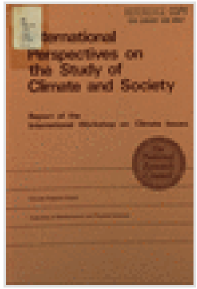

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to the
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NOTICE The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Foreword

The International Workshop on Climate Issues was conducted under the aegis of the Climate Research Board (CRB) of the Assembly of Mathematical and Physical Sciences of the U.S. National Research Council. The members of the CRB believe that this report provides a sound appraisal of many of the issues that will be considered at the World Climate Conference, to be convened by the World Meteorological Organization in February 1979. The publication is intended to serve as a reservoir of ideas and information for the Conference.

The International Workshop was convened to identify and examine a limited set of issues emphasizing the impacts of climate on society. It did not attempt a comprehensive treatment of questions related to climate, nor was its purpose to arrive at a balanced and detailed appraisal of scientific problems.

The report properly emphasizes the uncertainties surrounding both our knowledge of the carbon dioxide cycle as well as our ability to predict the climatic effect of any future increase in atmospheric carbon dioxide. The CRB supports this emphasis and reiterates the need for further work on the basic questions surrounding the problem. Until many of the outstanding scientific questions are resolved, it will not be possible to evaluate with confidence how important the socioeconomic consequences of carbon dioxide production will be.

Similarly, caution should be exercised in the use of scenarios of future climate change. The state of our understanding of the dynamics of climate and the impacts of climate on social and economic conditions is too uncertain at present to provide more than a basis for considering policy options. Our current knowledge does not constitute a proper basis for policy actions.

One of the activities of the Workshop was to examine estimates of economic impacts of climate on society. The members of the Workshop properly emphasized that there is a great need for quantitative estimates of these impacts. The quantitative estimates of economic impacts presented in this report are a first attempt, and the uncertainties surrounding these estimates are recognized in the report. The members of the CRB believe that, at present, such data are principally valuable as a basis for further discussions and revisions. It is rightly pointed out in the report that methods of impact analysis are wanting and considerable research in the area remains to be done.

The report of the Workshop makes a number of recommendations regarding institutional arrangements for the conduct of the World Climate Program. These questions are now being debated among international organizations and within the scientific community. It is not clear at present what the best institutional arrangements might be for the conduct of various parts of the World Climate Program, and the CRB has not yet formulated its own views on this matter, although it has embarked on a study of them.

The members of the CRB also believe that the difficulty of making reliable climatic predictions should be stressed. While developments in mathematical modeling and empirical approaches to long-range forecasting offer hope of improving prediction techniques, it would be unwise to leave the impression that the development of such prediction techniques is at hand.

Finally, the members of the CRB wish to emphasize that the oceans play a crucial but poorly understood role in the climate system. To improve our skill in climatic forecasting, it is therefore urgent that we take steps to improve our knowledge of the ocean's role in the processes of climatic change.

This report to the CRB presents the views of Workshop participants, who are responsible for its content.

Climate Research Board

Contents

Introduction

ROBERT M. WHITE, *Chairman*
International Workshop on Climate Issues

During the past decade, human societies have experienced a sequence of crises triggered by climatic events. Worldwide attention to the broad impact of climate on the economies of diverse nations has led many people to believe that there is a growing vulnerability of society to variations in climate. The recognized impacts have involved a variety of dislocations in social and economic conditions and expectations, ranging from direct physical distress to subtle price fluctuations. In recent years major droughts have occurred not only in the Sahel region of Africa but also in the grain-growing regions of the Soviet Union, throughout Western Europe, and in northeast Brazil. Variations in temperature as well as precipitation have been important. For example, ocean temperatures anomalies have been associated with crucial changes in fish stocks, most prominently in the Peruvian anchovy fishery. In North America, abnormally cold winters in 1976-1977 and 1977-1978 emphasized that vulnerability to climatic variation does not disappear with technological advancement. Indeed, by some measures, this vulnerability may increase. In general, as human activities have extended more and more into climatically marginal areas, ranging from polar environments to tropical arid zones, the sensitivity of man's well-being to climatic factors has received greater recognition, and consciousness of the need to plan with climate in mind has grown.

Moreover, we have come to the realization that industrial and agricultural processes and other human activities may have an impact on the climate. Of greatest concern are the possible consequences of the increasing use of fossil fuels and man-made changes in the biosphere, which result in increases of carbon dioxide in the atmosphere. Through its effect on the earth's radiation balance, such an increase in CO_2 may cause a warming of the global atmosphere. Plausible energy-use scenarios over the next century suggest that the global warming could approach the magnitude associated with past shifts from glacial to interglacial periods. Further, contamination of the stratosphere by chlorofluoromethanes and other chlorine-bearing compounds, which are potentially important "greenhouse" agents along with CO_2, may lead to decreases in stratospheric ozone concentrations and produce effects on climate and health. Such man-made changes in the climate would occur slowly but inexorably over the course of the next several decades and centuries. It must be emphasized that the scientific uncertainties surrounding such projections are great and that the potential effects of any changes will likely be a mixture of both the beneficial and the adverse.

The consequences of natural variations in climate and the projected consequences of possible man-made variations in climate have resulted in increased concern at both the national and international levels. It is the task of science to try to assist those who seek to reduce the vulnerability that causes this concern by bettering the understanding of climate variations, improving the ability to make predictions of natural variations, improving the accuracy and reliability of projections of human interference with the climate, and achieving a better understanding of the impacts of climate variations and change on society.

The task is an international one because the problems of climate are inherently global. Both natural and man-made variations of climate are inescapably worldwide in scope, being directly related to the planetary circulation systems. The study of climatic variations requires global cooperation in the taking of atmospheric, oceanic, and terrestrial observations. Field investigations of the pertinent physical processes require the participation of many nations. Furthermore, mathematical modeling of the climate system is such a complex and expensive research undertaking that it benefits greatly from international collaboration in the design of mathematical models and the comparison of model results.

The possible causes of man-made variations in climate can be accurately studied and effectively regulated, if necessary, only on a global basis. For example, it is necessary to consider all the global processes involving the interaction between the global reservoirs in the biosphere, the atmosphere, and the oceans that determine the global levels of CO_2. Moreover, substances that can affect global physical processes are injected into the atmosphere by many countries. For example, all nations contribute to the release of carbon dioxide to the atmosphere by burning of fossil fuels. Individual national efforts to control the release of such substances as CO_2 or other trace gases are insufficient on a global scale.

Finally, the impacts of climate variations on society, like the variations themselves, are not limited by national boundaries. A drought in a single region can have global effects on food supplies and prices.

Under the leadership of the World Meteorological Organization (WMO) and the International Council of Scientific Unions, plans are emerging for a World Climate Program, the objective of which is to provide the knowledge needed to reduce global vulnerability to climate variations. This World Climate Program is to be preceded by a World Climate Conference, a "Conference of Experts on Climate and Mankind." Its goal is to assess the state of knowledge of climate, the causes of variation, and its impacts. The World Climate Conference is scheduled to be convened in February 1979 in Geneva, Switzerland. The World Climate Program will be debated and its form approved at the WMO Congress in April 1979.

At present, it appears that the World Climate Program will have three components: research, data and applications, and impact studies. The research component will seek an understanding of the causes of fluctuations brought about both by natural and man-made processes. It will seek to determine the feasibility of developing techniques to predict climate fluctuations with greater precision, reliability, and credibility than can be achieved today. The research component will also be responsible for developing means to determine the sensitivity and reaction of the global climate to man's industrial, agricultural, land, water, and energy practices in order to understand better the consequences of human activity. The data and applications component will aim to improve the effectiveness of the use of currently available climatic information in various economic sectors. In many parts of the world even the simplest data base necessary to provide information for managing of agriculture or water resources is not available. Even in more advanced nations, there is room for more effective use of climatic data available in great quantity and diversity. Improved climatic applications based on data presented in useful forms can provide economic payoffs in the near term. Lastly, the impacts component will attempt to understand and to describe the impacts on society of climatic variability and change. There is an important need to understand how climatic factors directly affect various economic sectors and how these amplify and disperse through secondary and tertiary effects on the whole economic and social system. Such understanding is essential for directing the research and applications components of the World Climate Program at the most urgent problems and for enabling planners to make appropriate decisions relating to climate.

The World Climate Program will be the means by which international science will marshall its efforts to assist in the reduction of the vulnerability of society to climate variation and change. The World Climate Conference will take stock of what needs to be done and consider other actions that may be necessary by governments or international organizations. This Conference will have two general objectives. The first is to provide an authoritative assessment of the state of our scientific knowledge of climatic processes and change and to delineate the uncertainties. It will seek to project, on the basis of present knowledge, possible changes in future climate. The second objective of the Conference is to examine the impacts of climatic change and variability on other physical systems and on economic activity. The World Climate Conference will then be in a position to assess whether projected climatic changes, or the economic and social consequences of climatic variability, are sufficiently serious to warrant convening an international conference at the ministerial level to consider an international plan of action to ameliorate the impacts of projected climatic variation.

It is against this background of international action to plan and implement a World Climate Program and a World Climate Conference, that the Climate Research Board (CRB) decided to convene an International Workshop on Climate Issues.

When the WMO decided to hold a meeting in the spring of 1978 to coordinate preparations for the World Climate Conference, the CRB recognized this as an excellent opportunity to assist in clarifying international issues relating to climate, and arrangements were made to hold the WMO meeting and the CRB workshop conjointly. The interaction between a diverse group of scientists assembled by the CRB and those assembled by the WMO provided a unique opportunity of mutual benefit. Thus, the International Workshop on Climate Issues was convened jointly with the WMO meeting on April 24–28, 1978, at the International Institute for Applied Systems Analysis (IIASA) at Schloss Laxenburg, Laxenburg, Austria. The WMO Speakers' Coordination Meeting focused on the substance of the presentations for the 1979 conference, and invitees included those who will present the overview papers at the conference on the state of our knowledge of climate and the impact of climate on specific aspects of physical and social systems. While the WMO meeting reviewed our knowledge in particular subject areas relating to climate, the International Workshop sought to define and analyze the fundamental nature of climatic impacts, to identify appropriate criteria for international climate research, and to debate broadly the major issues that should be addressed at the World Climate Conference.

The morning proceedings of the conjoint sessions were conducted under the auspices of the WMO and in accordance with rules, regulations, and procedures of that organization, while the afternoon sessions were devoted to the International Workshop on Climate Issues under CRB auspices. This provided the necessary independence of action for both organizations, while the participants in each meeting joined in the work of both meetings.

In order to consider adequately climate issues as they affect nations with different societal structures, a widely representative group, including both natural and social scientists from both developed and developing nations, was invited to the Workshop. For the success of such a broad-ranging project, it was important to ensure an environment that would encourage consideration of difficult and sensitive problems. This was made possible by generous support from private foundations. We are indebted to the Andrew Mellon Foundation and the German Marshall Fund for providing the necessary financial resources.

We are also indebted to the IIASA for the contributions of a number of its resident scholars and for providing us with an atmosphere most conducive to the work of the group. Moreover, as the participants developed insights into the interplay between climate and other aspects of the environment and between climate and human society, an institute for systems analysis seemed ever more appropriate a setting for the Workshop.

The present report is a synthesis of the discussions, presentations, and other contributions of the Workshop participants. We are most grateful to the rapporteurs–John S. Perry, Stanley Ruttenberg, and Jesse Ausubel–who extracted the essence of meaning from these diverse inputs. The accuracy and coherence of the resulting report were immeasurably advanced by the editorial skill and judgment of Jesse Ausubel, who has been its principal editor and to whom special appreciation is due.

The report begins by providing a brief framework of some of the characteristics of climate and an overview of the role of climatic change and variability in global ecology and socioeconomic systems. Climate as an element in economic planning and decision-making is then considered, with emphasis on processes in advanced industrial nations. Because of the especially important impacts of climatic variability on developing nations, a separate section is devoted to the major climatic issues for these nations. The implications of our knowledge of climatic impacts for scientific and service priorities in the World Climate Program are discussed next. Finally, the possible content, organization, and management of an international program of climatic impact studies are examined.

On behalf of the members of the Workshop, let me say that I hope that the ideas that arose during our deliberations will serve as a useful reservoir of concepts for the future planning of climate activities.

1 Summary of Principal Conclusions and Recommendations

1.1 BACKGROUND

The International Workshop on Climate Issues was organized by the Climate Research Board as a contribution to the development of international programs relating to the interactions between climate and man. In particular, the Workshop was designed to identify some of the issues that might be addressed by the World Climate Conference to be convened by the World Meteorological Organization (WMO) in early 1979 and to formulate recommendations for long-term international efforts in climate such as the World Climate Program.

Events of recent years demonstrate the continuing sensitivity of the societies of the world to climate fluctuations lying within the normal range of variability. Moreover, credible and worrisome possibilities exist for irreversible man-made changes in climate that could tax the adaptive capabilities of the global environment and of human society. These problems are inherently international in character. *Strengthened international efforts related to climate are therefore essential.*

The state of the planetary environment is governed by external factors, including solar activity and changes in the earth's orbit, and is maintained by a host of complex internal processes such as the circulations of the atmosphere and oceans and the biogeochemical cycles that are the channels of interaction between the oceans, the atmosphere, and the biosphere. Man and his socioeconomic structures both depend on the planetary environment and have the potential to change it. Climate is but one variable in the global ecological and physical system. *Climate cannot be dealt with in isolation but* *must be considered as a dynamic element in a constantly changing global ecological system.*

1.2 ECONOMIC ASPECTS

Societies often view climate primarily as a hazard and neglect it as a resource. The differences in climate between regions provide comparative advantages and disadvantages, as do, for example, land and mineral resources. Physical characteristics of the atmosphere and possibilities for human modification of climate give climate some of the characteristics of common property. The economic value of the climatic resource and the economic consequences of changes in this resource are poorly known and little studied. *Climate should be viewed as a resource, and improved methods for determining the economic value of climate should be developed.*

Socioeconomic impacts of climatic variability take place through a complex set of interactions and depend markedly on the nature of the economic and social infrastructure of the regions affected. Direct effects of climatic anomalies on, for example, crops, water, and health are mediated by national, regional, and global socioeconomic conditions, with ultimate consequences varying according to the economic systems, level of development, and national policies. *Methods for determining the socioeconomic impacts of possible climatic fluctuations should be developed, and systematic and extensive studies of these impacts should be conducted.*

The present inadequacy of climatic information and the ineffective use of available climatic information hinder long-term economic and natural resource planning. Climatic shifts resulting from human activity, such as release of carbon dioxide from fossil-fuel combustion, may limit options for economic development. The inherent natural variability of climate demands a resilient and robust economic structure, especially as our knowledge of both natural and man-influenced climate is and may always remain imprecise and probabilistic. In spite of this uncertainty, climate information can be of great practical value in planning. *Improved methods for incorporating probabilistic knowledge of climate into economic planning should be developed.*

1.3 CLIMATE AND THE DEVELOPING COUNTRIES

The most direct and poignant impacts of climate variability frequently occur in developing countries. Many of these countries lie in climatically marginal areas or in zones of wide natural variability. Their growing links with world markets expose them to external stresses, while traditional internal stabilizing mechanisms are weak in some cases. Strengthened infrastructure for coping with the direct and indirect effects of climate variability, especially on agricultural systems, is needed in many developing nations. The developing nations also need better information in the form of (1) statistics on climatic variability, (2) short-range probabilistic forecasts, and (3) the probability of climatic change. This information can potentially be used at the farm level, the sectoral level, and the national or regional level, in planning and management of agriculture, energy, forestry, fisheries, and health care. *International action should be taken through the World Climate Program to attain the following:*

(a) *Improve the climatic data base available for the developing nations. This would include not only improvement in the climatic networks within the developing nations themselves but also better understanding and predictive ability with regard to global climate.*

(b) *Improve methods for the effective use of climatic information of all types in the developing countries to assist in their economic development.*

1.4 SCIENTIFIC PRIORITIES

Internationally organized efforts to improve our knowledge of climate are essential, and these efforts should be focused on a small number of key problems. Priorities for this work are determined by socioeconomic importance, scientific feasibility, and the need for an *international* rather than national effort. The scope of a world climate program should not be so broad as to prevent adequate concentration of limited scientific resources on the most essential problems. In this context, four areas for research are given priority:

1. *Climatic information development.* Climate data are needed to support both planning and scientific research; such data are now inadequate. Work is needed, particularly in the developing nations, to improve observing networks, extend scanty instrumental data by means of proxy data sources, apply advanced technology, and transform the data into usable information. *An urgent problem is the establishment and extension of climate data bases and development of usable climatic information in the developing countries.*

2. *Human influences on climate.* Human activities may potentially perturb many of the processes influencing climate. Both comprehensive, interactive models and analogs of past climatic fluctuations will help to increase understanding of these influences. The most widely recognized potential influence at present is an increased level of atmospheric carbon dioxide. *Assessment of the full implications of changing amounts of atmospheric carbon dioxide should be a major focus of international climate programs.*

3. *Predicting natural climate variations.* Climate models show encouraging promise of predictive skill over periods of weeks and possibly months. Even crude probabilistic forecasts would have economic value. Research is thus needed both to advance and to validate predictive models. In this effort, the ongoing work of the Global Atmospheric Research Program, including the Global Weather Experiment, is of crucial importance and must be vigorously pursued. *The understanding and prediction of climate variations on monthly and seasonal time scales should be a major focus for research on the physical nature of natural climate variations.*

4. *Assessment of climate impacts.* This problem was treated separately by the Workshop, and specific conclusions and recommendations follow.

1.5 CLIMATE IMPACT STUDIES*

Climate is a factor in many of mankind's problems, but reliable quantitative estimates of its role are rarely available. There is a strong need to mount an international program of study on the role of climate. These studies should attempt to determine the direct effects of climate variability on physical and biological systems; the indirect effects, as these are modulated by socioeconomic structures; and, on the basis of this understanding, the information and methods needed to support decision making and long-range planning. Climatic events of the recent past and their socioeconomic consequences offer a rich set of cases whose study offer an unusual opportunity for illuminating the impact of climate. *Climate impact studies, including diagnostic case studies of historical events, should be a major component of the World Climate Program.*

A variety of methods and approaches to the conduct of these studies is possible. Candidate cases for study should be chosen to span a range of climatic and socioeconomic conditions and decision-making environments. Preliminary analyses of feasibility should be undertaken before the commitment of major resources to specific studies. Studies should be conducted to the extent necessary and possible by multidisciplinary international teams with adequate representation from the regions affected by the climatic events under study.

The institutional arrangement for the conduct of international impact studies is critical to their success. Such arrangements should include the following elements:

1. *An intergovernmental lead agency.* The United Nations Environment Program (UNEP) is well suited to assume this role under an overall coordinat-

*WMO participants did not take part in the discussion of institutional arrangements, and this section does not reflect their views.

ing structure of a World Climate Program organized by the World Meteorological Organization.

2. *Establishment of an effective network of interested international, governmental and nongovernmental, and national institutions.*

3. *Establishment of a steering committee of experts selected on their individual merits to plan and recommend specific impact study projects.*

4. *Development of study teams satisfying the criteria outlined above to carry out the impact analyses.*

2
The Climatic Framework

The discussions of the International Workshop on Climate Issues were based on a generally accepted background of knowledge about climate. It would be impossible to present in detail this body of understanding within the confines of this report. Nevertheless, the principal features of the knowledge on which the Workshop developed its conclusions are outlined. The physical basis for the earth's climate and for its fluctuations, the nature of past variations in climate, the ways in which science attempts to learn about climate and to predict its changes, and the relationship of climate to environmental and economic factors have all been treated with some degree of completeness in other publications and documents, and a short bibliography of such references is given at the end of the report.

2.1 THE CLIMATE SYSTEM IN PERSPECTIVE

The general circulation of the atmosphere and, hence, the climate are determined by the basic features of our planet. Among these, we may mention the intensity and spectral distribution of solar radiation, the speed of the earth's rotation, the inclination of the earth's axis to the plane of its orbit around the sun, the mass and composition of the earth's atmosphere, and the character of the earth's surface—principally, the distribution and shape of land masses and water bodies and the physical relief and surface properties of the continents. On time scales relevant to mankind, these factors are usually regarded as unchanging external factors. However, mankind is increasingly able to alter some of these factors, for example, the composition of the atmosphere and the character of the earth's surface. Thus, in order to understand climate, we must understand both the inherent internal variability of the climate system under constant external conditions and the response of this system to changes in some of these determining conditions.

Before going further, let us clarify what we mean by "climate." It is perhaps simplest to say that climate is our description of the observed or expected statistical characteristics of the weather over some period of time, past or future. By "weather," we mean the individual events that we perceive from minute to minute as individual weather systems pass across the face of the globe. These individual weather systems of all sizes from clouds to giant storms are governed by the large-scale planetary circulation and the slowly changing boundary conditions cited above; they also have their individual internal dynamics and interactions with the large-scale circulation. To the extent that we can describe the detailed time-dependent behavior of these systems, we deal with weather; to the extent that we must treat them as statistical ensembles (even though time-dependent), we deal with climate.

Where, then, is the boundary between weather and climate? In the past few decades, it has become clear that there is a fairly well-defined limit to the time range of detailed prediction of individual weather events. In order to predict at all, we must have some model of the weather system. Let us, then, imagine that we had the most perfect model possible—an identical twin earth. Suppose we were able to create for an instant precisely the same weather, the same surface conditions, and all other conditions on this twin earth as on the real earth. Then the weather on both earths would evolve in the same way indefinitely. If we could somehow speed the evolution of the twin earth relative to our own, we could in a sense predict events on the real earth by looking at the model. But how would we know what sort of initial weather to impose on the model earth? We would, of course, observe the weather on the real earth as best we could, but we could never do this without error. Hence the initial weather imposed on the model would not be exactly right. As a result, the subsequent evolution of weather on the two earths would differ slightly, with the difference steadily growing with time. At some time, the weather in the model and that on the real earth would differ about as much as if we had just picked two days at random from the history of the real earth's weather. At this point the model ceases to be of any use in predicting the detailed evolution of weather, and we have reached the limit of predictability. Furthermore, since no model can be a perfect analogue of the natural system, the two evolutions would diverge even with identical initial conditions.

We do not have the luxury of an identical twin earth, but we can construct mathematical models that incorporate the principal physical processes governing the weather and that produce realistic sequences of weather events whose statistics agree well with the observed climate. Numerical experiments with these models suggest that the practical limit of predictability, in the sense defined above, is in the range of two to three weeks. This is not to say that all aspects of the weather are completely unpredictable beyond this range—indeed there are indications that some special features may be more predictable than the general run of weather. But it does indicate that weather for months, seasons, years ahead must be dealt with in terms of its statistics; that is, beyond a few weeks, we deal with climate.

2.2 CLIMATE MODELING

The principal research tools for the study of climate and the possibility of predicting the statistical characteristics of weather are numerical models of the atmosphere, the oceans, and the cryosphere. These incorporate the internal processes of the atmosphere, sometimes the internal dynamics of the oceans, the interactions between the atmosphere and the underlying sea or land surface, and the other forcing parameters to which the atmosphere must respond. The most complex and complete models, which incorporate all the main processes and treat the entire globe with a useful degree of resolution, are termed "General Circulation Models" (GCM's).

In operation, these models take a set of arrays of numbers defining the state of the atmosphere in terms of such variables as pressure, temperature, and wind and predict the evolution of that state over a brief period, resulting in a new set of numbers. In the most comprehensive models, the oceans and cryosphere are incorporated as part of the climate system, and their characteristics are also predicted, rather than being presented as boundary conditions. When given initial conditions representing a real weather situation, these models produce subsequent states resembling quite closely the real evolution of weather, the resemblance between model and reality steadily decreasing with time. But the climatic statistics derived from the model's weather events, whether starting from real weather or from some arbitrary initial state, continue to resemble closely the observed climate. Moreover, if we change some of the external conditions in the model—the land surface, solar radiation, atmospheric composition, for example—a different model climate is produced. Indeed, quite successful simulations of ice-age climate have been carried out in this way. Thus models are known to be useful not only for predicting individual weather events out to some range and for investigating the processes maintaining our present equilibrium climate but also for estimating with some degree of reliability the response of climate to changes in various factors. An unanswered question, however, is the degree to which models can predict the time-dependent changes in the statistical characteristics of weather over months, seasons, and years.

In the construction and experimental application of these models, it has become clear that the physical processes that must be dealt with depend on the time scale in which we are interested. For very short-range weather prediction, for example, a model that approximates the atmosphere as a thin film of incompressible fluid works quite well. For longer forecasts, the three-dimensional structure of the atmosphere, the processes of condensation, and some of the interactions with the underlying surfaces must be included. If we are to deal with periods of months or seasons, the interactions between the atmosphere and the oceans, the ice and snow masses, the changing moisture and surface characteristics of the land, and more must be taken into account.

An important application of models is the assessment of possible human influences on climate. Man may be able to affect climate in a number of ways. Through deforestation, agriculture, and large-scale irrigation projects man changes the land surface. Gases and particles injected into the atmosphere by human activities change the radiative properties of the atmosphere and possibly the processes of cloud formation and precipitation. A number of these effects have already been investigated with models, notably the possible climatic effects of increasing atmospheric carbon dioxide from combustion. An important objective of present climate research is to improve the precision and reliability of these studies.

2.3 PAST CLIMATES

Our knowledge of past climates has greatly improved in the last few decades. From instrumental records, geological evidence, and a host of indirect sources of data on past climate conditions, we have defined much more clearly the climatic history of the earth. It has become evident that climate varies on all time scales—seasons, years, decades, centuries, millenia—and that both the amplitude and physical causes of climate variations change as we move from one time scale to another.

On the scale of 100,000 years, there are glacial and interglacial cycles, which may be related in part to changes in the earth's orbit. The change in global mean temperature between the peak of the last glacial period and the warmest postglacial period was probably not more than about 6°C, although changes in high latitudes were substantially greater. Perhaps the best known climate variation on the scale of centuries was the "Little Ice Age" of the sixteenth to nineteenth centuries. In our own century, on the scale of decades, there was a well-established warming in certain portions of the northern hemisphere in roughly the first 40 years, followed by a decline in temperature. Changes of temperature of small magnitude like this last mentioned can be discerned only by careful statistical processing of the available observations, and their causal mechanisms are not clear. Nonetheless, these climate fluctuations are accompanied by regional changes in snow and ice cover, movements of fish stocks, changes in the growing season, and many other phenomena, which have significant effects on national and regional economies. Interannual variations also occur, and these can have pronounced economic and social impacts. Examples include the 1968–1973 drought in the Sahel region of Africa with wide-reaching consequences for human settlement patterns and the unusually cold winters of the past two years in North America, which significantly affected energy demand, transportation, and employment.

2.4 THE ECOLOGICAL VIEWPOINT

Climate and man may most usefully be discussed as components of a global ecological system that includes marine, terrestrial, and biological factors. Through constant interplay among these factors, mediated by a host of biogeochemical cycles of such substances as carbon and nitrogen, a quasi-equilibrium is maintained. Each factor in the system varies in time but stays within certain limits. In order to understand how this equilibrium is maintained, and what influences might disturb it, we must understand how these cycles work and their relationships. Studying climate as but one of the variables in an ecological system held together by biogeochemical cycles has recently proved to be a most fruitful approach.

Man is also an element of this global ecosystem. He has evolved, first physically and then socioeconomically, to enable him to survive within this global ecosystem. Changes in the system will affect his welfare, and his actions may change the workings of the ecosystem and therefore the average state of its components–including climate. We must therefore seek to understand climate as an element of an ecosystem that includes man and to understand man's relationship to a global ecosystem that includes climate.

2.5 CLIMATIC IMPACTS

The influences of climate on the physical world, societal organization, and economic activity are clearly pervasive. These "climate impacts" include not only the directly perceptible effects of climate on individual plants, animals, or people but also the complex indirect effects arising through a huge number of interrelationships. As our ecological viewpoint suggests, climate is only one part of an interactive system, and one should attempt to isolate the relationship between climate and any other individual factor only with considerable care. Indeed, the impact of climate on any single component of the system may be difficult to analyze correctly without taking into account many other components of the natural and social systems, as well as the complex interactions and feedbacks among them.

Before mentioning a few of the major impacts, two major distinctions should be made. First, one must distinguish between impacts on the natural world and impacts on man. On an earth without man, climate would still influence the growth and distribution of plants, animals, other biota, and even the geophysical structure of the earth's surface. Climate thus has a direct impact on these physical and biological systems. However, the existence of the human economy allows us to conceive of these impacts in a different way, as impacts on the physical productivity of natural resources–arable land, forests, and water supplies, for example–that are parts of man's socioeconomic system. Second, one must distinguish between these primary impacts and the secondary impacts that occur as the direct physical effects on individual components–arable land and the like–are transformed by economic activity into prices, levels of income, and levels of employment. Climate impacts may thus be measured by many different nonmeteorological indices: the acreage of corn planted versus millet, the gross tonnage of wheat grown, the mortalities from a flood, the loss of income to farmers from a drought or to shopkeepers during a severely cold winter, taxes to finance environmental control and protection, to name but a few.

With these points in mind, let us briefly survey a few of the more significant impacts. Renewable resources are generally considered to be the most heavily impacted sector. Climate affects the production of food and fiber, the productivity of rangelands, and fisheries and wildlife. These in turn raise issues of food prices, nutrition, international trade and balance of payments, and national self-sufficiency. In the area of energy, climate affects both supply and demand. Climate, for example, is a major determinant of both the capacity to generate hydroelectric power and the requirements for space heating. In transportation, climate determines the usability of sea routes, inland waterways, and mountain passes. Climate is one of the most valuable attributes of the environment for recreational activity, whether in the form of snow cover for skiing or balmy temperatures and azure skies for swimming. One illustrative example of the effect of climate is in the oil drilling in the Beaufort Sea, specifically at the southern boundary between the Arctic pack ice and the land. Here, the critical environmental factor is the movement of the pack ice, governed by wind, currents, and the characteristics of the ice itself. Each day of ice-free water is enormously valuable to this expensive operation in an area where only 100 to 120 days of ice-free conditions are expected each year. This is perhaps an extreme example, but, in general, engineering projects become more sensitive to climatic influences–both mean conditions and extremes–as they become more ambitious and larger in scale.

But man is not merely a passive victim of climate. He adapts to climate in many ways, and these adaptations–clothing, shelter, land-use, for example–are in themselves impacts of climate. Whether an architect calculates the balance of natural and artificial light or an urban planner estimates the carrying capacity of a given locale, climate influences the decision. Climate influences our choice of basic materials: one does not build grass huts in Iceland nor igloos in the Amazon. In social services, climate affects, for example, the demand for snow removal, sanitation, and fire protection, thus influencing greatly the cost of operating urban environments. Clearly, the range and variety of climate impacts is enormous, and in a short space it is possible to focus only on a few of the more important ones. In reviewing those that were discussed at the International Workshop, it is valuable to bear in mind the wide range of impacts that could have been dealt with in equal depth and detail.

3
Climate, Economics, and Planning

This chapter sketches some of the ideas that emerged at the International Workshop during discussions that attempted to relate climate to economics and planning. Discussions relevant to this area occurred at various times and in various contexts, so that, while this section draws the ideas together around certain themes, it makes no attempt to present a coherent treatise on the subject. On the contrary, it serves to point out the amount of work remaining to be done in this important area. In addition to the section based on Workshop discussions, the chapter offers two Annexes: a brief summary of a macroeconomic approach to climate presented by Ralph d'Arge and a case study on climate and decision-making in the energy industry presented by Chauncey Starr.

The discussions relating climate to economics and planning centered around several basic questions. In what sense is climate a resource? How is the value of climate assessed? Does the role of climate in human society change with economic development? How should climatic information be formulated and used in specific planning decisions? Perhaps the question most frequently asked in this area is "What are the costliest impacts of climate on society?" Developing reliable quantitative estimates necessary to respond to this question is a major task for researchers. While the desire for such estimates was often expressed at the Workshop, discussions also stressed the sound development of a basic conceptual foundation. For impact assessment, such a foundation will be especially important as the numerical answers eventually built upon it are taken into account by decision-makers.

3.1 CLIMATE AS A RESOURCE

Discussion of the "costs of climate" tends to direct thinking toward climatic disasters and hazards–droughts, frosts, floods. One might alternatively begin by asking how we make productive use of climate. Or, what would be the optimum climate? Societies would respond to such a question with a variety of answers. One might say a climate characterized by a reliable monsoon; another might say a climate with a specified level of sunshine; a third might prefer a climate that minimizes the demand for snow removal, heating, and air conditioning. Speculating in this way leads us to look upon climate as a resource. This is not to belittle the hazardous aspects of climate, which warrant careful consideration. However, climate provides conditions *favorable* for many human activities, and evaluation of these favorable conditions leads to the notion that climate can be treated as a resource.

Resources exist in a context of scarcity and value. One might initially question whether it is meaningful to consider something as plentiful as climate a resource. And, indeed, if the climate of earth did not vary in space and time, climate would not be interesting economically. It would be merely a uniform external condition in which economic activity takes place, something to which one would not bother to assign a value. However, climatic variability provides the scarcity and value that make the economics of climate worth considering. Climate varies in time. Seasonality, for example, in temperature, precipitation, solar radiation, and other aspects of climate permit or limit numerous activities. Similarly, climate varies in space. Climate of the tropics is inherently different from climate at the poles, and climate varies with changing land-surface conditions. The value of this differentiation in space and time is often subsumed into the assessment of land resources. Two pieces of land that are under different climatic regimes but are otherwise identical are likely to have different values. One might say they have different amounts of climatic resources.

If climate is a resource, then can it be held a form of property? Climate does not conform to the conventional notion of property meant in the sense of something that can be possessed, but one can certainly speak in terms of controlling access to particular climatic characteristics. One can in a sense "purchase" climate through ownership of a particular geographic location. As the possibility increases that man may alter climate either inadvertently or intentionally, climate becomes in a sense more purchasable or proprietary. By choosing one or another policy option, it may eventually be possible to obtain a certain kind of climate for the future in much the same way one buys future clean air or water.

Is climate a common property resource? Certain characteristics of climate suggest that in some sense it is. Exploring the common property aspects of the atmosphere helps to clarify this question. It is easy to see the atmosphere as common property, for example, as a receptacle into which many individuals and firms dump their wastes. If the atmosphere did not circulate, it would not be a shared or common resource. The dependence of climate on atmospheric (and oceanic) circulation suggests that climate too has the characteristics of a common. Is climate a *global* common? To continue with the atmospheric analogy, it is clear that the atmosphere mixes on more than a local or regional basis, and the mixing does not stop at national borders. Because of the global character of the atmospheric circulation, the atmosphere must to a certain extent be considered a global common. Climate may be described similarly. While microclimates and certain factors that influence them may be excluded, macroclimates and factors affecting the general circulation might be regarded for certain purposes from the perspective of a global commons.

3.2 ASSIGNING QUANTITATIVE VALUES TO CLIMATE

Like water and air, climate has been regarded in the past largely as an attribute of land and not as something that could be purchased or sold by itself. Nor was it evaluated economically or priced by itself. Partly, this is because climate, like air, was regarded as a "free good." But now climate, like many other environmental features, is increasingly seen as valuable and may be priced. A certain type of climatic condition is no longer merely an attribute of some land at a particular location. As the possibility that a particular climatic condition can be man-made arises, it is more obvious that climate can be assigned a price like fresh air or clean water. Climatic conditions are thus increasingly becoming "economic goods." As such, they should be internalized or regularly incorporated into economic analysis.

Internalizing climate into economic analysis is not a simple task. For several reasons climate is complex to quantify economically. First, the fact that it has common property features introduces difficulties. The prices assigned to commons by normal market operations are not considered by economists to be the "true" prices of the resources, so certain values have to be imputed on the basis of economic theory. A second difficulty arises from the fact that the value of climate may lie in its behavior over a period of time on the order of generations or more, while economic analysis has largely evolved to aid decision-making over a shorter period. The positive discount rates that are usually applied yield virtually zero present values for assets held in the distant future. Certain traditional techniques of cost-benefit analysis using discount rates are thus questionable in their application to climatic values. To overcome the problem of saying that the climate of the future has no economic value, members of the Workshop suggested that it would be desirable to develop a new societal macroeconomics that would take into account endowment values for the environment. However, placing a price on such assets is also an open question. Is it infinity or some particular amount?

Various means of estimating the value of climate were discussed. One measure that has been developed that can be considered a socioeconomic indicator of climatic values is the "comfort index." When we work, the physical degree of comfort is important to productivity. If it is hot and humid, for example, working hours will tend to be shorter, and the intensity of work or attention will tend to be lower. Climate can be similarly important for the enjoyment of leisure activities. Various kinds of environmental control or conditioning are responses to comfort factors. So, one approach to measuring the value of climate revolves around developing indices of comfort and quantifying the actions taken in response to specific assessed levels.

Another way to estimate the value of climate is to consider climate as a potential. In broadest terms, the goal of economic activity is to create "order states," to create utility out of situations in nature. Any good may be described this way. For example, an animal hide provides the potential for a pair of shoes. Through its differentiation in space and time climate provides the potential for various productive activities. These climatic potentials may be assessed as a function of costs, both monetary and nonmonetary. For example, the value of tropical zones might be realized in the development of new agricultural techniques and in small- and large-scale solar-energy technologies. The value of these is in principle measurable. The changes induced in climate if these are realized can also be assessed and the costs estimated. Through a comparison of costs and gains, one can begin to measure the economic value inherent in exploiting climatic potentials. Would one be able to get more out of climate from an economic point of view by accepting more perturbation or modification of it?

Efforts have been made to evaluate climate from the perspective of the impact of deviations of climatic variables over space and time. There are several ways to measure the resulting fluctuations—gains or losses—attributable to climate. One can examine production, find a change in the level of production caused by climatic factors, assume the gain or loss is replaced in another way, and estimate the minimum replacement cost. For example, how much would it cost to produce the same amount of a given agricultural commodity with irrigation replacing a certain amount of rainfall? Or what would be the cost involved in improving some land to the equivalent of some other land in another location so that they can be used for the same purpose in the same economic process? A second method looks at consumer losses. What does the consumer lose by paying higher prices? A third method measures gross product losses.

The value of better climatic forecasts can also be assessed. One way to do this is to determine how much farmers could save by choosing different planning for a particular activity on the basis of climatic information with other factors held the same.

The level of aggregation of statistics is important in assigning meaningful quantitative values to climate. Climatic variability or better climatic information may often only spur a redistribution of wealth. The whole economy is not necessarily damaged or improved unless there is a net positive change in overall production or in the efficiency of the allocation of resources. Climatic phenomena will on occasion benefit one sector while damaging another. For example, when climate reduces agricultural production, the rise in prices sometimes will create a net gain in income for farmers, while consumers will suffer from these same higher prices. However, a severe anomaly may reduce drastically the income of the agricultural sector and depress an entire economy. The issue of what level of aggregation or disaggregation is meaningful arises not only within a particular economy. In studying climate we tend to use global models and statistics covering very large areas, but the economic problems with which climate phenomena are connected may not be best described by global or other large-scale statistics. Drastic local effects may be hidden. While the negative effects may not be evenly distributed, neither are potential benefits. For example, better predictions of climate will certainly be much more valuable to some societies than to others.

3.3 VULNERABILITY TO ECONOMIC IMPACTS OF CLIMATE

Vulnerability to the economic impacts of climate is a function of the nature of both the process through which the impacts occur and the development of the economy. Climate affects economies and economic planning through a complex set of interactions. These include the nature and intensity of climatic variability and change, natural ecology, human settlements, and the socioeconomic and political arrangements that regulate human activity. Climate can determine directly the physical effects in many areas, such as level of production in agriculture and demand for energy or water. However, society mediates these effects, and climate appears in the economy primarily in an indirect form. Thus, the deaths, injuries, dislocations, and direct physical and biological damages are transformed through social and economic linkages into, for example, costs for warning systems, land-use management, disaster relief, and insurance or changes in the price of goods. The path from changes in physical stocks or flows to changes in price and other secondary effects is not always clear. Neither is it certain which effects are the most important.

The lack of a deterministic relationship between climate and the state of economies is exemplified by comparing the drought years 1975 and 1972 in the Soviet Union. The 1975 drought was worse than the 1972 one, with grain harvests lower and foreign purchases higher; yet this was not amplified into a global economic perturbation of the sort that occurred in 1972. Somehow, the physical effect was mediated and diminished in its secondary impacts.

Does a society's relationship to climate change with economic development? The French philosopher Montesquieu suggested more than 300 years ago that climate is an important influence on political and economic systems, and, indeed the present North-South dichotomy can be described as a climatological division. The developed countries are largely extratropical. Technology has allowed, or perhaps been developed by, these countries to accommodate social complexity in normal temperate extremes. The large infrastructure of development may also enable developed countries to benefit more readily from improved climatic services, such as forecasting.

If we are concerned about the vulnerability or resiliency of a whole structure and not of a single crop, more economically diversified societies should face fewer climatic risks. If development is characterized by diversification, then development should reduce vulnerability to climate. Of course, a subsistence economy may be diversified and protected or self-sufficient at the local level in a way that an advanced economy is not. Moreover, measurements of losses due to climatic factors made in *absolute* monetary terms give the impression that climatic vulnerability in developed countries is increasing. However, the *relative* vulnerability may be decreasing. The argument is also made that, because of interdependence and the belief that mankind is functioning closer and closer to the margin of resources, overall global vulnerability to climate is increasing. This argument holds that it is more and more difficult for any nation to insulate itself from the impacts of climatic variability and that the impacts will tend to be more and more amplified as time goes by. For all of these arguments, it is important to keep in mind changing cultural standards and expectations, which underlie notions of vulnerability and judgment of the seriousness of impacts.

The lesser or differing vulnerabilities of developed countries can be illustrated by an example of options for agricultural policy. Given the probability that one damaging frost will occur in ten years, a country may emphasize a policy either to (a) use high-yield seeds and make up for one bad year in the following good years or (b) plant late using fast-maturing, lower-yielding varieties. Option (a) is usually judged better in a developed country. A developed society might withstand a depressed economy for a brief period without crisis, while a similar climatic event could spell disaster for a developing country. In the developing country, a frost might trigger an unacceptable social perturbation.

3.4 THE IMPACT OF ECONOMIC ACTIVITY ON CLIMATE

While a society is affected by certain kinds of natural variations in its climatic resource, economic development also puts increased pressure on climate. In developing countries, primary concern at present is focused on potential modifying effects of deforestation and other land-use practices. In developed economies, the addition of CO_2 to the atmosphere through burning of fossil fuel is believed to be the leading potential mechanism of influence. In the future, a rising share of CO_2 from fossil-fuel use may come from the developing countries. High levels of economic activity may possibly result in significant interference in particular aspects of climate, especially biogeochemical cycles. While problems relating to the carbon cycle have already been stressed, there is concern, although less pressing, about other cycles as well. The effects in these individual cycles may be much greater and more important than the associated changes in global climate. In this connection, members of the Workshop took note of recent indications that the effects of man-made decreases in stratospheric ozone on tropospheric climate would be quite small.

One area that has generated concern is release of man-made heat, particularly in urban-industrial concentrations or at "energy islands," where large-scale energy conversion is carried out. Participants in the Workshop believed that the effect of such heat release on global climate will be insignificant for a long time to come. Experiments with present models of the atmospheric circulation indicate that a release of 150 or 300 TW (1 TW = 10^{12} watts), 20 or 40 times the present global annual energy consumption, can influence the atmospheric circulation, but more realistic amounts of heat release have not been investigated. At the same time, some individuals noted that there may be significant local effects from heat release when it has the same order of magnitude as natural energy densities. Indeed, one cannot preclude the possibility that heat islands will lead to changes larger than expected, if they are located in geographic areas important for large-scale circulation features that can be influenced by regional changes in the energy budget. The development of massive water desalinization systems is another example of the kind of advanced industrial project that would have major links with climate.

Methods of assessment of the economic impacts of climatic changes should not differ for human-induced and natural changes in climate. However, responsibilities for regulation or adjustment may be quite different. There are some precedents in international law on environmental questions similar to those raised by climate modification. Legal, economic, and institutional questions in this area deserve further exploration.

3.5 CLIMATE AND POLICY PLANNING

The uncertainty associated with the interplay between climate and human activity conflicts with the growing importance of climatic information for economic planning. Scientists, like others, are reluctant to take responsibility for the consequences of their predictions, and they are acutely aware of the danger of premature applications based on weak data or modeling capabilities. Certainly the net social cost of erroneous predictions of human-induced climatic change might be quite large. This situation may not be quite so sensitive as it seems, because economic planners do not simply require predictions, but information in general that can lead to intelligent formation of options. This distinction might be partially expressed by the contrast between warning and prediction, which are different kinds of scientific statements about the future.

The IIASA Workshop on Carbon Dioxide, Climate and Society came to a characteristic conclusion in this area of climate and policy planning. At that meeting, an attempt was made to assess what the level of confidence in the projected warming was and what level of confidence would justify taking a strong policy position. The possibility of societal adjustment to a given climatic scenario was also examined. The participants at the IIASA CO_2 Workshop concluded that society could adjust, although the consequences of a problem such as the melting of the Antarctic ice cap would be very serious. Finally, they agreed that the prudent policy must not rigidly adhere to a particular line but must keep options open.

The CRB International Workshop further explored decision-making in energy-connected areas. The energy industry is interested in climate change and variability because it must engage in long-range planning. An investment that takes place over a period of 10 years may be followed by 30 to 40 years of plant operation. When one looks as much as 50 years ahead, it is necessary to take into account all boundary conditions, and climate is one of these. How does one make use of and build in resilience to climate factors? First, one must look at alternative policies. What are the resources required to achieve them? What are the impacts of the alternatives? Second, one must examine the ability of the society to accommodate and respond to change. Can it technically intervene or introduce environmental controls now and in the future? Social factors must also be studied. Are such solutions as population shifts, shifts of wealth among various sectors, or rationing feasible? Finally, one must also try to estimate the uncontrolled natural background. In summary, the kind of climatic information that really matters is that which allows forward budget planning, in which one prepares for a wide range of eventualities, and in which one does not ignore the less probable scenarios, only devotes less planning effort to them.

Such embedding of scientific knowledge into policy-making is no longer idealized. However, in the area of environmental problems, there is a general lack of compatibility between government and science. The political process is, almost by definition, limited to a time frame of something like 10 years, whereas the sort of time frame needed for climatological planning is more often 50-100 years. Clearly, issues such as employment and energy availability in the near term will occupy much more of the government's time than planning for very long-range eventualities. What alerts decision-makers to climate—for example, the impacts of recent cold winters in the United States—is usually a single dramatic situation in the present, not a probability distribution over a century. Other than at the times when a particular climatic disaster occurs, the impacts of climate on society tend to be diffuse. This situation leads to a discrepancy between private and social costs. The overall cost may be high, but the cost to each individual may be quite small. The spread over time between impact and adjustment, especially for human-induced factors, further increases the difficulty in making economic and policy decisions about climate. The direct incremental costs of regulation occur in the present, while the benefits and total societal costs are in the distant future. It is thus not surprising that even in many forward-looking policy units the planning process does not accommodate climate.

Normal competition in management practices allows only a low priority for a component like climate that is often diffuse and distant. Climate impact studies will help to determine how climatic information can be used more appropriately in the planning process.

It may be that rates of social and environmental change have accelerated so much as to diminish the value of historical lessons. At one time, ecology may have been taken as given for an economy over a human lifetime. This becomes less and less true. The novelty and speed of future changes may be such that there is no alternative to accommodating to climatic change through adjustment of social factors. If we accept such adjustment, we become as interested in learning the rapidity of climatic change as in its ultimate magnitude. A policy position is implicit in this attitude, and participants in the Workshop distinguished it from other attitudes decision-makers may take. This position appears to say that a change in ecology may or may not be desirable, but we do not know enough to manage it. A second position holds that we do know enough to manage. A third position sets out as its premise that no change in ecology is permissible. The members of the Workshop did not debate the merits of these positions, which again raise the difficult questions of responsibility and regulation in environment areas.

Along with these wide-ranging discussions of climate, economics, and planning, the Workshop considered some specific approaches in the area, which are presented in Annexes A and B following this chapter.

ANNEX A
A Macroeconomic Approach to Climate—Summary of Transcribed Remarks Delivered at the Workshop

RALPH d'ARGE
University of Wyoming

Ralph d'Arge presented a sketch of some of the findings of the economic and social measures section of the Climate Impact Assessment Program (CIAP), undertaken in 1974 by the U.S. Department of Transportation.* While this study was unrealistic in several important ways, it is a pioneering work for making quantified statements about the economic significance of climate. One of the tasks of the study was to make estimates of the annualized economic cost of postulated climatic changes. The results for a -1°C change in mean annual temperature with no change in precipitation were presented at the Workshop and are summarized here.

In the study, costs (or benefits) that would take place over a specified period of time are measured in dollars. The costs assume a steady movement over 70 years to a -1°C change in global temperature. The study does not examine "adjustment costs," i.e., the cost of changing from an economy adapted to the present climate to one adapted to a cooler climate, only the overall difference. It is important, however, to note that for many effects the adjustment costs—because of abruptness, the existence of feedbacks, a shift from benefit to cost through time, or some other factor—may exceed the net change in significance to society. [See Section 3.2 for a discussion of related points.]

The study includes a number of natural and human resources. In the natural resource sectors, where appropriate, biological production functions have been built. These relate, for example, temperature to corn yield by

*A. V. Grobecker, S. C. Coroniti, and R. H. Cannon, Jr. (1974). *The Effects of Stratospheric Pollution by Aircraft, CIAP Report of Findings*, DOT-TST-75-50, Department of Transportation, Washington, D.C.

region and yield to price. Then price adjustment is translated into a loss or benefit. Such relations of price and change in quantity are normally considered valid for relatively small changes in quantity. The robustness of the individual sectoral models varies from quite good for grain to very shaky in forestry and health. The coverage of the statistics also varies from the United States to the world. Final figures represented are net adjustments, which may, it must be noted, disguise large offsetting numbers. Overall, the figures derived refer to perhaps 25–40 percent of the global economy.

TABLE 1 Estimates of Economic Costs of Temperature Change[a]

Sector Impacted (Coverage)	Annualized cost, 1974 (Millions of 1971 U.S. Dollars; Negative Sign Denotes Benefit)
A. Natural Resources	
Agriculture	
1. Corn production (60% world)	-21
2. Cotton production (65% world)	11
3. Wheat production (55% world)	92
4. Rice production (85% world)	956
Forest products (U.S.)	661
Forest products (Canada)	268[b]
Forest products (U.S.S.R.)	1383[b]
Marine resources (world)	1431
Water resources (two U.S. river basins)	-2
B. Human Resources	
Health impacts (world) (excluding skin cancer)	2386
Urban and physical resources (U.S.)	
1. Indirect cost estimates (wages)	3667
2. Direct cost estimates (wages)	
Residential, commercial, and industrial fossil-fuel demand	176 to 232
Residential and commercial electricity demand	-748
Housing, clothing expenditures	507
Public expenditures	24
Aesthetic costs	219

[a]-1°C change in mean annual temperature over 70 years, no change in precipitation, 5 percent interest rate assumed.

[b]Figures presented to International Workshop on Climate Issues, not included in original CIAP report.

The study is based on the neoclassical economic concept that benefits in the future are less valuable than ones in the present. This idea tends to bias costs downward. A discount rate of 5 percent is applied. In contrast, the ability of individuals to adjust over time suggests that the estimates may be too high. Moreover, only a simple relationship between change in temperature and economic benefits or costs is examined. Feedback effects, for example policies taken to mitigate the effects of costly impacts, are not taken into account in the forecasts. Of course, such a deficiency may be partially compensated for by the use of the positive discount rate, which tends to diminish the importance of future events.

Table 1 summarizes the results of the study.

D'Arge cautioned that the annualized costs presented cannot be summed consistently, that the coverage is uneven, and that generally the numbers are of the crudest sort. For purposes of discussion, d'Arge estimated that *the discounted present value* of a $-1^\circ C$ temperature change over 70 years would be on the order of $1.4 trillion. While in specific areas the costs might be significant, members of the Workshop believed that such an overall cost is small if the movement to it is gradual. The question of the shape of adjustment paths of course remains open, but at first look it appears that the economic adjustment costs *of this particular scenario* are acceptable.

ANNEX B

Climate and Energy Planning—Edited Transcript of Remarks Delivered at the Workshop

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After the decision is made to build a power plant, it is 10 years before the plant is in operation, a plant that will have a lifetime of 30-40 years. Therefore, in an examination of what technological developments to support, what directions to proceed on, and what uncertainties to try to cover through research and development, we must try to look ahead almost 50 years. This time span is a very important element in the decision-making process. It means that we have to take into account all the alternatives and all the possible changes that may occur in the boundary conditions in which the energy industry operates. Climate is one of these. What is the basis on which we make our decisions? We make a specific premise that the only things we cannot control are natural phenomena. We can control the allocation of our existing resources, and we can also control the type of resources that are produced in the future. Technical development is one of these resources.

How do we go through an analysis? We try to optimize a societal benefit-cost relationship. We integrate it over the time span we are examining (40-50 years). We try to discount it to present values to serve our ultimate function of helping to allocate present resources. The discount rate may be a plus or minus; it is not necessarily always in one direction. We take into account the uncertainties in the information, particularly because uncertainty gets broader as you go out in time. We essentially do a probabilistic analysis of what is likely to happen and what the alternatives are.

On the issue of climatic impact on energy supply, there are three different approaches. One is to consider how one might control this impact. That raises the question of alternative energy supplies. We look at all the alternatives and at the resources required, not only the immediate capital resources required for any one of these alternatives but also the current operating costs to maintain them. We look at the impacts of the alternatives, not just economic or social impacts but also political and institutional. We try to come up with a benefit-cost analysis and a balance of these in examining the alternatives.

A second approach examines the ability of the society we serve to accommodate a change, as for example a climatic one. What are the response mechanisms other than changing the energy supply? What can society do to respond to a climatic impact? We look at factors like environmental control, now and in the future, sociological shifts, population shifts, industry shifts. Again we use a benefit-cost analysis to estimate how difficult it is, for example, to shift populations or to control the environment.

There is a third approach. We consider the uncontrolled background arising from natural fluctuations. There is no use trying to control something to a higher degree than probably will be experienced as a result of natural fluctuations. If the accommodation of society to those fluctuations would take place anyway, what we are seeking to control becomes unimportant. In the light of these approaches, experts on climate are thus discussing matters of vital significance to us. Specifically, there are two areas in which we want to learn from such a group. What are the natural fluctuations that are likely to occur in the next 50 years? How do they compare with the climatic impacts that may come from various types of energy supply?

How do we establish a basis for the analysis? We look at the problems that create the energy demand. These have been well described on a worldwide basis by the publications here at IIASA by W. Haefele and W. Sassin on the future energy scenarios. These numbers are probably as valid as any about the worldwide energy demands in the next 50 years. They are based on population growth and gradual economic improvement per capita worldwide in the developed and underdeveloped world. They have a high degree of reliability. These trends have a certain consistency about them. The trends follow population growth and economic growth, and these are slowly changing variables. It does not make much difference whether they change by ±10 percent, the problem stays in magnitude about the same.

If you will look at these projections for 50 years, some serious questions arise. If you try to supply this kind of energy growth out of fossil-fuel sources and you do it with the technologies that we have at present, you find that you will, in 50 years, double the carbon discharged to the atmosphere that we have today. It is obviously not a trivial amount. The magnitude of this is very large. We do not know what the climatic impact of that kind of growth is apt to be.

In view of the potentially serious consequences, what are the energy alternatives? There are four alternative supply scenarios. First, to continue with the mix of fossil fuels, nuclear power, and advanced technology like solar and wind. This is essentially the path the world is following. A second alternative, if one wanted to reduce the climatic impact of fossil-fuel combustion, is to seek high usage of nuclear energy and try to substitute for fossil fuels. That is not a direction the world is taking, but it is an option. A third alternative is to go to all the renewable resources and drop coal and nuclear energy. Emphasize solar, wind, ocean thermal, things we do not have, biomass, which we do have, and geothermal, which we have in very limited amounts. There is a fourth alternative: to reduce energy consumption by depriving ourselves of the resource. The economist will tell you to do this by making it scarce and, in effect, raising the price. That fourth alternative should not be overlooked because it may be forced on us if we do not do other things. These supply scenarios must be examined from a benefit–cost basis.

If we take the first alternative, the mix with fossil expansion, we face the problem that was discussed here of macroclimatic modification. The mean temperature going up will be accompanied by alterations of the weather distribution. This means that food production patterns are altered, the living environment changes, and there may be a lot of consequences. This set of changes is one of the risks or costs. This evaluation is very important—we need it but do not have it. There is a second problem if you go on with the present agenda. There is a nonuniform distribution of uranium ore. As resources start getting scarcer, the likelihood of political stresses, trade imbalances, and competition among nations increases. This political consequence is not trivial. There are also long-term impacts of depletion. If we use up our energy resources and do not invest in things that produce more energy for us, eventually we face a world in which most of the resources have been taken out. It is important that some of the production that we get out of energy use be invested in energy systems that will continue to give us energy output. The fast breeder might be such a machine. Fusion devices might be, if they come about. The need to make a capital endowment, an investment, in something that continues to give us long-term energy supplies after the fossil fuels are gone is great. These are very long-term issues, but issues that may become very pressing within the next 50 years, if we follow our present path.

The second alternative, of pushing nuclear energy very hard and having it substitute as fast as we can for fossil fuels, raises other risks. It is argued by some that expansion of nuclear power may stimulate nuclear-weapons proliferation. There is also the question of nuclear-product waste and disposal and its impact on the environment. Such leakage from waste storage, if it occurred, would be local and not global. There is also the issue of reactor safety. There are no scenarios for nuclear-power accidents with global implications. Those in the nuclear business consider all these risks to have a very, very low probability. But, the opposition to nuclear expansion is probably more philosophical and political than technical anyway. Interestingly, it represents the one energy source that we now have that has minimal environmental impact.

The third alternative is to develop all the renewable resources, solar, wind, ocean thermal, and so on. It is quite clear when you make any kind of analysis of this alternative that it is intolerably expensive at present. The reason is very simple. They are very diffuse sources, and the capital cost of bringing these diffuse energy sources together and converting them into usable forms is substantial. The material requirements and the construction man-hours per unit of power output for sources like wind, solar, and ocean thermal are factors of 10 to as many as 100 times more than material and labor requirements for nuclear or fossil plants. The capital resources of the world cannot sustain such costs. Roughly 10 percent of the gross national product (GNP) of the United States is made available for investment purposes each year in industrial, business, and commercial investments. Of that 10 percent roughly one sixth (16-17 percent) currently goes into building electric power systems in the United States. To multiply that by a factor of 5 would essentially deprive all other industry of capital resource for investment, unless the annual savings out of the GNP were doubled. I do not believe that the world is going to be able to accept this expense, especially if it has the option of going with fossil fuels or nuclear energy. The renewable systems are also not without major environmental impact. If you try to supply the electricity of the United States out of solar energy, you would in effect have to build the equivalent in area of all the cities in the United States just to collect enough solar energy to do it. The material flow that would have to go through is equivalent to all the material flow that we send into our industry today. These are enormous numbers. We can talk about putting the solar water heater on the house and we can talk about putting on a solar collector to give us a fuel substitute for part of the year in the home, but that is a very small fraction of the total problem. Substituting these renewable resources for the total energy production system will have massive consequences, and it is an unlikely direction for the world to take as a way out of a climatic impact.

Energy deprivation is the fourth approach, and it brings into the picture several other costs. If energy constraint reduces real income, and there is an inverse relationship between income and birthrate, it is plausible to argue that energy deprivation will be connected to an acceleration of population pressures. Second, there will be an increased incentive for military acquisition of energy resources. In general, the enhancement of national and international tensions and a reduction in real income per capita can be expected to result in a worldwide increase in social problems.

These are very brief sketches of the four alternatives. What are the questions about the risks associated with them? First, can we quantify them? We can only do it roughly so far. Second, how do we compare the alternative outcomes? For example, how does one evaluate the most likely outcome of energy deprivation versus the probability of radioactive release from a high nuclear strategy? Finally, how do we look at other global risks and their interaction with alternative energy scenarios?

Changing the energy system toward nuclear energy, solar energy, or deprivation is one group of alternatives responses to the risks associated with a large climatic change arising from the present mix with fossil-fuel expansion. The result is always a set of costs from the new system and a set of costs from the dislocation. In addition, there are institutional issues. For each of the scenarios, there is a question of how a large reduction in fossil-fuel use would be accomplished and accepted internationally. There is also a question of how the world would accommodate to incomplete or nonuniform abandonment of fossil fuels. As one perceives the problems associated with changing the system, the desirability of investigating the possibility of adjustment to climatic change increases. Such adjustment will involve significant developments, including alteration of comparative national economic status, population shifts to benign climates, and technical intervention to control microclimates, and they are worth putting in perspective.

What can we learn from a historical perspective on adjustment to past climatic change and shifts in wealth and population distribution? The time constant for population shifts is probably around 10^2 years. So is the time for a wealth shift. My impression from climatologists is that natural large variations in climate occur on the order of 10^3 or more years. If in fact the past climate had been unchanging historically, our philosophy might be very different, but because of natural changes through which mankind has lived, it appears that the philosophy can be flexible. The question then becomes, what is the time constant for man-made climatic change. If it is greater than 10^2 years, perhaps adjustment is less costly than interference with human endeavors. This is a question for sociologists as well as economists and scientists.

A technical perspective on climate change is also worth examining. There is a significant precedent for population shift encouraged by technological modifications. We are increasingly able to accommodate to new areas by environmental conditioning–heating, cooling, irrigation, fertilizing. In the United States, we have shifted an enormous section of our population from the northern part of the country to the southern as a result of air conditioning. It has taken less than a hundred years to make that kind of shift. Moreover, it is intellectual arrogance for us to assume that we can now predict our technical capabilities 100 years hence.

This analysis leads me to a series of general conclusions. First, all foreseeable future paths have significant risks. This has always been true, but it is new to be asking global questions about different possibilities and outcomes.

My second conclusion is that before we start putting in arbitrary and mandatory restraints to reduce climate change, we should look at the alternative risk and response mechanisms to such changes. My third conclusion is that marginal changes in large uncontrollable risks (like war or natural disasters) may be more significant than creation of some new and manageable risks. For example, what might be the importance of a worldwide population shift due to a climatic change compared to the potential risk for global catastrophe from transportation of human diseases or agricultural pests?

Finally, let me conclude with a remark that applies to all the people in the professions–scientific, sociological, and technical. We have a responsibility for the consequences of the advice and analysis we present to the political decision-makers of the world. We have to be very cautious about predicting futures that are really based on limited perspectives and unverified methods and information.

4
Climate and the Developing Countries

4.1 GENERAL REMARKS

Direct and indirect effects of climatic variability can be particularly severe and destructive in developing countries. Numerous recent occurrences of climatic variability exceeding the usual year-to-year fluctuations illustrate the variety of ways in which the impacts arise. Study of these events leads both to useful assessments of the role of climatic variability in human affairs and to important guidelines as to how current and prospective knowledge of climate might contribute to improvements in human well-being through reduction of the vulnerability of society to climatic variability and change. Such study also shows that more often than not climate itself is but one of many physical and societal elements that interact to produce what is perceived purely as an impact of climatic variability.

Several important points apply across all the impact areas considered. First, climatic information at several time and space scales is needed, especially short-term information mainly for local use, and medium- and longer-term information for use at the national or regional level. Second, in order to get information to users, means of communication must exist or be provided. Finally, in order for information to be used effectively, it must be tailored quite specifically to needs and capacities in individual areas.

4.2 CLIMATE AND FOOD SUPPLIES

Among other things, agriculture creates a product that is at once food—a local need for humans and livestock—and a commodity—something to be traded or sold for other goods and services. The analysis of production, distribution, and availability of food as affected by a "climatic event" must take into account the complex character of this good. Several categories of food-climate problems were identified.

Failure of a food crop in a local area so that local needs for one season are not met. In rural developing areas, the economic conditions and lack of suitable transportation often isolate regions so that the most effective safeguards, such as storage of emergency foodstocks, must be arranged locally. In some areas, traditional systems have developed enough carryover from one season to the next to allow subsistence survival through a one- or two-year food-production deficit. In some regions, storage facilities are lacking or inadequate for protection against spoilage or wastage from insects and rodents. Factors not related to climate can obviously be improved in many ways, but availability and use of climate information to take best advantage of growing conditions and to make wise plans for storage of food stock against the more common fluctuations, say up to a one in five- to ten-year variation, could help significantly to diminish the effect of periodic shortages.

Prolonged adverse climatic condition (e.g., Sahel 1968–1973). While there is some evidence of worldwide adverse climatic conditions in general during the period 1968–1973, the Sahel region of Africa was affected in the most sustained way. Adverse conditions developed gradually enough that the "drought" was not clearly perceived for several years. A drought of this severity and duration could normally be expected every 25-50 years. However, during previous climatic conditions of similar magnitude, social and political infrastructures in the Sahel were quite different from today, and its people were able to adjust adequately through traditional ways to the prevailing climate by, for example, shifting settlement patterns. By 1968, social and political structures and attitudes had evolved to a state that rendered such traditional adjustments impossible, unacceptable, or insufficient. However, the Sahelian populations were still in a situation where their societies were isolated from other groups that had not suffered so greatly, and thus from easy access to relief. During the local shortages of food stocks and water in most of the semiarid regions (which had by then become arid), some areas were still able to export food and other agricultural commodities, but none of the income could help directly the other Sahelians in need. Food aid from the outside could be brought in quantity only to a few staging areas. Lack of transportation facilities made it difficult to distribute the food and supplies further, so the population moved to the food depot areas, creating new social and health problems. In some regions, wells were sunk to enlarge water supplies, but there was not enough for irrigation purposes, nor was there time to produce food.

While there was an indisputable shift in rainfall patterns that resulted in much lowered food production over a widespread area, there is good evidence that, given the existing infrastructures, advance knowledge of the climatic phenomenon may have been only minimally useful. The rather bleak judgment is that recognition of the full physical dimensions of the drought could not alter the fact that little flexibility existed.

Indirect impacts of climate on food supplies (e.g., malnutrition). The occurrence of malnutrition is widespread, but data are not readily available because malnutrition itself is usually not a reportable disease, although it is an important precondition for widespread health problems and morbidity. Malnutrition information collected recently in an International Federation of Institutes for Advanced Study (IFIAS) project shows that malnutrition is common even in regions that export agricultural products. There is a tendency to assume that agricultural areas will be sufficient in food supplies, but of course many agricultural areas are devoted to nonfood crops. In fact, most developing countries export nonfood agricultural products. While malnutrition is brought about more by various socioeconomic factors than by climatic factors, adverse climatic factors can be crucial in causing agricultural unemployment, and the resulting reduced levels of income may contribute to inadequate food consumption. This link between climate variability and malnutrition may be an important one, particularly in areas not devoted to food crops or in areas where food crops are grown principally as cash crops.

4.3 CLIMATE INFORMATION AND AGRICULTURAL PRODUCTION

In principle, climate information on a wide range of time and space scales can be used effectively to improve local agricultural production, conserve water resources, use fertilizer and energy resources optimally, and, in general, reduce vulnerability to changing conditions. In practice, even in highly developed societies, not all such information is available, nor is the available information used as effectively as it could be. Farming has long been a successful human enterprise, relying a great deal on traditional methods and empirical information, and incentives for farmers to accept new methods and use new information are often lacking. To make climate information most useful to farmers in developing areas, analyses must be made of the current agricultural conditions and practices. Then, useful physical climate information can be identified for various time scales. Progress is being made in some regions in identifying the kind of information useful to small farmers and the means of communicating with them, e.g., radio.

For one growing season this information might include optimum planting time for each crop in each region; balancing risks of planting early or late against uncertainties in the climate outlooks; ground moisture reserves and moisture availability during the growing season, so that irrigation can be planned to minimize waste of water; and advisories during the season (mostly "weather" type of information). The information might also include any positive departure from normal variability that might be taken advantage of by increased planting, intercropping, and other techniques and any negative departure that could be countervailed to a useful extent by change in practices or cropping patterns. The outlook for natural or man-induced *long-range trends* might also be taken into account in long-term planning in land use, development of new agricultural areas, shift of agricultural practices, or even for decisions to abandon previously usable lands.

Some of these kinds of climatic information are within the current state of the art or are foreseen as available in the next few decades. It is highly uncertain whether we will attain adequate understanding of the physical climate system to make possible usable outlooks for more than one year. Moreover, one cannot assume that social, political, or economic infrastructures exist or could be brought into being that will make use of climate information, were it available, for the benefit of individual small farmers or even for large planning units. Better use of information and evolution of human institutions to make such use possible should decrease the vulnerability of agriculture to the commonly experienced range of climatic variability. Rare and exceptionally severe events and long-lasting shifts demand different kinds of preventive, ameliorative, and adaptive measures. For both normal variability and emergency situations, communication facilities and practices can be improved or introduced to disseminate information on climatic conditions to rural populations.

In general, in agriculture there are opportunities to improve and in some cases regulate production to be in closer harmony with the existing physical environment and its variability in time and space. Much useful information is now available but not necessarily used. One step to improve this situation would be the introduction or expansion of meteorology and climatology in agricultural curricula and the training of local agricultural government agents or advisors.

4.4 CLIMATE AND WATER MANAGEMENT

Water management at all levels is essential for the maintenance of human life. In developing countries, water management has usually focused on agricultural systems. Increasingly, competing demands are being placed on water supplies; and decisions must be made about allocating water among various purposes, including agriculture, energy generation, and other industrial and civil uses. The sound design of water systems is dependent on, among other things, knowledge of the geomorphology of an area and its climatic conditions. As the possible risks that may result from poor water management grow, the value of climatic information goes up. Climatic information on various time and space scales can be provided in different regions, which would contribute to improved design of water storage, development of new capabilities, and more efficient use of water. However, the utility of climatic information should not be exaggerated in the presence of constraints imposed by geomorphological factors and human institutions.

4.5 CLIMATE AND FORESTRY

Forests are an important part of local ecology through their roles in relation to such factors as soil, moisture, erosion, and shelter for animals. Clearing land for agriculture or firewood changes the character of the land and may affect local climatic conditions by altering temperature, moisture control, and albedo. Large-scale deforestation may also be a factor in significant climatic changes, because on a global basis forests are a sizable part of the total biomass that enters directly into the carbon cycle. As reforestation becomes more and more desirable, particularly in developing countries where the highest priority must be given to renewable resources, climatic information can play a role in optimum management of the forest resource.

4.6 CLIMATE AND URBANIZATION

Many social, economic, and political activities provide incentives for population movement to established cities or newly created centers. Adverse climatic conditions may contribute to this movement, which in a short time often leads cities to exceed their carrying capacity, as measured by water supplies, local fuel sources, and waste disposal facilities. Consequent deforestation and pollution may lead in turn to a deterioration of the microclimate. Even given large financial resources for applying technological solutions, these situations pose difficult questions. Do and, indeed, can national, regional, and local planners take into account climatic factors, possible future climatic shifts, and other natural factors in attempting to manage such seemingly inexorable social changes as urbanization? What kinds of physical information could be useful to civil engineers in developing countries?

4.7 CONCLUSION

In the developing world, climatic change and variability, both positive and adverse, have a profound and often immediate impact on the population, but the full impacts will be determined by many nonphysical factors, such as social, economic, and political structures and cultural habits and patterns.

These human elements must be considered in assessing impacts of recent physical events so that climate factors can be placed in their proper perspective in planning for future use of climate data and in evolution of social systems to reduce their vulnerability. Unless the complexity of the development process is appreciated, efforts to use climatic information to contribute to it are not likely to realize their potential.

Additional viewpoints on these issues are presented in Annexes C and D following this chapter.

ANNEX C
Climate Impacts and Socioeconomic Conditions—Edited Transcript of Remarks Delivered at the Workshop

ROLANDO GARCÍA
International Federation of Institutes for Advanced Study

I would like to discuss the impact of climatic fluctuations on the food systems in developing countries. As part of a study of the impact of drought on society,* I have been analyzing the impact of climate during the year 1972. The report of this project is expected to be published in 1979 under the title "Nature Pleads Not Guilty." My work in connection with this project has led me to view the impact of climate on the food system of a given society as a complex nonlinear problem. The structure of the society receiving the climatic impact is as important–and sometimes more important–than the nature and intensity of the climatic anomaly itself. Moreover, within a single country a given climatic influence may act in quite different ways on different productive sectors. This is particularly evident in developing countries, where the structure of the productive system varies widely according to whether food is considered to be a commodity produced for export and for the demands of urban populations or alternatively as an essential human need. These facts do not show in the national statistics of agricultural production.

I have found that studies of climatic impacts can be obscured by global statistics. Local and regional problems either disappear or are distorted. An uncritical examination of production and trade statistics on food and a superficial correlation with climatic anomalies may also lead to erroneous conclusions concerning the international food crisis. Such was the case, in my opinion, in the sky-rocketing of grain prices in the period 1972–1974 that has

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*"Drought and Man: the 1972 Case History," a project commissioned by the International Federation of Institutes for Advanced Study (IFIAS).

been attributed to widespread simultaneous drought in the Soviet Union, the Far East, India, and the Sahel region of Africa.

The conditions in the Sahel provide a good example. This was a region of famine. The horrible consequences of that famine have largely been responsible for the renewed worldwide interest in climate, which is bringing about a World Climate Conference. The famine and other social consequences shocked the world. The fact that surprised me was that the actual deficit of food production in the Sahel was very small relative to the amount of human suffering in the Sahel drama. The deficits that brought about the famine were of the same order as the systematic errors in official statistics. The true impacts of the drought in the Sahel cannot be understood solely in terms of the output of agricultural production.

The Sahel is by no means the only example. The worst famine in our century took place in Bengal in 1943-1944. The usual explanation is that the famine resulted from the failure of the rice crop because of floods. It is also recognized that the situation was much aggravated by the war; at that time the invasion of Burma resulted in the cutting off of the exports of rice to India. This is only a partial explanation. It is true that the floods were the immediate cause, and it is true that there was famine resulting in the death of 2 million to 4 million people. If one probes deeper, however, you find the following: there was a shortfall in the winter rice crop in 1942, but it was, in fact, not so serious as it was claimed to be. An estimate of the shortage of rice was made in December of that year by the Government of India. Taking account of loss of rice from Burma due to the war and an indifferent rice crop generally in Bengal, the Indian Government requested the British Government to supply an additional 600,000 tons of wheat. I found it strange that a shortfall of 600,000 tons of grain could cost 2 million to 4 million lives. What happened? Simply, the famine was not the direct result of the shortfall in the rice crop. Recently, Amartya Sen,* an economist of the London School of Economics, analyzed food prices, the inflation produced by the war effort, and other economic and social factors. He clearly shows that it was the dislocation of food prices resulting from speculation that prevented adequate food availability. It was the disparity between food prices on one hand and wages and employment on the other that produced the catastrophe–one of the most severe in this century.

The official "Famine Inquiry Commission" appointed after the Bengal famine reduced the estimated number of deaths to 1.5 million. It is currently believed that there were at least 3 million deaths. It also increased the estimates of damage produced by the floods. We now know, however, that the

*A. Sen (1977). Starvation and exchange entitlements: a general approach and its application to the great Bengal famine. *J. Econ. (Cambridge) 1*, 33-59.

floods are not the whole story—nor even the most important factor. One must examine the entire chain of events triggered by the floods. Inevitably we find that climate, economic, and social factors are so interwoven that it is necessary to study and understand the entire climate-economic-social system.

In general, in many developing countries the situation that must be understood is different from that in developed countries. For example, in developing countries a rather large sector of agricultural workers are salaried. When a bad year occurs, malnutrition quickly follows. You would not expect malnutrition to occur the same year as the bad harvest because each year you have carryover food stocks produced in the previous year. But this is not the case. If there is a failure of the harvest, there is no employment for the workers. If there is no employment there is no salary, and when they have no more salary they cannot buy food. The effect is felt immediately, as the people have no bank accounts to draw upon. Malnutrition can exist in the face of adequate food stocks. A good harvest in the year following a bad harvest does no good. It may turn out that at no moment was there actually a shortage of food in the country—only a shortage of income to purchase it. The impact of one year of bad weather can thus be tremendous on a rural population working for a salary. This type of effect disappears completely when you merely consider food-production statistics in correlation with weather phenomena.

In the case of the Sahel, the situation is more complicated but exhibits many of the same properties. From the data available to us, we analyzed in the IFIAS study what happened to food production in the Sahelian countries during the drought period. The drought started in 1968-1969, became aggravated, and culminated in 1972-1973. However, Niger, one of the countries most severely affected, exported $30 million and imported $10 million of food in 1972. The total food deficit according to the FAO studies for all the countries of the Sahel in 1972 and 1973 was 700,000 tons of grains. Just how large is 700,000 tons of cereal? One measure is that in the United Kingdom in 1972, 30 million tons of grain were used as fodder for livestock. For the entire developed world, more than 400 million tons of grain were used for livestock.

There have generally been two views about the Sahel tragedy. The first holds that drought aggravated by population density and overgrazing explains the events. The second is that cash crops eliminated self-subsistence agriculture on the one hand and pushed the nomads to very vulnerable marginal lands on the other. Our analysis leads us to the conclusion that these explanations have elements of truth but are oversimplifications. One cannot explain what happened merely by the drought, merely by overpopulation, merely by overgrazing, or merely by the emphasis on cash crops. It was only when we went deeply into a study of the socioeconomic conditions of the regions in the Sahel that we began to understand the dynamics of the problem. Our view is that the catastrophe resulted from the increased fragility of the whole economic and social system, which required only the triggering effect of the drought to cause a collapse.

I can cite another example, a very simple one. Northeast Brazil has had continuing problems with drought. But Nature is not alone responsible. Some Brazilian writers have referred to a drought "industry" in northeast Brazil. To protect against drought, the government, according to law, is obliged to assist affected farmers by providing credits and other types of help. Whenever there is a decrease in rainfall, there is pressure to declare an emergency that can release government assistance in the form of credits and land improvements, for example. This assistance invariably goes to the big farmers. The pressure, therefore, for declaring emergencies is great, even if the drought is not severe. I sometimes wonder what analysts like myself will do a century from now when they go back to the records in Brazil to analyze the declarations of drought. The relation to real physical droughts is tenuous indeed.

It is hard to avoid the conclusion that it is dangerous to generalize. The social, economic, and political factors are so variable from one developing country to another that it becomes essential to consider climate impacts in the specific socioeconomic systems in which they occur. The climate impacts in developed and developing countries are widely different in most cases. Let me illustrate. Suppose that in a developed country like France you have one killing frost in 10 years. You may have two strategies for coping. You can either use high-yield crops and procedures with low frost resistance giving you nine good harvests and one bad one, or you can use techniques that produce lower but more reliable yields. I have been told that there is a greater economic return using high-yield, low-frost-resistance methods even if there is one year of failure. The same strategy applied in a developing country results in tragedy. It results from the pattern of work. If work on the land is lacking for one year, there is a tremendous impact on the society. The effect is much larger than the climatic anomaly would lead you to expect. You can obtain enormous amplifications of small climatic effects, as in the Bengal famine, mainly as a result of the socioeconomic conditions. The strategy for coping with climatic anomalies must be different for different socioeconomic systems.

Climatic information is often poorly used in the agricultural strategies of developing countries. Tanzania is a country that suffers from droughts. Sorghum and millet are the crops best adapted to local climate and have been the staples of Tanzania for generations. Recently, the World Bank in attempting to assist Tanzania provided credits to step up corn production. Corn is a high-yield crop, but unfortunately it is more susceptible to drought. In addition, the hybrids that are being used require periodic renewal of the seeds (imported), as well as fertilizers and pesticides. Thus, in bad years, it can be expected that farmers will be in particularly serious trouble. The reason why credits are provided for corn and not for sorghum and millet must be explored.

To sum up, climatic impacts in developing countries cannot be understood unless you consider the problem in its whole complexity: the atmosphere, the soil, the total ecological system, human activities, the food system, and the interaction with society. It is only by such a systematic approach that we can provide the beginnings of an understanding of the real impact of climate. It is the total structure of society that is affected. The key problem is the vulnerability, not of a single crop, but the vulnerability of the whole socioeconomic structure of the society, including the political system. Unless we analyze the totality we cannot claim to understand what is meant by the impact of climate.

ANNEX D
How Can the Climatologist Help the Developing Countries? Edited Text of Remarks Delivered at the Workshop

ROGER REVELLE
University of California, San Diego

In developing countries, climate has its greatest impact in the zones of widest climatic variability—the warm, semiarid and subhumid zones, particularly the regions of monsoon climates.

These regions of developing countries include nearly all of the Indian subcontinent; the semiarid and subhumid regions of China; Thailand and parts of Indo-China; much of the Middle East; part of Africa north of the Sahara; the Sahelian zone south of the Sahara, extending from Senegal through the Sudan to Ethiopia; parts of southern Africa; northeast and southwest Brazil and parts of the central Brazilian plateau; northern Mexico; large areas of Argentina and Chile; and the coastal zone of Peru.

The present populations of these regions total more than 1500 million people, 60 percent of the population of the developing world. With the rapid growth of populations, a sustained high level of agricultural production is becoming more and more critical. All resources are being stretched closer to their limits, and climatic variability is an increasing threat to the survival of people at the margin of subsistence. Fortunately, the climates in most of these regions are warm, so that crops can be grown throughout the year, provided sufficient water can be made available.

Three kinds of knowledge about climate are important in the less developed countries: (1) the statistics of climatic variability, determined by suitable measurements over time and space, combined with the analytical manipulation of these measurements; (2) the ability to make short-range probabilistic forecasts of what the weather is likely to be a month to a year from now; and (3) the probability of climatic change—that is, the probability at some time in the future of a change in the mean state of the climate and/or in the frequency distribution of different states. From the standpoint of decision-makers, the first kind is most important at present.

Let us examine a few impacts of these three kinds of climatic information for less-developed countries, in agriculture, energy, forestry, fisheries, and health, realizing that there are many other aspects that might be discussed, given sufficient time.

AGRICULTURE

We shall discuss decision-making in agriculture at four levels: the individual farmer, the agricultural sector in a particular country, the national level, and the global society as a whole.

In traditional peasant agriculture, the farmer's decisions as to what crops to plant and when to plant them were made long ago, over many generations, by a combination of trial and error and canny observation of local climatic variability. The principal basis of these decisions was risk-aversion–the necessity to produce enough food for survival in years when the climate was "bad." Market forces had little influence because the crops were not sold but consumed within the village. And few decisions were necessary at the sectoral, national, or international levels.

With the unprecedented growth of populations in developing countries during this century, a transformation to market agriculture has become necessary. This means that the farmer must buy fertilizers, farm tools and machinery, and other inputs in order to increase his yields per acre, and he must sell a large part of his crop to pay for these inputs. With market agriculture there is much more flexibility, and the farmer must make decisions each year as to what crops to plant, when to plant them, the quantity and kind of inputs to purchase, and when to sell his harvest. Moreover, decisions need to be made at sectoral, national, and international levels, to ensure as adequate a food supply as possible for large and growing populations.

The farmer's decisions will be better if he can take account of the probability distribution of the timing and quantity of water supplies, potential evapotranspiration, and solar insolation. In a region of low and uncertain water supplies, he will plant millets instead of maize in the African Sahel and groundnuts instead of rice in Indian Saurashtra. He will be reluctant to borrow money to buy fertilizers. Where the danger of floods during the monsoon season is high, the Bangladesh farmer will plant floating rice, or nothing at all, and concentrate his efforts in the sunnier, more dependable winter seasons. If even moderate rainfall is likely in April and May, the Pakistani farmer will not plant cotton, because the cotton will waste its photosynthetic production in vegetative growth, and what bolls do develop will be severely damaged by pests stimulated by the moist environment. In regions where the monsoon starts and stops intermittently, the farmer will hold back half or more of his seed, to be able to make a second or third planting if the first planting fails for lack of moisture.

Agroclimatic information collected and interpreted by competent interdisciplinary scientists will be especially useful at the farm level in areas of rainfed agriculture, where crops that are not traditional for a particular region, such as fruits, nuts, vegetables, soya beans, and oil seeds, are being introduced for the first time. At the sectoral level, the agroclimatologist can give climatic specifications to the plant breeder who is attempting to produce better adapted varieties.

In most of Asia, rainfall and runoff are concentrated in the few months of the monsoon season. Irrigation and drainage development and flood protection, at a total estimated cost of more than $100 billion, are essential if agricultural production is to be increased sufficiently to feed the growing population during the next 25 years. Beside providing water to farmers in the dry season, thus permitting two or three crops to be grown during the year, surface reservoirs and wells will smooth out the variability in water supplies within the rainy season. If the underground aquifer is sufficiently large, it will also be possible to reduce year-to-year variability by pumping down the water table during the dry years and recharging the groundwater during wet years.

Accurate information on the frequency distribution in time and space of rainfall and runoff throughout a river basin is obviously essential for the design of irrigation, drainage, and flood-control systems. But it is less obvious that such information is also necessary to optimize the management of these systems after they are constructed. In operating a surface reservoir, for example, the principal action involving a human decision is to release water through the penstocks and electricity-generating turbines or the irrigation tunnels in the dam. Though the action is simple, the decisions as to when and how much water to release throughout the year are complex. They will depend on often conflicting demands for irrigation and for electric power, on the economic and political weights assigned to these two uses, and on the best available estimates of river runoff into the reservoir during the remaining months of the year. All three of these decision factors rest in part on climatic statistics.

In the management of an underground reservoir, the mean depth to the water table should be maintained at an optimum level, such that water-logging and high evaporation rates will not occur during one or several years of heavy rainfall or river runoff, while pumping costs will be kept as low as possible after one or several dry years. Again, information on year-to-year climatic variability is essential.

At the national and international levels, the size and location of food-storage facilities, the quantity and kind of food reserves, the tonnage of ships for international food transfer, national pricing and procurement policies for agricultural products, and planning and institutional development for imports and exports should all be (but seldom are) based in part on both regional and global statistics of climatic variability.

Would climatic forecasts over 1 to 12 months help decision-makers at different levels? Under present conditions, such forecasts might be least useful to farmers and most useful at national levels. What does the farmer do with a forecast that says there is 75 percent probability that next season's rainfall will exceed 400 mm, instead of the 50 percent probability given by the statistics? Doubtless he should do something, for example plant a more water-sensitive but potentially more profitable crop or increase the amount of fertilizer that he will apply. But he is not likely to do either of these things unless sectoral or national actions are taken to assure the prices he will receive if he has an abundant harvest and to insure him against crop failure if the forecast turns out to be wrong.

At the sectoral level, climatic forecasts would enable fine tuning of the decision rules for release of reservoir waters. Forecasts of higher than normal rainfall or runoff should also stimulate planning and mobilization of forces for flood control. Forecasts of future weather conditions leading to increased pest populations would be helpful in organizing plant-protection measures.

At the national level, both regional and global agroclimatic forecasts would be useful in setting procurement prices, planning and allocating resources for food imports, or planning and organizing for exports of agricultural products.

At the international level, no institutional mechanisms for using global forecasts and little realization of the need for them now exists. But this does not mean that such institutions are not needed.

At present, our level of understanding of possible long-term changes in the mean state or the year-to-year variability of the global climate is low. For example, we are unable to estimate changes in patterns of precipitation and runoff with an increase in average air temperatures brought about by an increase in atmospheric CO_2. Under these circumstances, planners and decision-makers in less-developed countries cannot be expected to take much account of these possible changes. The world community, however, should act to ensure that sufficient planning and investments in irrigation, drainage, and energy conversion are undertaken to prevent a deterioration of per capita food supplies that might result from adverse long-term climatic changes brought about by the profligate use of energy in developed countries.

The leaders of less-developed countries can be expected to take greater responsibility for those actions of their own citizens that may be causing deterioration in the regional hydrologic cycle. For example, destruction of forests in the Himalayan foothills of Nepal, India, and Pakistan is probably resulting in more frequent and more severe floods in the Indo Gangetic Plains, on which more than 400 million people depend for their food supply. Equally serious, although less certain, may be a steepening of the river hydrographs, that is, an increasing concentration of annual river flows during the four months of the monsoon season, because of destruction of water-holding vegetation and soils. This may diminish surface water supplies for the winter crops.

Time does not permit more than a cursory review of the ways in which planners and decision-makers can use climatic information in other areas. Therefore I shall discuss these in summary, even telegraphic form.

ENERGY

1. To define areas where wind energy can be used economically (e.g., for pumping irrigation water), maps are needed of the monthly distribution of wind velocities, especially the number of days per month in which the average wind velocity is less than 2 or 3 meters per second. Windmills characteristically do not work at all below these wind velocities.

2. Development of biogas energy converters depends on the annual temperature regime. Different cultures of anaerobic bacteria are most effective within a relatively narrow temperature range. Here joint research by microbiologists and climatologists is needed.

3. The choice of flat-plate or focusing collectors for solar energy, and even the economic feasibility of using solar energy for different purposes, will depend in part on the daily, seasonal, and annual variations in cloudiness.

4. Development of run-of-the-river hydropower depends on seasonal hydrographs, mainly of small streams, and their variability from year to year.

5. The balance between thermal and hydroelectric power plants in any region depends on the frequency and length of droughts that reduce the water supply to reservoirs and increase the demands for power for pumping irrigation water. The 1972 drop in agricultural production in India was in part due to the fact that the nearly empty reservoirs could not supply sufficient electric power for pumping, and there was too little backup from thermal power stations.

FORESTS FOR FUEL, FORAGE, AND TIMBER

1. Selection of fast-growing tree species for forest plantations depends on the seasonal balance between water supply and evapotranspiration and on humidity, annual temperature regime, soil-water relationships (including soil salinity), and the variability of all these features from year to year. Much experimentation in different localities is needed to establish these relationships.

2. The possibility of intercropping, and the choice of crops to provide early returns to capital-poor farmers who are starting a forest plantation, depends on these same climatic factors, but the requirements for year-to-year stability may be more severe.

FISHERIES

1. Most fish production in less-developed countries comes from shallow-water nearshore or freshwater fisheries, the latter often in man-made ponds. The effects of climatic variability have not been much investigated but are probably small.

2. A few fisheries in less-developed countries–notably the anchovy fishery off Peru, the shelf fishery off India's Malabar coast, and Korea's wide-ranging distant-water fishery–appear to be more or less critically dependent on variation in oceanographic conditions, that is, in the ocean climate. For example, Peru's anchovy catch went from 12 million to less than 2 million tons in one year following the occurrence of the oceanographic phenomenon called El Niño. These relationships need further study before they can be used effectively in the management of the fisheries.

HEALTH

1. Several health problems in less-developed countries are closely related to climatic conditions, as these are reflected in the ecology of the infectious organisms and their vectors, for example, animal and human diseases associated with the Tse Tse fly in Africa, river blindness, malaria, Chagas's disease and schistosomiasis. But it is not easy to see how climatologists can provide much help in the solution of these problems.

2. The quantity as well as the quality of water supplies in rural areas of less-developed countries is a basic factor in the people's health, particularly in the incidence of trachoma and gastroenteric and skin diseases. Climatologists, having local knowledge of year-to-year variations in precipitation, runoff, and evaporation should be consulted in appraising the planning and development of domestic water supply systems in rural areas.

DATA IN LESS-DEVELOPED COUNTRIES

Finally, something needs to be said about the distressing shortage of data concerning hydrologic and other climatic parameters in most less-developed countries. Often only a few limited types of observations of questionable accuracy are available for only a few years. One of the major problems of climatology in an effort to help less-developed countries is to find and apply sophisticated methods of data analysis that will make it possible to make better use of short series of fragmentary, inaccurate measurements for the many purposes that we have described or suggested in this paper.

5 Scientific Priorities for International Climate Programs

Efforts–national or international–to improve man's ability to deal with climate must be based on understanding of climate itself. But even the narrowest definition of climate implies an awesome range of possible research investigations and climatic services. The resources available for climate research–computer power, observational platforms, money, and above all skilled manpower–are finite. Similarly, resources available to provide climatic data and services are limited, especially in developing countries. The complexity of the climate system suggests that research must be sustained over a period of decades, if we are to produce significant advances. The widespread lack of a climate data base similarly confronts us with the need for sustained effort. There is, therefore, a real danger of casting our net too wide by setting in motion international climate programs that include everything but that spread resources so thinly that no real impact is made on crucial issues.

5.1 CRITERIA FOR PRIORITY ASSESSMENT

It is, therefore, vital to develop clear priorities for scientific research and climate data and services. Selection of priorities may be based on a few key criteria:

1. *Socioeconomic.* Which climate problems imply significant impacts on human society? The significance may be judged in terms of the potential economic costs of the problem or the unquantifiable human and social costs.
2. *Scientific.* Which climate problems are scientifically tractable, are ripe for investment, and show promise of yielding useful results?

3. *Institutional.* Which problems clearly demand international efforts for their solution?

On the basis of these criteria, four major areas may be identified on which internationally organized activity should focus.

1. Development of an adequate climate data base and associated services, especially in the developing world.
2. Improvement of our understanding of the problems associated with increasing airborne concentrations of carbon dioxide as a consequence of fossil-fuel combustion and other human activities.
3. Improvement of our understanding of the causes and mechanisms of climate variations on monthly, seasonal, and interannual time scales, with a view to developing capabilities for prediction.
4. Development of methods and carrying out of studies to elucidate the full economic and social impacts of climate variability and change. Some organizational principles, criteria, and methodology for such a program are discussed in Chapter 6.

No order of priority is assigned to these four areas, since a balanced program of work in all is required and can be sustained as part of the world climate effort.

5.2 IMPROVING OUR CLIMATE DATA BASE AND ASSOCIATED SERVICES

Knowledge of the past and contemporary variability of climate serves two general purposes.

First, climatic information is directly usable in planning. We have little capability to predict future climates, but what has happened in the past is certainly *possible* in the future. The sophisticated economies of the developed nations already utilize climatological information and services extensively for a wide range of planning applications. Needs for similar information and services are at least equally pressing in the developing nations, and we will discuss these needs below. Thus, knowledge of the characteristics of climate is of universal and fundamental importance for realistic and sound long-term development planning.

Second, such knowledge is essential as a basis for development and testing of models of the climate system that may help us to predict natural man-made climate fluctuations. We have but one earth as a laboratory and but one present-day climatic regime to explore within our lifetimes. The record of past climates, preserved in considerable detail in a host of media, provides us with a well-stocked library of information on past climatic regimes differing markedly from our own. This knowledge is therefore of unique importance in the development and validation of climate models designed to investigate possible future climates markedly different from today.

Many types of data are needed to meet these needs in research and practical applications. Some specific scientific problems have specialized needs for data whose acquisition can best be considered as part of the scientific program itself. But a vast range of research and applications problems require the most complete possible climatic base, ranging from detailed instrumentally based contemporary records to reconstructions of climates of the distant past.

Data and Information Needs for Development

Needs for improvement of climate data differ from one region of the globe to another and even from one nation to another. In many of the developed nations and some of the developing nations, the climatic data base for national and regional planning of agriculture, water-resource development, land-use planning, and energy allocation, for example, is well developed. In other regions, especially in the developing nations, this data base is poor, scanty, or nonexistent. Rational and effective development planning is thus hampered by the lack of an objective basis for decision-making.

One theme that arises repeatedly is that the currently available climatic data base is totally inadequate to meet the pressing needs of the developing nations. The observational and communications networks for acquiring even the simplest observations of temperature, soil moisture, sunshine, rainfall, river flow, and other phenomena are totally inadequate, and the present international arrangements for improving these climatic-data networks are ineffective. Moreover, critical observing stations at sea and in remote areas are frequently abandoned because of inadequate funding. Available data are not assembled into usable and accessible information. These deficiencies should be remedied.

Technological advances provide some prospects for improving the acquisition and processing of contemporary climatic data. Earth-orbiting satellites, for example, can make major contributions in supplementing and extending the observational network and in accelerating the interchange of climatic data. Computer systems make possible the collation and organization of very large data bases with a facility not hitherto attainable. However, these potential capabilities will not in fact be achieved without conscious planning that takes into account the real needs of the research community, the developed nations, and above all the developing world.

Greatly strengthened international efforts are needed to improve the present arrangements for the acquisition and employment of climatic information for development planning. These efforts must include improvement of the acquisition, exchange, and processing of climatological observations; provision of financial and technical support to developing nations to improve their own capabilities; better international coordination of systems for providing climatological information from space-based monitoring and observing systems; and support for the maintenance and establishment of critical observing, communication, and processing facilities that may be beyond the immediate needs and capabilities of individual nations.

Relevance of Data on Past Climates

In the past few decades, our ability to reconstruct the details of past climatic regimes has advanced remarkably. A host of "proxy" data sources–historical records, deep-sea and glacier cores, pollen deposits, and tree rings, for example–have been used to obtain indirect yet quantitative information on past climates. The resolution, representativeness, and accuracy of sources of data on past climates vary widely. Deep-sea cores yield information extending into the geological past, but with coarse resolution in time. Pollen records from varved lake sediments may provide data on continental climates on an annual basis. Tree-ring data can overlap with data from instrumental records and may be cross-calibrated with these observations to extend their spatial and temporal extent. These varied data sources can enable us to reconstruct the global and regional patterns of climatic change associated, for example, with past cooling and warming trends in global climate, and can furthermore contribute to the study of the full range of climate problems.

These indirect data sources are particularly important in the developing nations, where instrumental records are often scanty. Indeed, proxy data may in many cases provide the only feasible source of climatic guidance for development planning. Man's engineering works often have projected lifetimes extending half a century or longer. Planning for irrigation systems, water storage dams, and power plants all require a knowledge of the variability of climatic conditions, which can only be obtained from climate records many centuries in length. Reconstruction of the past is thus indispensible for planning of the future.

As noted elsewhere, information on past climates also provides us with possible analogs to future climates resulting from human interventions and data bases needed to verify physical models to predict these effects.

Internationally organized efforts to reconstruct data on past climates from proxy sources are needed:

- To inventory and to assess the available resources of data on past climates;

• To bring together these diverse sources of data in a homogeneous, calibrated, and readily usable form;

• To reconstruct the large-scale patterns of climate variability; and

• To identify gaps in the climatic record and to plan work to fill these gaps.

5.3 UNDERSTANDING HUMAN INFLUENCES ON CLIMATE

The list of possible mechanisms by which man may influence climate is long and appears to grow steadily. The members of the Workshop examined a variety of possible climatic threats by man's activities. For example, injections of chlorofluoromethanes and oxides of nitrogen into the atmosphere present a possible threat to the stability of stratospheric ozone. Present indications are that at least the effects of the oxides of nitrogen are less threatening to man and to the climate than had been believed only a few years ago.

In contrast, injection of ever-increasing amounts of carbon dioxide from combustion of fossil fuels remains a worrisome problem. The outlines of this problem are familiar and hardly require elaboration: combustion inescapably liberates carbon dioxide; about half of the man-made carbon dioxide remains in the air; despite its low concentration, the gas plays an important role in the radiative energy budget of the atmosphere; numerical models indicate that significant global warming could result; and economic reality suggests that we must burn fossil fuels for many decades to come. It should be noted that release of other industrial gases, principally the chlorofluoromethanes, adds to the "greenhouse" effect and thus to possible future warming. Also, CO_2 is released from net deforestation, and some scientists believe that the rate of release from biomass destruction equals that from fossil-fuel combustion. Cautionary notes must be sounded: predictions of future atmospheric CO_2 concentration become uncertain, particularly beyond 20–30 years from now; small changes in cloudiness could compensate for large changes in carbon dioxide; and there is no guarantee that the overall effect of climatic changes would be in the aggregate damaging to the welfare of the human race.

Nevertheless, because of its tremendous socioeconomic implications and the inescapable need to make major decisions in the relatively near future, assessment of the full implications of changing levels of carbon dioxide and other radiatively important pollutants should be a major focus for international climate research efforts for some time to come.

Climate models will be essential tools in this task. As noted above, data on past climates will be no less essential, both to validate our predictive tools and to provide analogs of the detailed climatic implications of a warmer earth. Models for the study of the long-term effects of increased carbon dioxide concentrations must take into account the oceans, the complex processes of atmospheric chemistry, the natural and perturbed carbon cycle, the interactions between climate and the biosphere, and other factors. Development and validation of such models will clearly require international collaboration.

We must explicitly recognize political realities in planning the assessment of the carbon dioxide question. If there are indeed climate changes, some regions will benefit, and others will suffer. If controls are required, the impacts on particular economies will again differ widely. We can hardly expect that nations will readily accept conclusions derived by others nor restrictions devised by others. An international program aimed explicitly at an internationally accepted consensus is therefore as essential politically as it is scientifically.

5.4 RESEARCH ON WEEKLY, MONTHLY, AND SEASONAL CLIMATE PREDICTION

Prospects for Prediction

Numerical general-circulation models have demonstrated an impressive capability to simulate the major features of present and past climates. Moreover, promising possibilities for extended prediction are also being detected. In the United Kingdom, for example, experimental numerical forecasts of 10-day averages for periods of up to 80 days into the future are now being prepared and evaluated. In the United States, numerical forecasts out to 10 days are now issued routinely, the last 5 days of the period being represented as averages. These forecasts show some skill, i.e., the predictions are correct more frequently than would be expected from random choice and climatological probabilities. Many other countries also issue experimental forecasts for monthly and seasonal periods based principally on statistical and empirical approaches. Skill in these time ranges is, however, marginal. No interannual forecasts have demonstrated significant skill. This research, while carried out in only a handful of major laboratories and operational facilities, clearly has broad international significance. Predictions of this type could provide statistical guidance on probabilities—averages over some time period, storm tracks, general weather character, and likelihood of extreme events, for example—which would be of great economic value to all countries.

With an appropriate international effort, we could learn within the next decade whether usefully skillful predictions of climate commencing at the 2- to 3-week theoretical limit of conventional numerical methods and extending out to periods of months and seasons are feasible. Indeed, some participants in the Workshop believed that there is some prospect of actually developing practical operational capabilities within this period. The quest for extended climate prediction should therefore be a continuing objective of international programs in climate research.

The Usefulness of Prediction

Such predictions have great potential value to the economies of both the developed and developing world. Seasonal predictions, for example, would reduce the uncertainty in existing models of crop response employed to forecast agricultural outputs. Interannual predictions would improve planting strategies through selection of crops and individual strains. In developed nations, planning of weather-dependent aspects of such activities as energy production and consumption, transportation, and marine resource development could be accomplished more effectively. World agricultural and commodity markets might become more stable. National management of water resources could be improved. Predictions of anomalies in large-scale events such as the Asian monsoon or regional droughts as in the Sahel could lead to more timely international action to prevent human suffering.

However, it is by no means certain that the mere availability of statistically skillful prediction will produce the anticipated practical benefits. The realization of benefits from advanced predictions of climatic conditions will depend on the ability of specific economic and political structures to respond. Climate is, after all, but one element in the complex and interconnected system in which humanity lives. New information on future climate anomalies is itself a perturbation in this system, and its effects may not automatically be beneficial. The economic interaction with climate is poorly understood. International programs are therefore needed to devise improved methodologies and mechanisms for effectively using climatic predictions in national and international decision-making.

Research Needs—the Role of GARP

Effective programs in climate research are being pursued or developed on both national and international levels. These programs seek to acquire the basic understanding of climate fluctuations, which is essential for the prediction of climate. Pre-eminent in the international arena is the Global Atmospheric Research Program (GARP), a joint endeavor of the World Meteorological Organization and the International Council of Scientific Unions. It is generally recognized that the present work of the Climate Dynamics Sub-Program of GARP will form the core of the research component of a future World Climate Program. GARP programs, which form a closely coordinated ensemble, therefore merit the strongest continuing support by the nations of the world as we plan future efforts directed specifically toward the problems of climate.

In this connection, it is well to recall that the Global Weather Experiment, which will be conducted in 1978-1979, is designed to provide the basis for research in the numerical modeling of weather and climate over most of the next decade. This comprehensive global data set will for the first time permit the detailed study of interseasonal climate transitions and indeed the entire annual cycle of climate. The successful execution of the observational program and subsequent data processing and research efforts is therefore of the highest importance.

Additional viewpoints on the topics of this chapter are presented in Annex E following this chapter.

ANNEX E
On the Scientific Nature and Status of the Global Climate Problem

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Climate is the synthesis of weather over a period long enough to establish its statistical characteristics, and climate prediction is concerned with determining how the statistics will change in the future as the external or boundary conditions change. Climate and its variations are therefore usually described in terms of such statistics as mean or average values, deviations from the mean, and probabilities of extreme events.

It has been the practice to use an averaging period of 30 years, but, since atmospheric fluctuations occur on all time scales, it may be inappropriate to choose a specified period that may be unrepresentative and therefore unreliable as an estimate of future conditions. In any case, climatological records, of whatever length, are so dominated by irregular fluctuations with few, if any, regular cycles or trends, that they provide no real basis for *predicting* the climatic variations likely to be experienced in the next few decades. At best they can be used to estimate the *probability* that fluctuations of a given magnitude and duration may occur within a specified time interval and to judge whether a particular even is "abnormal" in the sense that it lies well outside expectation based on the past statistics. Thereby it is possible to indicate the range of fluctuations and the associated degrees of risk. Rare events that occur only once in a century and smaller fluctuations that last only a few years may both have important economic and social consequences.

Predictions of the extent and duration of climatic changes are not possible at present and must await greater understanding of the underlying causes, whether internal or external to the atmosphere. The first step is to understand the physical basis of the currently observed climate. This requires the building of models to represent essential climatic processes and interactions. Fairly simple models that ignore or grossly simplify some parts of the problem can be used to explore specific aspects. For example, they may be two-dimensional and assume that the complex motions of the atmosphere can be represented crudely by zonal averages or, in order to isolate the role of the oceans in climatic change, they may regard the atmosphere as a random forcing mechanism for the oceans.

However, by far the most promising approach is the development of complex numerical models that treat the atmosphere as a turbulent, rotating fluid heated by the sun and exchanging heat, moisture, and momentum with the underlying continents and oceans and that allow for seasonal changes in solar radiation, ocean-surface temperatures, and land-surface characteristics. Although such models are necessarily simplified representations of the real atmosphere, they have been remarkably successful in predicting the weather several days in advance and in simulating the main features of the present global climate, including seasonal changes and specific events such as monsoons. Allied to the most powerful computers, they have become the primary tool for examining the sensitivity of climate to natural changes, e.g., in the sun's radiation, the land surface and vegetation cover, soil moisture, and sea-surface temperatures, and to possible man-made changes to the carbon dioxide, ozone, dust, and heat content of the atmosphere and for judging whether these are likely to be distinguishable from natural climatic fluctuations. They would also be needed for calibrating simpler models should these prove useful for indicating changes in the gross features of the climatic system. The numerical models also offer the best chance of making useful monthly or seasonal forecasts and, eventually, of longer-term predictions.

On the other hand, the models contain notable deficiencies, and high priority must continue to be given to their development and improvement. In particular, there are severe difficulties in the simulation of clouds and their effects on radiative heat transfer and in treating interactions between the atmosphere, the ice sheets, and the oceans, which, being great reservoirs of heat, almost certainly exert a strong long-term control on the climate. Meanwhile, good judgment must be exercised in asking sensible questions of models and in interpreting their numerical answers in light of the known limitations and defects of the model behavior.

The actual *prediction* of future climatic changes, as distinct from the simulation and sensitivity studies just described, poses a formidable scientific problem. It is especially difficult because it is not possible, as in daily weather forecasting, to check such long-term predictions against observation. The best that can be done is to build models that incorporate all the potentially important processes and interactions, to check as far as possible individual components against continuing observations, and, perhaps, to test how well the models can simulate *past* climates. Bearing in mind what is already known about the limits of atmospheric predictability on much shorter time scales, there can be no assurance that climate predictions are even possible. In the absence of a unique climate model, and in view of the fact that any given model starting from different initial conditions tends to produce rather different steady-state climates, any prediction is likely to be probabilistic rather than deterministic in nature. To establish what is possible will require extensive research based on more advanced and complex models requiring the most powerful computers, which may be beyond the capability of most individual nations.

Improvement of the global coverage of weather observations (also required for weather forecasting), especially over the oceans and tropical and polar regions, will be required as input to the models and to test their ability to simulate mean seasonal and annual cycles, including major features such as the monsoon. In addition it will be necessary to monitor slowly varying parameters such as the solar radiation, earth's heat balance, land-surface changes, and changes in atmospheric composition, e.g., carbon dioxide, ozone, and dust. The most important and difficult gap to close will be the monitoring of the oceans to establish their interaction, through the transfer of heat and moisture, with the atmosphere.

The foregoing discussion suggests that a comprehensive research program should have the following main components:

1. Reconstruction of past climates from instrumental and proxy data but concentrating on the historic record of the last few thousand years, in order to determine the nature and extent of climatic variations. This will provide a data base for statistically based assessments of future trends and for validating numerical model simulations of past climates.

2. Acquisition of comprehensive computerized data sets on the present climate to provide better climatological service for model development and validation and to study mean annual and seasonal climates and their variations. The First GARP Global Experiment (1978–1979) will provide the first comprehensive global set of conventional weather observations covering one annual cycle. It will also be necessary to monitor at least the upper layers of the ocean; the sea and continental ice sheets; changes in the land surface and its biological cover; the incoming solar radiation; and the carbon dioxide, ozone, and dust content of the atmosphere. Most of these data, except the subsurface ocean data, should be provided by satellites within the next few years. Of related interest is the study of long-range transport and removal of SO_2 and other pollutants.

3. Development and validation of improved computer models for the following purposes:

(a) To obtain a better understanding of the various processes governing climate and its variations including interactions between the atmosphere, oceans, and cryosphere (sea ice, snow cover, and ice sheets).

(b) To assess the degree to which climate is sensitive to both natural and man-made perturbations. Priority should be given to the problem of carbon dioxide and other radiatively significant trace gases. Since the effects are likely to be stronger at high latitudes, it will be necessary to investigate in some detail the likely impact on the melting of ice sheets and the changes of sea level, as well as the consequences for agriculture and other economic sectors. The possibility that the ozone shield may be diminished by the release of nitrogen oxides, chlorofluoromethanes, and other substances also merits continued study, especially as recent calculations carried out in the U.K. Meteorological Office suggest that increasing CO_2 may lead to an *increase* in stratospheric ozone and largely offset the effects of these other compounds.

(c) To assess the degree to which natural climatic changes may be predictable, starting with monthly and seasonal forecasts for which there is a strong demand and a reasonable expectation of success.

All these research aspects, and perhaps some others, should be included in international climate programs. However, the work can be done only by nations, and at present the bulk of it by just a few. In particular, advanced climate models have been developed in very few countries.

6
International Programs for the Study of Climate Impacts

6.1 INTRODUCTION

A comprehensive climate program is likely to consist of three major components, dealing respectively with research into the processes of natural and human-induced climate variability, climate data and services needed to describe and to cope with climate variability, and the impacts of climate variability on human society. Because this third area of assessment of the impacts of climate variability on man's activities had yet to be clearly formulated by any group, considerable attention at the Workshop was devoted to defining the appropriate goals, methods, and institutional arrangements for international programs for the study of the impact of climate.

Climate is one of many areas of concern to mankind competing for attention. Reliable quantitative estimates of its influence on human well-being are needed to help make a rational allocation of resources between work on climate and other efforts directed toward improving the health and productivity of society. This knowledge is also needed to assign priorities among the many things that could be done to aid society in coping with a variable climate. What are the most pressing problems? What information, what capabilities would best assist us in coping with variable climate? Furthermore, what adjustments in societal mechanisms could minimize the adverse effects of climate variability or permit more effective use of information on climate?

It is evident that the impact of climate on society as a whole, and indeed the total impact of climate on any component of society, is determined by a

WMO participants did not take part in the discussion of institutional arrangements, and this chapter does not reflect their views.

complex set of interactions. The impact of climate must, therefore, be evaluated in a context including the characteristics of climate itself, the nature and evolution of ecological systems, the pattern of human settlement and activity, and the socioeconomic and political factors that influence human activities. The immediate effects of climate variability on specific components of the physical-biological system are only part of the required larger analysis. In such a coupled, nonlinear system, the total impact of a climate variation is likely to be quite different from the sum of the immediately perceptible and readily quantifiable effects. At the same time, these interactions make it exceedingly difficult to extract the climatic "signal" from the "noise" induced by other factors and their interactions. In 1972, for example, the effects of a series of climatic anomalies were greatly magnified by other factors to produce among other things unusually large changes in world food prices.

The regional impact of the 1976-1977 winter climate in the U.S. Pacific Northwest is another example. Northward movement of storm tracks greatly reduced snow-pack accumulation and thus curtailed hydroelectric power generation. Power allocation policies gave highest priority to public utilities for sale to private residential consumers and reduced the power available to industry. Widespread job losses were among the severe regional economic impacts. Furthermore, the same hydrological facilities are responsible for supplying water for irrigation, much of it pumped by hydroelectrically generated electricity. Thermal power facilities were available to provide backup, but at much greater cost. Forecasts of power and water availability, based on techniques applicable to more normal conditions, led to fears of severe and long-lasting agricultural damage, creating political pressures for drastic and expensive emergency measures. These forecasts proved to be overly pessimistic, leading to widespread anger at the actions that had been taken.

While the most noted climatic phenomena are the extreme ones, it is important to recognize that the natural world and human society are probably more shaped by climatic normals and the usual range of climatic variation. The pattern of agricultural development in the Indian subcontinent has largely been determined by the expected cycle of the monsoon and can accommodate to, for example, normal year-to-year variations in the date of onset and "break" monsoons. Extreme variations, however, may overstress the adaptive capacity of the system, with distressing consequences.

6.2 OBJECTIVES OF THE STUDY OF CLIMATE IMPACTS AND THEIR IMPLICATIONS

The above considerations led to the definition of certain objectives for climate impact studies:

• To determine the effects of climate on the various sectors of the natural world and of human economic and social life, such as hydrology, agriculture, and energy. Again, this objective should include analysis of the ways in which both "normal" and "extreme" climatic variability influences these sectors.

• To determine the *indirect* effects of climate, its expected variability, and extreme climate anomalies that, with the direct effects, form the total impact of climate upon society.

• To determine the characteristics of natural and human systems that make them vulnerable or resilient to climatic fluctuations.

• To determine the kind of climatological information needed to serve:

(a) Short- and medium-range decision-making intended either to decrease adverse effects of unfavorable climate or to take advantage of favorable conditions with reference to a given natural or human system.

(b) Long-range development planning to improve the efficiency and to decrease the vulnerability of human systems to climatic fluctuations.

These objectives have several implications for the studies:

• As noted above, the studies must recognize the interactive, interlinked nature of the systems being dealt with. Studies of individual elements, such as the response of a particular crop to climate variations, must be designed to permit later integration into analyses of whole systems.

• Meaningful studies of the total impact of climate will have to be conducted in a transdisciplinary framework in which disciplinary expertise is fully employed, but no single disciplinary model is enforced. The economic, sociological, and physical-scientific points of view should all be utilized.

• The studies must have unquestionable integrity and therefore credibility in the eyes of decision-makers. This implies an institutional framework that can both insulate the study process from special-interest pressures as far as possible and provide access to reliable data sources.

• Studies should be conducted under generally agreed on and stable methods to permit intercomparison of results.

• At least for the immediate future, work should center on diagnostic *case studies*, supplemented by studies of critical individual physical and biological processes. This approach is necessitated by the need to study the operation of the total system and our present lack of understanding of the workings and interactions of individual components. As this understanding evolves, it may become feasible to infer general principles and to construct meaningful simulation models to assess the impacts of future hypothetical climatic fluctuations. Specific historical case studies are clearly not the only ultimately useful class of impact studies. However, at our present level of understanding of the interactions between climate and society, concrete and specific case studies are essential for future, broader research and thus should have the highest priority for near-term climate impact study.

6.3 METHODS FOR THE STUDY OF CLIMATE IMPACTS

A four-phase plan for impacts studies was developed.

Phase I: Identification of Candidate Cases for Study

A small multidisciplinary management group (see below for further comments on institutional arrangements) should identify a certain number of events as potential candidates for intensive analysis and assessment. The following selection criteria were believed to be appropriate:

A. Climatic Characteristics

Regions characterized by clearly defined climatic features (monsoon, semi-arid, subtropical, for example) should be selected. From the climatic record, periods of significant fluctuations in these climatic features should be identified. Reliable data must be available for the selected periods. It is therefore likely that recent periods will be chosen. However, well-documented historical cases may be of considerable interest. For these periods, preliminary indications of either favorable or adverse effects on the societies and economies of the affected regions should be sought.

B. Socioeconomic Characteristics

Objectively quantifiable indices of socially important and potentially climate-sensitive sectors of national, regional, or global socioeconomic systems, e.g., food production, water resources, and energy demand/production, should be selected. Historical periods of significant fluctuations in these indices should be identified. Again, the availability of reliable data should be a major consideration. For these periods, preliminary indications of possibly causal or at least related climatic fluctuations should be sought.

C. Critical Decision Points

Classes of significant decision-making in which climatic considerations have or should have an influence, e.g., agricultural support/export policy, hydrological development, and harbor construction, should be identified. Specific decisions with favorable or unfavorable consequences should be identified. For these cases, preliminary indications of significant climatic influence on the making of decisions or on the outcomes of the decisions should be sought.

Phase II: Feasibility Study and Selection

Phase I will yield a number of potential candidates for intensive study. These may be ranked in priority order on the basis of how well they meet all the suggested criteria. For example, the best candidate study would involve a region with clear climatic characteristics, a period in which particular climatic events in the region were associated with particular socioeconomic perturbations, and a limited number of clearly definable policy decisions in whose making and working out the climatic influence could be clearly discerned.

A tractable number of possible case studies fitting these conditions should then be selected for further investigation to determine the feasibility of conducting intensive studies. To allow scientific investigation, the cases selected should provide variety in a number of dimensions, e.g.:

- Varying degrees of severity for a given type of climatic fluctuation, e.g., drought, temperature;
- Similar types of climatic fluctuation in different social and economic contexts, e.g., market economies, centrally planned economies, developed and developing economies; and
- Similar climate-dependent decisions in different climatic or socioeconomic contexts.

Each of these cases should then be studied in enough depth to determine to what extent the criteria stated under Phase I are in fact met and whether the resources (institutions, people, data) required for a full study are available. Responsibility for these studies may be assigned to different groups, but it will be important to ensure that comparable and compatible methods are employed. Coordination between the groups is therefore essential.

On the basis of these investigations, a smaller number of cases should be selected by the steering/management body for intensive study.

Phase III: Performance of Case Studies

A detailed plan for the actual conduct of the case study was not developed at the Workshop. It is, however, highly important that the early studies be carefully designed both to yield useful results and to evolve effective methods for later studies. With these ends in mind, it is suggested that a couple of points be considered in the design of the case studies. First, the few studies of climatic impacts carried out so far—e.g., the U.S. AID/MIT study project on the Sahel, the IFIAS "Drought and Man" project, CIAP (cf. Chapter 3, Annex A), the U.S.A.-Canada-Mexico "Living with Climate Change" program—should be drawn upon for guidance, both positive and negative. Second, impacts should be studied from within the nations and regions investigated as well as from outside. Wherever possible, experts and institutions within the study areas should be utilized both to ensure that the information, values, and perceptions of those directly affected are taken into account and to enhance the credibility and acceptability of the study's results to decision-makers within the nation or region. In the case of developing nations, it may be difficult to assemble the needed disciplinary skills; in such cases international teams may be required. Mechanisms for mobilizing such teams are discussed in the next section.

Phase IV: Synthesis of Results

As the results of case studies become available, efforts should be made to extract general inferences concerning the effects of climate variability on human society. This work should attempt to answer such questions as the following:

- What specific impacts of climate variability can be modeled now or in the near future on the basis of existing knowledge and on the assumption that the socioeconomic infrastructure will remain unchanged?
- What major specific impacts of climate variability cannot now be modeled or predicted quantitatively? Why? What are the principal barriers to achieving useful capabilities?
- To what extent can the *overall global and regional* impacts of climate variability and change be modeled and predicted? What accuracy will be required in individual components for such modeling? What interactions must be taken into account? What are the ranges of climatic and systems variation that can be accommodated in such modeling?
- How well could the full implications of *changed future configurations* of the global (or regional) socioeconomic system(s) be modeled and predicted? Do we understand enough about the general characteristics, interactions, needs of society to make such predictions feasible?
- In what fields could pilot studies be foreseen to test the applicability of physical climate data to planning and management?
- In what fields does it seem that lack of suitable social and economic infrastructure impedes the use of physical information on climate variability? How could the evolution of more suitable infrastructures be stimulated?
- How separable are the physical and human aspects of the consequences of climatic change?
- For what areas is climatic variability itself the appropriate focus or starting point for future work?
- For which areas are other factors the major focus or starting point?
- What are the ranges of variability, time, and space scales in which the climate system or the human system are the appropriate foci for impact study research?

Note on Historical Case Studies from the More Distant Past

A number of major historical transitions from one level of socioeconomic activity to another show an apparent association with regional climatic changes. These transitions have occurred in places where the physical geography today is such that under completely natural conditions (i.e., absence of human activity) the regions appear unsuitable for agricultural use and support small, if any, human populations. For example, much grain was produced for the Roman Empire, and substantial settlements existed in regions of North Africa now sparsely settled. Regions of the Negev Desert, now usable for only very limited pastoralism, were at one time inhabited by the Naboteans, who were able to farm by means of a simple yet sophisticated system of conserving and using the area's rainfall. For these two regions, it is tempting to conclude that "climatic change" induced the cessation of extensive human activities. It may have been, however, that these marginal regions really underwent political or social changes, or changes in patterns of human use, so that they were either inadvertently transformed or reverted back to an earlier unfavorable natural condition. Intelligent redevelopment of the regions might therefore again enable populations to be supported. Currently little-used lands could possibly be more productively used, and new insights into the interplay of human and natural ecosystems might help further identification of problems and design of remedial measures. Indeed, in the Negev, several areas are being used experimentally, in much the same way as the Naboteans used them, to explore the possibility of agricultural production under contemporary climatic conditions. Moreover, in areas such as desertification, studies and discussions often concentrate on a few causal factors like overgrazing and exceeding of water-supply capacities and on such remedies as massive irrigation. Historical case studies could offer another viewpoint and encourage imaginative use of what groundwater, direct rain, or runoff exists.

Feasibility studies could be undertaken to assess the possible use of such historical cases. It will be necessary to establish whether the data base is sufficient to describe the events well enough to use them as case studies and to ask questions that would provide information relevant to contemporary efforts.

6.4 INSTITUTIONAL ARRANGEMENTS

Institutional arrangements for the conduct and support of climate impact studies should be flexible, should permit the carrying out of politically sensitive studies, and should produce credible and convincing results. The active participation of both intergovernmental and nongovernmental organizations is essential. Intergovernmental bodies can provide access to data and resources necessary for the conduct of studies and provide means for the flow of results into decision-making processes in intergovernmental and national bodies. Nongovernmental bodies provide indispensable additional channels to the academic and intellectual communities. Funding for the climatic impact studies should come from organizations of the United Nations system and possibly from outside the United Nations system to insulate the study process from political pressure.

Many diverse institutions have a strong interest in the conduct of climate impact studies. The specialized agencies of the United Nations system, including the World Meteorological Organization, the United Nations Scientific, Educational, and Cultural Organization (UNESCO), the Food and Agricultural Organization (FAO), and the World Health Organization (WHO), are potential participants and possible sources of funding. Among the interested international nongovernmental agencies is the International Council of Scientific Unions (ICSU) through its many subgroups such as the Scientific Committee on Problems of the Environment (SCOPE). The International Institute for Applied Systems Analysis (IIASA), which is sponsored by the Academies of Science or similar organizations of 17 different nations and is a unique and excellent bridge between Socialist and non-Socialist countries, has a strong capability to assemble multidisciplinary international groups. Individual universities and academic institutions at the national level also have extensive expertise and ought to be encouraged.

The role of the WMO in the impact studies component of an international climate program is likely to be very important. The WMO has taken responsibility for planning the overall structure of a World Climate Program and will play a major role in the research and data and applications components of the effort. Assigning responsibility for the impact studies component as well to the WMO would therefore undoubtedly help to ensure effective coordination among all three components.

However, impact studies require a comprehensive examination not only of climate variability itself but of its relationships to world economic, social, and political systems and their interrelationships. Only a portion of this extremely broad field of research lies within WMO's area of responsibility and expertise. While impact studies will certainly require significant inputs from WMO, assumption of management responsibility for impact studies by the WMO would involve this scientific and technical organization in activities and investigations for which it is not, and should not be, adequately prepared. Climate impact studies will require an equal partnership between intergovernmental and nongovernmental bodies concerned with agriculture, health, marine resources, economic development, and other areas of importance to society, as well as the scientific and technical aspects of climate itself. Therefore, an agency within the United Nations system having a broader coordinating role and a tradition of work in the social and economic analysis of environmental impacts would be a more suitable leader and manager of the impact-studies component of the World Climate Program.

The United Nations Environment Program (UNEP) has a tradition of organizing consortia of governmental and nongovernmental national and international organizations to conduct broad interdisciplinary programs concerned with the interactions between human society and the environment. The agency's broad charter and lack of disciplinary bias facilitate the development of balanced assessments, while the considerable financial leverage inherent in the United Nations Environment Fund aids in the mobilization of adequate resources for complex and comprehensive programs. UNEP has, moreover, already developed successful programs closely related to climate-impact studies in collaboration with the International Federation of Institutes for Advanced Study (IFIAS) and IIASA. In these programs sponsored by UNEP, IFIAS has demonstrated its ability to involve experts from the developing countries in the study of climate impacts, while IIASA has focused the talents of systems analysts, mathematicians, and resource experts on the relationships between climate and energy. UNEP has also maintained close and harmonious ties with the WMO in a broad range of projects.

On the basis of these considerations, members of the Workshop concluded that lead-agency responsibility for the climate-impact-studies components of the World Climate Program would be appropriately assigned to the United Nations Environment Program, under the general coordinating authority of the WMO for the program as a whole.

In summary, an effective institutional framework for an international climate impact studies program should include the following elements:

- Designation of a single intergovernmental agency to lead the climate-impact-studies program. While the need for the participation of many organizations is recognized, UNEP appears uniquely suited to assume this role.
- Establishment of a loose consortium or network of interested and contributing international organizations, both governmental and nongovernmental, together with interested national groups as needed. This assemblage of potential contributors might include, for example, WMO, FAO, WHO, UNESCO, ICSU and its unions and committees, together with various national academies, institutes such as IIASA, university groups, and national research institutions. Clearly not every member of this network would actively participate in every study. Rather, the group would form a pool of resources potentially available for employment in any particular study.
- Establishment of a steering committee of experts appointed in their individual capacities to advise the lead agency and the members of the consortium on the design and implementation of impact studies. Panels under this committee may need to be established to deal with individual studies or

groups of studies. Appropriate arrangements for responsive Secretariat support would also be necessary.

• Development of study teams of organizations and individual experts to carry out the impact studies as outlined earlier in this chapter and as recommended by the steering committee. The arrangements evolved by UNEP and IFIAS for the "Drought and Man" project now in progress might well serve as a prototype for the management and funding of these study-team efforts.

The above general guidelines do not, of course, fully define the structure of what may develop into a complex international program. Indeed, an overly elaborate organizational superstructure should not be constructed prematurely. What is needed is a simple, robust, and resilient structure that can get the job done.

In conclusion, it should be reiterated that the study of impacts is likely to be a long-term, ongoing global task, and a program should make no promises as to when major action-oriented recommendations will be forthcoming for consideration by governments. The case for a strong international program is best justified by the long-range importance of the issues and the fact that sufficient insight is now available to guide intensive research constructively, with the objective of providing greater professional understanding of these issues.

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