européenne en mars 1985. Cette convention a été signée depuis par plusieurs autres pays. Les signataires des 21 articles de la convention se sont engagés à protéger la santé publique ainsi que l'environnement des effets nocifs de la réduction de la couche d'ozone. On a aussi conclu à Montréal (Canada) en septembre 1987 un Protocole relatif à des substances qui appauvrissent la couche d'ozone qui entrera en vigueur dès qu'il aura été ratifié.

Plusieurs pays ont décidé de réglementer la production ou l'utilisation des CFC en vue de protéger la couche d'ozone. Les États-Unis ont interdit l'emploi des CFC dans les aérosols en 1978 et le Canada les a imités peu de temps après en interdisant les principales utilisations des CFC. Le Conseil de la CEE a pour sa part décidé en 1980 de défendre aux pays membres d'augmenter la production de CFC ainsi que de réduire de 30 %, par rapport aux niveaux de 1976, l'emploi des CFC dans les aérosols d'ici à la fin de 1981.

5.3 Lignes de conduite visant à réduire le transport à grande distance des polluants atmosphériques

On constate depuis quelques années que le transport à grande distance des polluants atmosphériques, et en particulier les composés soufrés et azotés, contribue à l'acidification des sols, des lacs et des eaux souterraines, de même qu'à la dégénérescence des forêts. Même si les rapports de cause à effet de ce transport ont été démontrés plus clairement que ce n'est le cas pour le réchauffement attribuable à l'effet de serre ainsi que pour l'appauvrissement en ozone, les interventions politiques ont été entravées par des discussions sur l'analyse coûts-avantages, la viabilité économique des stratégies et d'autres détails du même genre. Les préoccupations relatives à la pollution atmosphérique ont cependant donné lieu à la signature d'une Convention sur la pollution atmosphérique transfrontière à grande distance par 34 pays ainsi que les membres de la Communauté européenne en novembre 1979. Cette Convention, qui avait la forme d'un accord-cadre, faisait état des problèmes qui devaient être résolus en matière de pollution atmosphérique ainsi que des responsabilités qui incombaient aux signataires à cet égard; elle est entrée en vigueur en mars 1983, après avoir été ratifiée par le nombre de pays exigé. Un Protocole sur les émissions de soufre a aussi été signé en juillet 1985 et est entré en vigueur en septembre 1987. Les pays signataires de ce Protocole se sont engagés à réduire les émissions de dioxyde de soufre, ou leurs flux transfrontaliers, d'au moins 30 % d'ici à 1993 (par rapport aux niveaux de 1980).

5.4 Aspects communs des lignes de conduite

Les effets des changements atmosphériques, dont la montée des océans, les risques pour la santé et la dégénérescence des forêts, constituent une source majeure de préoccupation pour la population du globe. C'est pour cette raison qu'en ce qui concerne l'appauvrissement en ozone et la pollution transfrontière, un grand nombre de pays ont signé des conventions reconnaissant l'existence des problèmes ainsi que le rôle qu'ils doivent jouer en vue de résoudre ces problèmes. Des protocoles prévoyant des stratégies précises d'intervention viennent maintenant s'ajouter aux conventions déjà conclues.

La couche d'ozone et les gaz à effet de serre sont deux questions d'intérêt mondial dont les répercussions en matière de lignes de conduite sont différentes de celles des autres problèmes environnementaux. De plus, les liens étroits qui unissent ces deux questions laissent supposer qu'elles devraient être considérées de concert dans le cadre d'un grand ensemble de problèmes touchant les gaz à l'état de trace et le climat.

Dans un cas comme dans l'autre, il est clair que si nous décidons d'attendre d'acquérir davantage de certitude avant d'appliquer ces lignes de conduite, nous devons être prêts à courir le risque que la vitesse des changements attribuables aux gaz à effet de serre, à l'appauvrissement en ozone et aux dépôts acides soit plus marquée que si nous intervenons aujourd'hui même.

6. L'ATMOSPHÈRE ET LE LEADERSHIP MONDIAL

6.1 Défi politique

6.6.1 Qu'a-t-on fait jusqu'ici?

Comme on l'a vu dans la section précédente, diverses lignes de conduite ont été mises en oeuvre relativement à l'appauvrissement de la stratosphère en ozone et au transport à grande distance des polluants atmosphériques. Pour ce qui est du réchauffement causé par l'effet de serre et de la dégénérescence des forêts, les membres de la communauté scientifique ont pris de plus en plus conscience de l'étendue du problème au cours des vingt dernières années. Ils ont proposé en 1985, au terme d'un examen approfondi du problème des GES, que les chercheurs et les décideurs commencent à unir leurs efforts en vue de déterminer l'efficacité des mesures de rechange ainsi que des rajustements qui s'imposent. Cette collaboration s'est amorcée à l'occasion du colloque tenu à Bellagio en 1987 et se poursuivra pendant la Conférence mondiale sur l'atmosphère en évolution en 1988.

6.1.2 Que faudrait-il faire?

Si l'on veut relever de manière prudente les défis que présente l'atmosphère en évolution, deux types d'intervention sont nécessaires. Il importe tout d'abord de sensibiliser davantage la population à la nature des problèmes actuels ainsi qu'aux moyens à prendre pour les résoudre. On doit prendre grand soin, en procédant à cette sensibilisation, de présenter les problèmes de façon objective, sans exagération ni sensationnalisme. L'expérience a démontré que des mesures nationales ou internationales n'étaient entreprises qu'après que le degré de sensibilisation à l'égard des problèmes à résoudre ait augmenté sensiblement. Ainsi, dans le cas du transport à grande distance des polluants atmosphériques, c'est le phénomène de la dégénérescence des forêts ("Waldsterben"), notamment en Europe centrale, qui a poussé les gens à intervenir. De la même façon, la découverte du "trou" provoqué par la disparition de l'ozone dans l'Antarctique a amené les médias à s'intéresser au problème de la couche d'ozone dans la stratosphère.

Une fois que les problèmes causés par l'atmosphère en évolution seront mieux connus, on pourra ensuite conclure des ententes, des conventions et des protocoles. Même si des conventions ont déjà été signées en vue de la protection de la couche d'ozone ainsi que de la réduction du transport à grande distance des polluants atmosphériques, il reste encore à évaluer les protocoles du point de vue scientifique de même qu'à resserrer les règlements existants afin de ramener les émissions à un niveau acceptable. De plus, en raison du caractère mondial de l'atmosphère, il faudra peut-être en venir à créer un droit de l'atmosphère qui complèterait d'autres conventions et protocoles déjà conclus, dont le Protocole sur l'ozone signé à Montréal en 1987, et qui pourrait même englober ces conventions et protocoles.

6.1.3 Stratégie d'intervention

Il faudra de toute évidence recourir à de nombreuses mesures à long terme si l'on veut réagir adéquatement au changement climatique. Ces mesures devront être prises à plusieurs niveaux différents. Au niveau individuel, il pourra s'agir par exemple de décider du système de chauffage qu'il convient d'installer dans une maison, du type de semences qui seront plantées dans un champ donné ou encore du nombre d'arbres qui devront être abattus. Si la sensibilisation du public au sujet des questions déjà mentionnées est efficace et que l'aide gouvernementale est adéquate, les décisions individuelles pourraient être compatibles avec les préoccupations globales. Il sera nécessaire de disposer à cette fin d'infrastructures et de systèmes de soutien appropriés à l'échelle communautaire.

Diverses mesures devront également être mises en oeuvre au niveau national. Les gouvernements devront examiner les politiques existantes, notamment en ce qui concerne l'énergie et les forêts, et les modifier de manière à réduire le rythme du changement climatique. De plus, l'aide gouvernementale consentie pour la recherche et le développement dans le domaine des technologies de remplacement devra être considérablement augmentée. Les sociétés, les banques, les groupes d'investissements et les organismes non gouvernementaux devront aussi tenir compte de l'atmosphère dans la planification et le déroulement de leurs activités.

Il faudra également veiller à ce que l'on dispose à l'échelle internationale des instruments et des organisations nécessaires pour concevoir et mettre en application des ententes, des conventions et des protocoles permettant de coordonner les activités entreprises ainsi que de combler les lacunes existantes en matière de connaissances et de renseignements. Les banques, les industries, les organisations régionales et les groupes semblables d'envergure internationale devront également participer à l'élaboration de lignes de conduite en réponse au changement climatique. On prend aujourd'hui un grand nombre de décisions en supposasnt que les conditions qui prévalaient récemment resteront toujours les mêmes. Or, tel n'est pas le cas et c'est pourquoi une plus grande sensibilisation aux problèmes peut aider à envisager ces derniers dans une juste perspective. Une collaboration étroite entre les chercheurs et les décideurs d'organisations internationales (dont des industries) favorisera également la mise au point de lignes de conduite appropriées.

6.2 Défi scientitique

Toutes les questions qui ont été abordées dans le présent rapport sont fort complexes du point de vue scientifique. Il existe des incertitudes pour chacune d'elles, dont certaines qu'il sera difficile ou même impossible de faire disparaitre. Toutefois, peu importe la complexité de ces questions et les incertitudes qui s'y rattachent, les chercheurs peuvent fournir de précieux renseignements aux décideurs, surtout si la nature des incertitudes et aussi des certitudes est définie avec précision. En outre, une plus grande collaboration entre les chercheurs et les décideurs permettra de faire en sorte que la recherche scientifique soit directement orientée vers les questions que les décideurs sont susceptibles de poser.

6.3 Concertation internationale

Il est évident que les activités de l'homme provoquent des changements importants dans l'atmosphère. Ces divers changements auront des répercussions majeures sur l'environnement et la société, surtout si le rythme auquel ils se produisent continue d'augmenter. La majorité de ces changements auront de lourdes conséquences. C'est pour cette raison qu'une concertation s'impose à l'échelle internationale. Les réactions au changement climatique exigeront un solide leadership, une coopérations sincère ainsi qu'un appui constant entre tous les groupes concernés. Il est urgent que l'on passe à l'action et les décideurs ainsi que les chercheurs devront relever avec courage les défis qui se présentent à eux.

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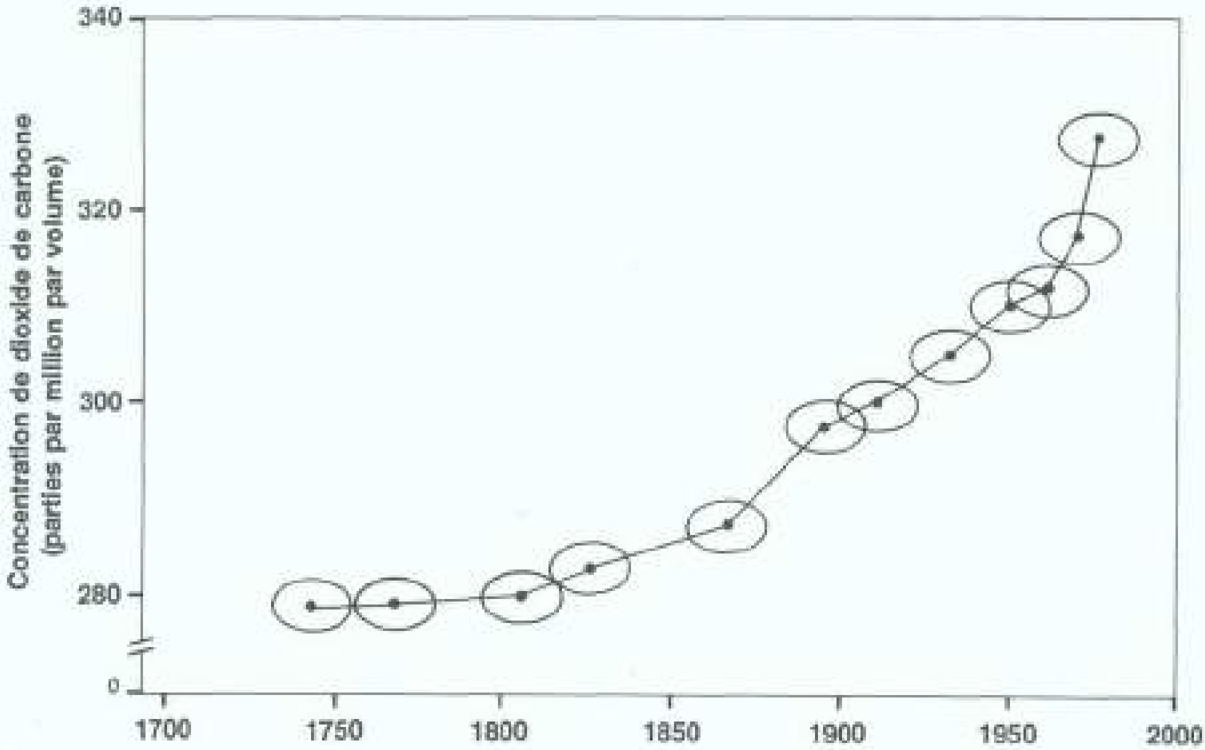

Figure 1a.
Concentrations de CO_2 mesurées dans des glaces de glaciers formées au cours des deux derniers siècles (Neftel et col., 1985)

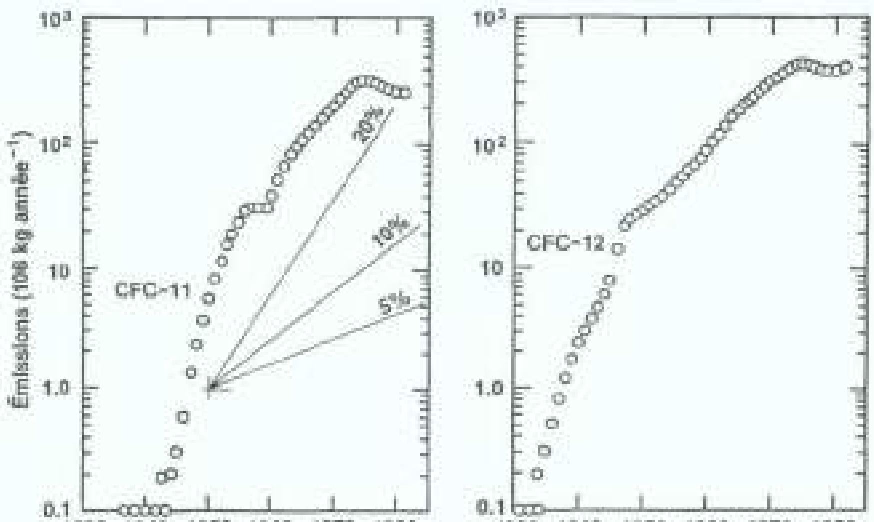

Figure 1b.
Historique des émissions de CFC-11 et CFC-12 (Bolle et col., 1986)

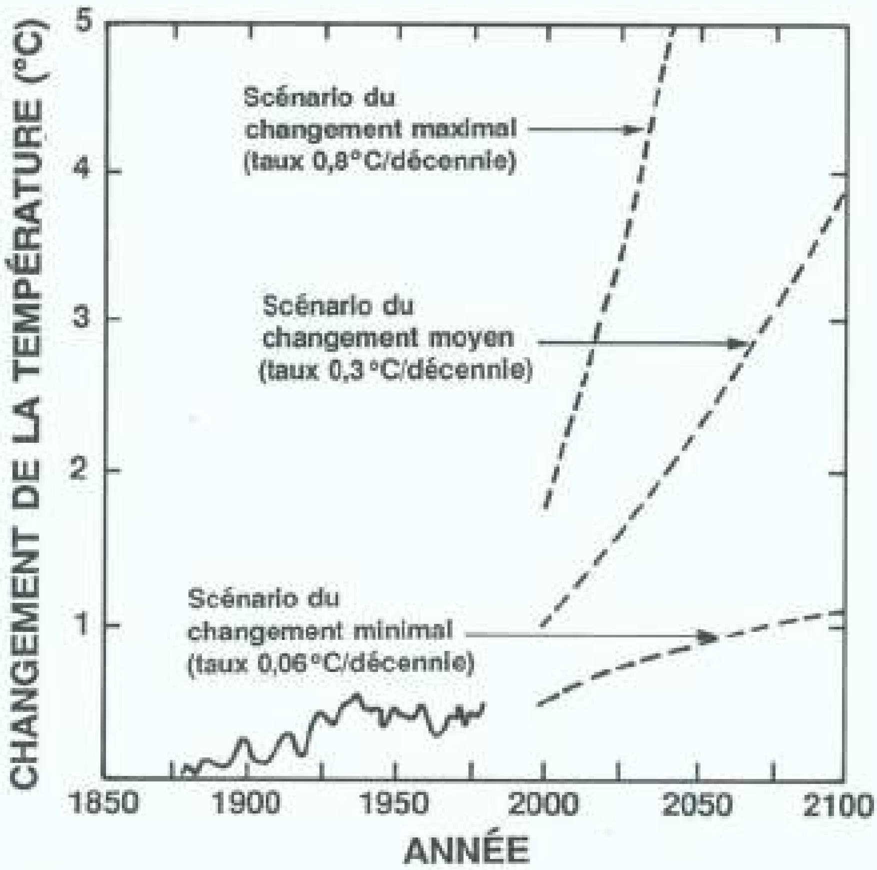

Figure 2.
Scénarios du changement de la température mondiale attribuable à la libération continue de GES.

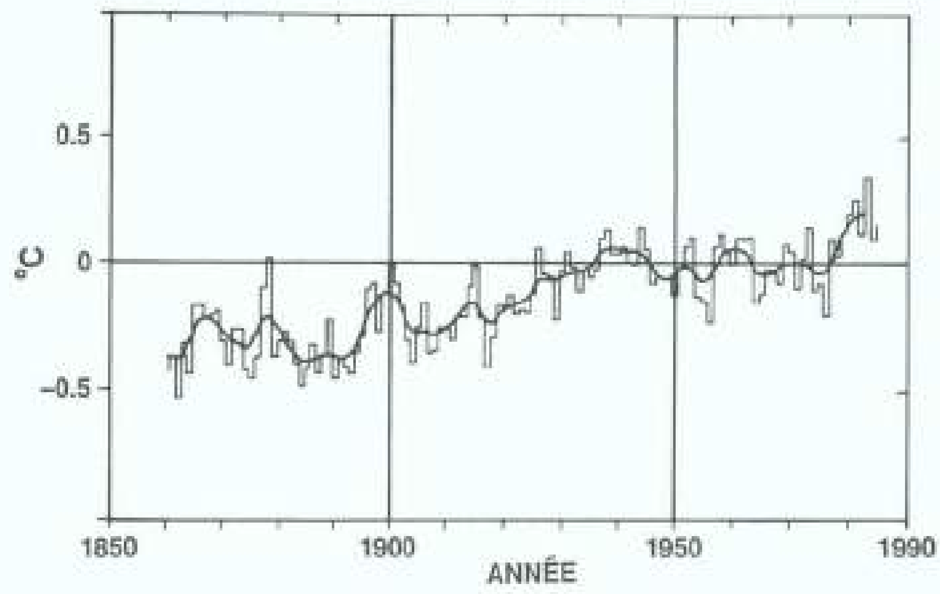

Figure 3.
Changement de la moyenne annuelle de la température mondiale. La courbe lissée montre les valeurs sur 10 ans après filtrage gaussien (Jones et col., 1986).