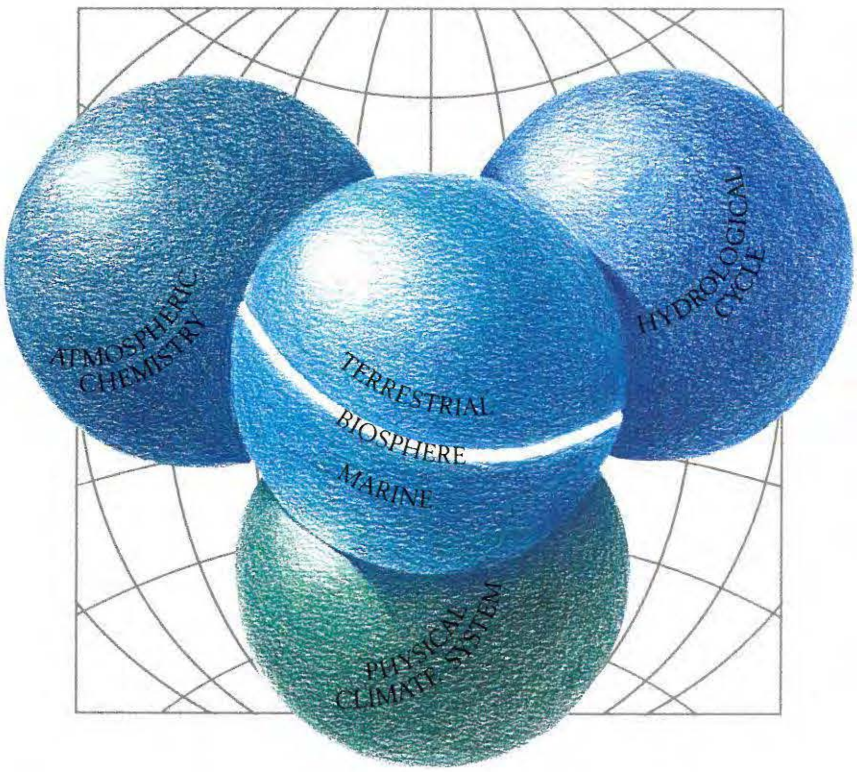
GLOBAL IGBP CHANGE

REPORT No. 4 1988

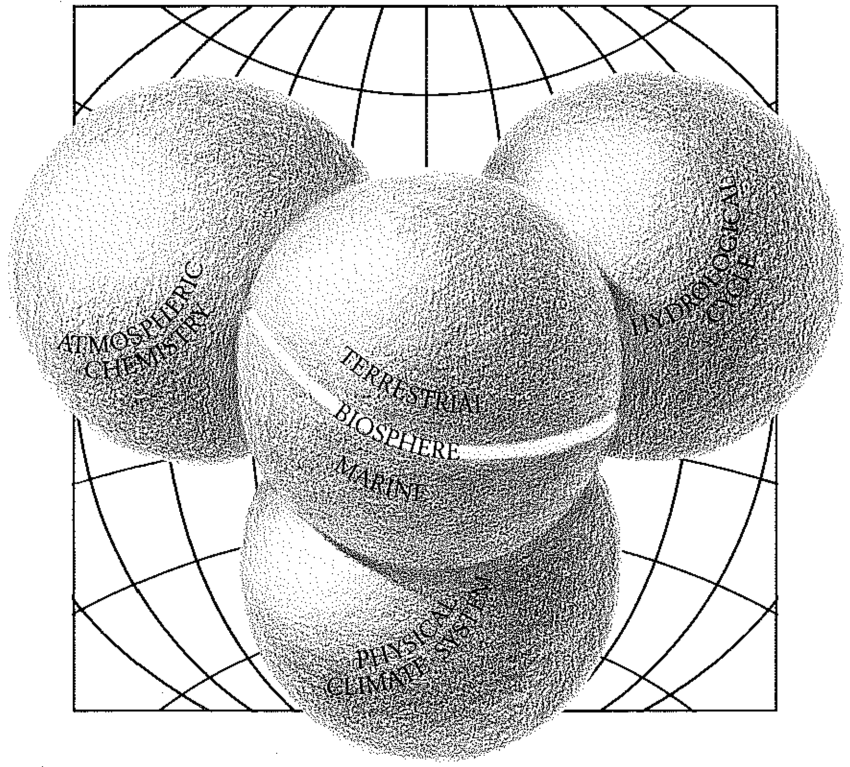


The International Geosphere-Biosphere Programme: A Study of Global Change IGBP

A Plan for Action

GLOBAL IGBP CHANGE

REPORT No. 4 1988



The International Geosphere-Biosphere Programme: A Study of Global Change IGBP

A Plan for Action

A Report Prepared by the Special Committee for the IGBP for
Discussion at the First Meeting of the Scientific Advisory Council for the IGBP
Stockholm, Sweden, 24–28 October, 1988

August, 1988

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)

Special Committee for the IGBP

J. J. McCarthy (USA), Chairman
R. Herrera (Venezuela), Vice-Chairman
W. S. Fyfe (Canada), Treasurer
T. Rosswall (Sweden), Executive Director
P. J. Crutzen (FRG), Member of the Executive Committee
V. M. Kotlyakov (USSR), Member of the Executive Committee

B. Bolin (Sweden)
M-L. Chanin (France)
E. S. Diop (Senegal)
S. Dyck (GDR)
J. A. Eddy (USA)
T. Nemoto (Japan)
H. Oeschger (Switzerland)
S. I. Rasool (USA)
J. S. Singh (India)
V. A. Troitskaya (USSR)
B. H. Walker (Australia)
J. D. Woods (UK)
D. Ye (China)

Coordinating Panel on Terrestrial Biosphere - Atmosphere Interactions.
P. J. Crutzen (Chairman), M.-L. Chanin, R. Herrera, T. Nemoto, S. I. Rasool

Coordinating Panel on Marine Biosphere - Atmospheric Chemistry Interactions.
T. Nemoto (Chairman), B. Bolin, S. I. Rasool, J. D. Woods

Coordinating Panel on Biospheric Aspects of the Hydrological Cycle.
S. Dyck (Chairman), V. M. Kotlyakov, B. H. Walker

Coordinating Panel on Effects of Climate Change on Terrestrial Ecosystems.
B. H. Walker (Chairman), R. Herrera, V. M. Kotlyakov, J. S. Singh, D. Ye

Working Group on Global Geosphere - Biosphere Modelling.
B. Bolin (Chairman), E. S. Diop, J. A. Eddy, J. D. Woods

Working Group on Data and Information Systems.
S. I. Rasool (Chairman), S. Dyck, W. S. Fyfe, V. A. Troitskaya

Working Group on Techniques for Extracting Environmental Data of the Past.
H. Oeschger (Chairman), M.-L. Chanin, E. S. Diop, J. A. Eddy, W. S. Fyfe

Working Group on Geosphere - Biosphere Observatories.
R. Herrera (Chairman), E. S. Diop, W. S. Fyfe, V. M. Kotlyakov

The international planning for the IGBP has been supported by grants from ICSU, the Andrew W. Mellon Foundation, UNEP, Unesco, and national contributions.

Cover illustration by IdéoLuck, Stockholm, SWEDEN.

Table of Contents

1

Foreword

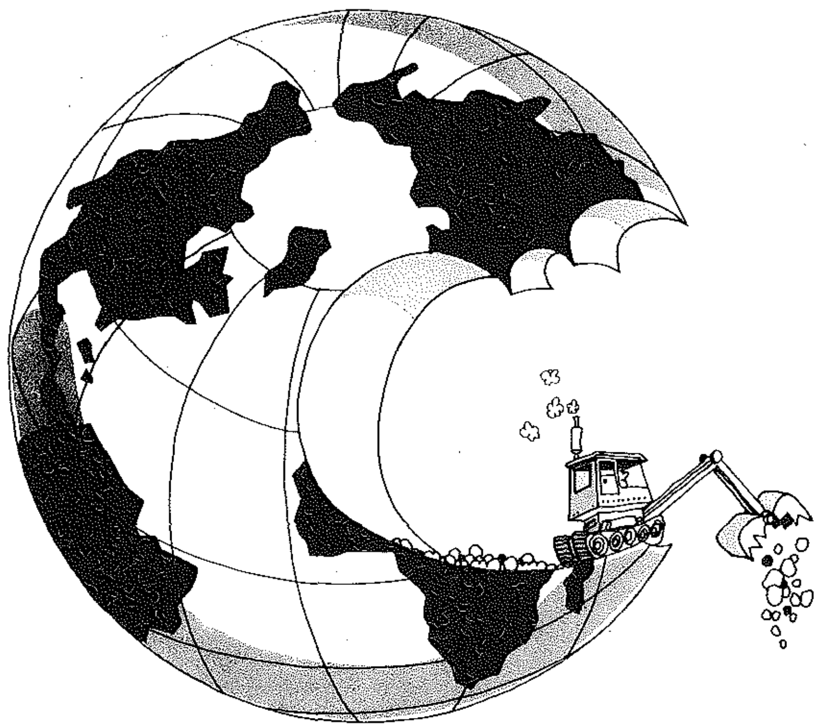


Illustration by Nils Petersson. *Ambio* Vol. 1, No. 1 (1972). Used with permission.

In September 1986, the ICSU General Assembly in Berne (Switzerland) decided to establish the International Geosphere-Biosphere Programme: A Study of Global Change (IGBP). According to Sir John Kendrew, President of ICSU:

> *"The IGBP will certainly be the most ambitious, the most wide-ranging, and in its impacts on our understanding of the future possibilities for mankind the most important project that ICSU has ever undertaken. Its purpose is to study the progressive changes in the environment of the human species on this Earth, past and future; to identify their causes, natural or man-made; and to make informed predictions of the long-term future and thus of the dangers to our well being and even to our survival; and to investigate ways of minimizing those dangers that may be open to human intervention. From the point of view of fundamental science it is the extended study of the dynamics of the whole Earth system - its geology, its oceans, its atmosphere and its climate, and the thin green layer on its surface that we call the biosphere; a scientific enquiry offering immense intellectual challenges and rewards. So the programme will be scientifically exciting as well as immensely significant in charting the future of our species. It will necessarily continue for many years and will require the collection and analysis of huge amounts of data of all kinds using the most sophisticated techniques and the most powerful computers. It will be a major endeavour of the scientific community in every country of the world".*

The IGBP is being planned by a Special Committee appointed by the ICSU Executive Board. Current members of the Committee are:

J. J. McCarthy, Chairman (USA), B. Bolin (Sweden), M.-L. Chanin (France), P. J. Crutzen (FRG), E. S. Diop (Senegal), S. Dyck (GDR), J. A. Eddy (USA), W. S. Fyfe, Treasurer (Canada), R. Herrera, Vice-Chairman (Venezuela), V. M. Kotlyakov (USSR), T. Nemoto (Japan), H. Oeschger (Switzerland), S. I. Rasool (USA), T. Rosswall, Executive Director (Sweden), J. S. Singh (India), V. A. Troitskaya (USSR), B. H. Walker (Australia), J. D. Woods (UK) and D. Ye (China, Peoples Republic of).

Addresses of the members of the Special Committee are given in Appendix 3.

The first meeting of the SC-IGBP (this acronym is presently being used instead of SCGB) took place in Paris in July 1987. The Committee reviewed and endorsed the objectives for the IGBP as proposed by the ad hoc Planning Group. The report from this Group formed the basis for the ICSU decision in 1986 to launch the programme:

> *"To describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions.*
>
> *In concentrating on interactive biological, chemical, and physical processes the IGBP will of necessity put less emphasis on studies that, though they have great strengths and momentum of their own, are already being addressed in existing initiatives, or that will less clearly contribute to our understanding of the changing environment for life on timescales of decades to centuries. Priority in the IGBP will therefore fall on those areas of each of the fields involved that deal with key interactions and significant change on time scales of decades to centuries, that most affect the biosphere, that are most susceptive to human perturbations, and that will most likely lead to practical, predictive capability."*

Thus, through an improved understanding of the Earth system, a primary goal of the Programme is to advance our capablity to predict changes in the global environment. The development of this capability will require cooperative efforts with systems modellers in order to incorporate the appropriate level of understanding of relevant global biological, geological, and chemical processes into physical models of the Earth system.
The first SC-IGBP meeting defined underlying themes specifying aspects of the IGBP that will

receive special emphasis throughout the development and implementation of the programme. Each theme will contribute to the unique character of the scientific core of the IGBP, but because of their pervasive nature, it would be difficult and of questionable value to single any one theme out for individual programmatic development.

The themes identified, which are further discussed in Section 3, include:

Documenting and Predicting Global Change. Entails identifying natural processes contributing to global change by studying the record of the past; assessing the effects of current anthropogenic impacts on the coupling of biogeochemical processes and the physical climate system; and testing our understanding of these processes in predictive models.

Observing and Improving Our Understanding of Dominant Forcing Functions. The effects of external forcing by solar and orbital phenomena and crust-mantle processes are of great significance across the full breadth of IGBP-related research. In addition, attention must be given to indeterminate natural forcing that arises from inherent short-term instabilities in the Earth system.

Improving Our Understanding of Interactive Phenomena in the Total Earth System. Key interactions among physical, chemical, and biological components of this system will be nonlinear; we must be able to describe them in order to assess their potential to produce rapid changes and sharp spatial gradients.

Assessing the Effects of Global Change that Will Cause Large-Scale and Important Modifications in the Availability of Renewable and Non-renewable Resources. To do this we must focus certain research efforts in sensitive areas most likely to be impacted; we must also work to develop understanding and predictive capability at the regional level.

Further, Special Committee discussions identified an initial list of four areas for significant IGBP research. Coordinating Panels, composed of Special Committee members, were appointed to identify research objectives in each of the four areas. Other experts have contributed substantially to these activities. The SC-IGBP will increase the membership of these Panels for the further planning of IGBP research projects.

The initial four Coordinating Panels are:

* Terrestrial Biosphere-Atmospheric Chemistry Interactions
* Marine Biosphere-Atmosphere Interactions.
* Biospheric Aspects of the Hydrological Cycle
* Effects of Climate Change on Terrestrial Ecosystems

For reports from the Coordinating Panels see Section 5.

In addition, the Special Committee established Working Groups to assess current and anticipated research capabilities in four areas:

* Global Geosphere-Biosphere Modelling.
* Data and Information Systems
* Techniques for Extracting Environmental Data of the Past
* Geosphere-Biosphere Obervatories.

In each of these areas, it is anticipated that either new developments or special nurturing of ongoing or planned activities will be necessary in order to implement the IGBP. For reports from the Working Groups see Section 6.

The first meeting of the SC-IGBP (ICSU, Paris 16-19 July, 1987) drafted a constitution for the IGBP, which has been approved by the Executive Board of ICSU (May 1988; Appendix 9). The constitution calls for an Executive Committee consisting of a Chairman, a Vice-Chairman, a Treasurer, the Executive Director, and two additional members of the SC-IGBP. At its first meeting the Special Committee elected Professor James J. McCarthy (Harvard University, Cambridge, MA, USA) as Chairman, Professor Rafael Herrera as Vice-Chairman, Professor William S. Fyfe as Treasurer, and Professors Paul J. Crutzen and Vladimir M. Kotlyakov as the two additional members of the EC-IGBP. Professor Thomas Rosswall, Executive Director of the IGBP, was appointed by the ICSU Executive Board. The report from the first meeting of the Special Committee has been circulated to all scientific and national members of ICSU and to a large number of other organizations and individual scientists.

The second meeting of the SC-IGBP took place at Harvard University, Cambridge (6-8 February, 1988) and a report was also prepared from that meeting. The Special Committee received and reviewed progress reports from the four Coordinating Panels and four Working Groups and decided on the venue and dates for the first meeting of the Scientific Advisory Council (SAC) for the IGBP (24-28 October, 1988, Stockholm, Sweden).

The SAC-IGBP shall, according to the constitution, advise on the scientific content of the IGBP, assess its findings and make recommendations for the general policies of the Special Committee. This forum, at which National IGBP Committees and ICSU Scientific and National members can meet and discuss the programme, is considered vital to the success of the IGBP. Observers from other organizations will be invited to attend SAC meetings. The SAC meetings will be chaired by the President of ICSU. In order to ensure broad participation of the ICSU family in the programme, all ICSU members are invited to attend this meeting and no distinction will be made between members and non-members of the IGBP.

The IGBP Executive Committee has met twice; (4-5 December, 1987, Cambridge, MA, USA and 4-5 June, 1988, Budapest, Hungary). It is expected that both the SC-IGBP and the EC-IGBP will meet twice a year during the planning phase for the IGBP.

Planning since July, 1987, when the Coordinating Panels were established, has led to the organisation of a number of planning workshops. The IGBP meetings are listed in Appendix 4. We are grateful to all those scientists who took part in the meetings for their efforts in preparing overview presentations, for active participation during the discussions, and for help in preparing the draft reports.

2

The Rationale

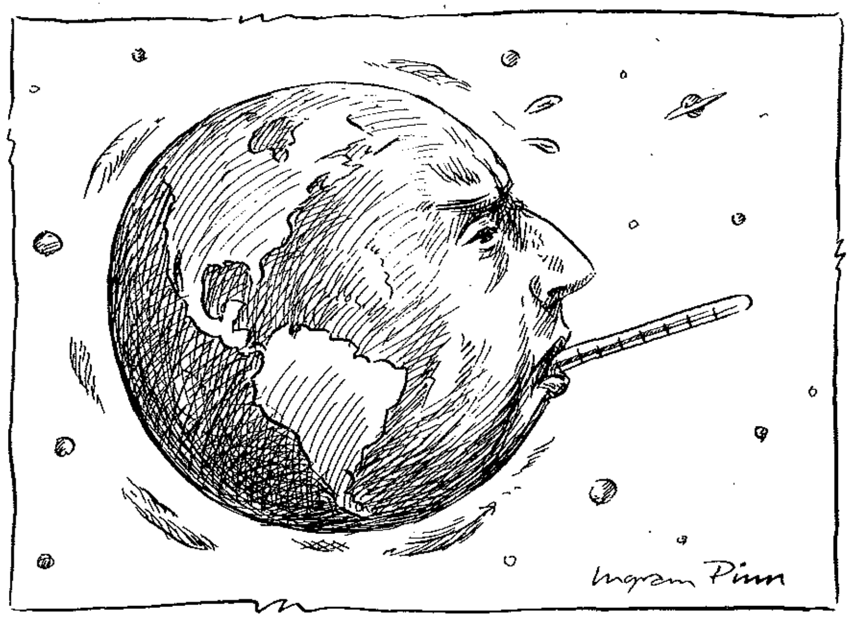


Illustration by Ingram Pinn. *New Scientists*, 30 June 1988, p. 83. Used with permission.

Humankind has been altering the environment for at least two million years. During most of this time, Man's influence has been local in scale and only recently has it increased to global proportions.

During the Roman era, most of the forests of the Mediterranean were destroyed, and human activities had begun to affect the regional environment. However, it was not until the Industrial Revolution that local human activities began to change the global environment.The effects are best seen in the documented increase in atmospheric carbon dioxide; mainly a result of the burning of fossil fuel. The human impact on the global environment can be expected to become more and more acute given the rapid growth of the world population. If unchecked, this impact might become so serious as to be second only to that of global nuclear war. These were the views expressed in the conference statement from on "The Changing Atmosphere: Implications for Global Security" held on 26 - 30 June, 1988, Toronto, Canada.

In 1972 the UN organized a conference in Stockholm on the "Human Environment". The conference focussed on environmental problems at a truly international level. This was a major event and led, among other things, to the establishment of the United Nations Environment Programme (UNEP). Less than two decades have passed since the UN meeting. However the picture has changed dramatically. While attention in 1972 was on national and regional problems, we are now faced with global issues on an unprecedented scale: *"This is a unique time, when one species, Humanity, has developed the ability to alter its environment on the largest (i.e., global) scale and to do so within the lifetime of a single species member"* (R. M. Goody, in JPL Report D-95, Pasedena, CA, USA, 1982).

It is no longer enough to bring national governments to an awareness of environmental changes in their own territories or those of immediate neighbouring countries. We are now faced with problems of truly global dimensions as evidenced by increases in tropospheric concentrations of greenhouse gases with future effects on climate and decreases of stratospheric ozone. These, and other global consequences of human activities, have the potential to jeopardize the habitability of our planet.

The major problem is that the scientific understanding of the functioning of the most important ecosystem of all, the Earth, is still meager. Whereas ecosystem science, the study of the complex interactions of biotic and abiotic variables in specific terrestrial or aquatic systems, was recognized as a field of its own in the 1960s, Earth systems science, the understanding of these phenomena on a global scale, has just begun. This poses an urgent challenge to the international research community. This area of research is not only of theoretical scientific interest, but has become a necessity in order to minimize the consequences of natural and human induced changes.

The ad hoc Planning Group for the IGBP identified four major reasons for initiating the IGBP at this point in time:

A growing realization that biotic and non-biotic components of the biosphere are inextricably interlinked, as exemplified in studies of the cycling of chemical elements critical to life, the sensitivity of climate to biotic and anthropogenic processes and an array of questions arising from the study of the effects of the documented global increases in greenhouse gases.

The fact that human impacts on the Earth now approximate the scale of the natural, interactive processes that control the global life-support system. Ready examples are climate change resulting from rising levels of anthropogenic trace gases in the atmosphere, acidic deposition, deforestation, soil depletion and desertification.

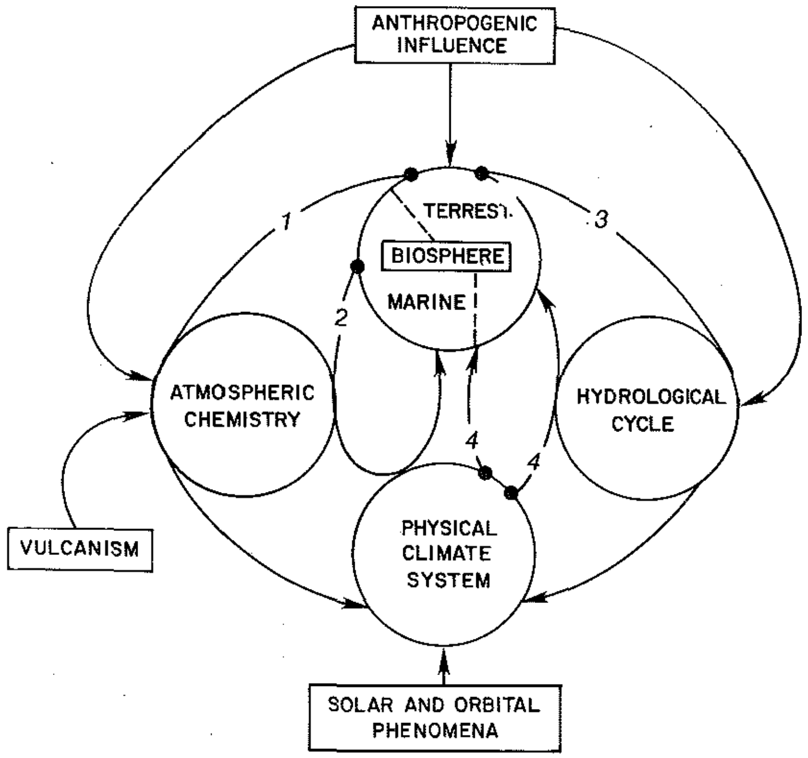
An appreciation of the limits to habitability of the Earth; of the ability of the planet to support life; to produce adequate food supplies, fodder and fiber; and to maintain the quality of air, water and soils, and the integrity of the chemical cycles essential to life.

Contemporary advances in technology and in science that make it possible to study the Earth as an interactive system. These *include new abilities to examine the Earth from space, and, equally important, the emerging capabilities of telecommunication, data handling, and numerical modelling that are needed for global data handling and worldwide information exchange. Programmes of global observations have already been successfully carried out. Pilot information systems are now in operation, numerical models are now contributing to a detailed understanding of individual Earth components, and new conceptual models are now being developed to explore the linkages that form the Earth into a living system.*

Human impacts on the Earth have already reached a scale that in many cases approximates that of the natural processes. However, all the evidence shows that on the time scale of decades to centuries, human impacts on the Earth will exceed those of the natural processes. For this reason, and based on the deliberations during the two years subsequent to the ICSU General Assembly in Berne, it is evident that the decision to initiate planning for an IGBP was timely. The scientific community, especially the ICSU family, but also UN organizations such as UNEP, UNESCO and WMO, has responded in an enthusiastic and constructive way. "Global Change" issues have been addressed by the scientific community both at the international and national level. But, it is not only scientists who have shown an interest. Politicians and decision makers have also reached a new awareness of global problems and the urgent need to address such issues. As an example, we quote from the agreement of the summit meeting between USA President R. Reagan and USSR General Secretary M. Gorbachev (Washington, December, 1987) *"to promote broad international and bilateral cooperation in the increasingly important area of global climate and environmental change".*

3

Underlying Themes



The Special Committee has identified a set of underlying themes that define the scope of the research unique to the IGBP, within the context of the established objective and priorities for the programme (see Section 1). The four themes constitute the scientific basis of the IGBP. The development of research projects that fully embody these themes is a fundamental responsibility of the Special Committee.

The Underlying Themes are:

Documenting and Predicting Global Change

Global changes are the product of natural processes that have over time defined the life-sustaining character of the Earth system and a growing suite of relatively recent large-scale anthropogenic perturbations that are quite different in character. In order to identify the respective roles of these different perturbations we must document past changes in the Earth system. Contemporary capabilities to identify the changes that are occurring today must be fully utilized, and the most appropriate observation systems must be put into practice in order to document future changes on a global level, through calibrated and coordinated monitoring networks. Long-term series of global data will also be essential to test modelled predictions of the global changes that are likely to occur in the future. These data, and the information systems to make them readily available, will constitute the principal legacy of the IGBP to future generations of scientists and decision makers.

The strategy is, firstly, to exploit the record of the past to identify the processes that contribute to global change, especially the coupling between biogeochemical processes and the physical climate system; secondly, to assess the effects of current major anthropogenic impacts on these couplings; and, thirdly, to test our understanding of the underlying processes in predictive models. A timely example is the role of the greenhouse gases in climate change. A fuller documentation of the record of past changes in the composition of the atmosphere and their relationship to changes in climate, will allow the development of testable hypotheses that link the key biological, chemical, and physical processes. This documentation will include analyses of the paleo-record on land, in ice, lake and ocean sediments. An understanding of these linkages will also depend on studies of contemporary change in the Earth system.

The research recommendations of the IGBP Coordinating Panels and Working Groups will address activities that include:

- Collecting and analysing data to identify both the natural processes that lead to global change and the effects of such changes.

- Incorporating, in predictive models, the nature and extent of past changes, an understanding of couplings between biogeochemical processes and the physical and climate system, and all available information on current and anticipated anthropogenic impacts.

Observing and Improving Our Understanding of Dominant Forcing Functions

The effects of external forcing by solar and orbital changes, solid-Earth processes, and human activities (Fig. 3.1) are fundamental elements of global change. Certain of these are now widelystrongly implicated as possible mechanisms of major variability in the Earth system. Identification of the role of Milankovich cycles in the distribution of solar energy on the Earth's surface has given rise to theories regarding the timing of glacial to interglacial transitions in the Pleistocene. Solar activity in short-term, 11- and 22-year cycles, as well as medium-term variations on a century scale that may link, for example, the Maunder Minimum in the 17th century to the Little Ice Age, are also of significance for the climate system. Changes in the flux of solar energy received by the Earth can affect not only the physical properties of the Earth's surface and lower atmosphere, and the chemistry of the middle atmosphere, but also the fundamental biological processes such as photosynthesis and respiration, which on land and in the ocean are functions of the available light and temperature.

It is equally evident that the release of materials from the deep Earth by, volcanoes, geysers, and marine vents have affected the morphology and composition of the Earth's surface, its

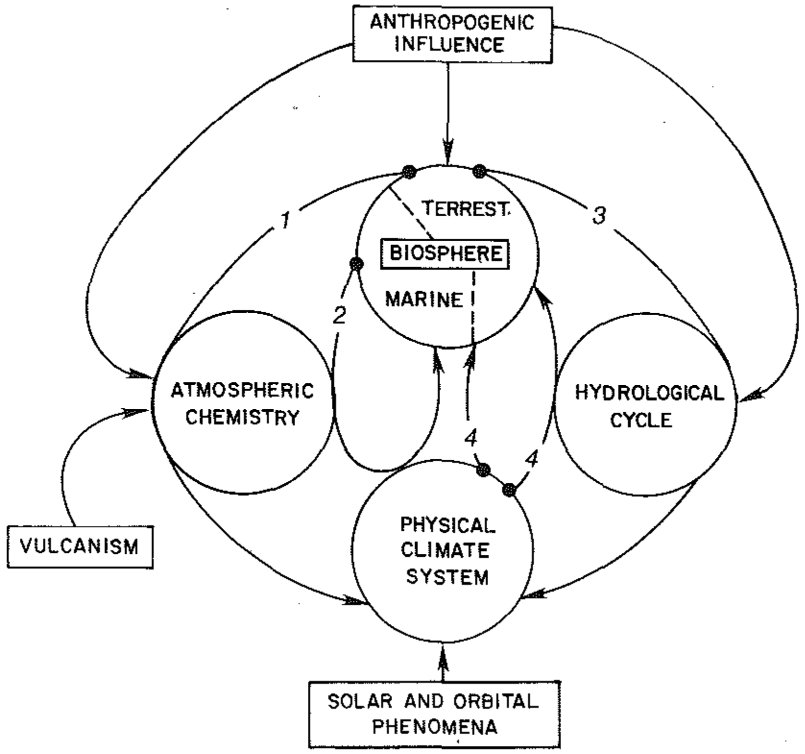


Figure 3.1.

atmosphere, and its oceans with major implications for the planetary life-support system. Some hypotheses link past periods of major volcanic eruptions to global patterns of species extinction. Short-term impacts of major volcanic eruptions on atmospheric turbidity, and hence on climate, have also been documented. The regulation of the cyclic and acyclic character of these phenomena, and their potential for significant global change, needs to be assessed.

The response of the Earth system to natural change, such as changes in albedo associated with changes in snow, ice, and vegetation cover, or crustal rebound in response to the burden of retreating glacial ice sheets can arise from physical instabilities. In some instances hypothesized negative feedbacks may constitute the controlling factors. The rate of change is also an important aspect of these considerations. This is particularly true of biological systems that may have flipped from one stable state to another in the course of long-term climate cycles in the past. These systems may react much differently during periods of more rapid and perhaps more extreme climate change in the future.

The IGBP needs to consider the full range of anthropogenic activities that have contributed and are contributing to global change. Land-use practices, for example, have important implications for terrestrial carbon storage, cycling of essential nutrients, albedo, and hydrology. The significance of these activities for global change can be assessed through studies of current conditions and practices as well as through historical and proxy records.

The research recommendations of the Coordinating Panels and Working Groups will develop activities within this theme, addressing:

- The magnitude and significance of external forcing by solar and orbital variations and solid Earth phenomena.

- Indeterminate natural forcing due to transient or short-term perturbations in the Earth system.

- Anthropogenic forcing attributable to changes in atmospheric chemical composition and changes in land and water use.

Improving Our Understanding of Interactive Phenomena in the Total Earth System

Key interactions in the Earth system, especially biological responses to physical and chemical changes in the environment, are typically non-linear. This becomes particularly important when we consider that the anticipated global warming of the next half century could be of the same magnitude as that experienced by the Earth's ecosystems since the last glacial maximum 18,000 years ago. The species of animals and plants that have survived in temperate and subtropical latitudes over the past few million years have successfully adapted in numbers and geographic range as climate has warmed and cooled. The climate conditions projected for the near future are beyond the range of experience of these organisms, and the rates of change involved may be unprecedented.

Based upon records from the past, as derived from glacial ice, and marine sediments, and the results of ocean-atmosphere models, putative links now describe feedback mechanisms among climate, ocean mixing processes, and biological processes at high latitudes. Upper-ocean mixing processes in even small areas of the Earth's oceans can invoke rapid changes in the carbon content of the atmosphere in response to changes in global temperature.

The research recommendations of the Coordinating Panels and Working Groups will develop activities within this theme that include:

- Developing descriptions of non-linear interactions among physical, chemical, and biological components of this system, through modelling and process studies.

- Quantifying the potential of these interactions to generate rapid changes from slow forcing and to induce sharp spatial gradients from large-scale forcing.

Assessing the Effects of Global Change that Would Cause Large-Scale and Important Modifications that Affect the Availability of Renewable and Non-Renewable Resources.

Ultimately, the research projects of the IGBP should contribute to a predictive capability for assessing the availability of the natural resources that will be needed by future generations. Local, and in some instances regional, implications of industrial and agricultural practices have always been evident. We now know, however, that certain effects of the industrial and agricultural practices of contemporary society have global implications. Combustion of fossil fuels, extensive land clearing without timely and commensurate regrowth, massive modifications in hydrological systems, and production of long-lived chemical compounds are but a few of the more obvious examples. Analyses of the effects of global changes on our resource base, through agriculture, forestry, and fisheries, should focus initially on those mariginal areas which are most sensitive to these perturbations.

Much of the concern with the effects of global change will be focussed at the local or regional scale, but we cannot presume that wider effects can be predicted by studying phenomena at this scale only. Global warming, for example, will influence temperature, precipitation, and wind patterns over whole continents and the oceans. To anticipate regional effects, we must determine the global forces behind this change, and how continental and subcontinental weather patterns are derived from global-scale processes. At the same time, most analyses of the effects of global change on our resource base must be made in a regional context, since global averages are too crude a guide for the assessment of possible effects on the future patterns of resource availability. Models of the global climate system will provide outputs which can be used to assess effects on regional resources. The major challenge concerns problems of spatial and temporal variability and resolution.

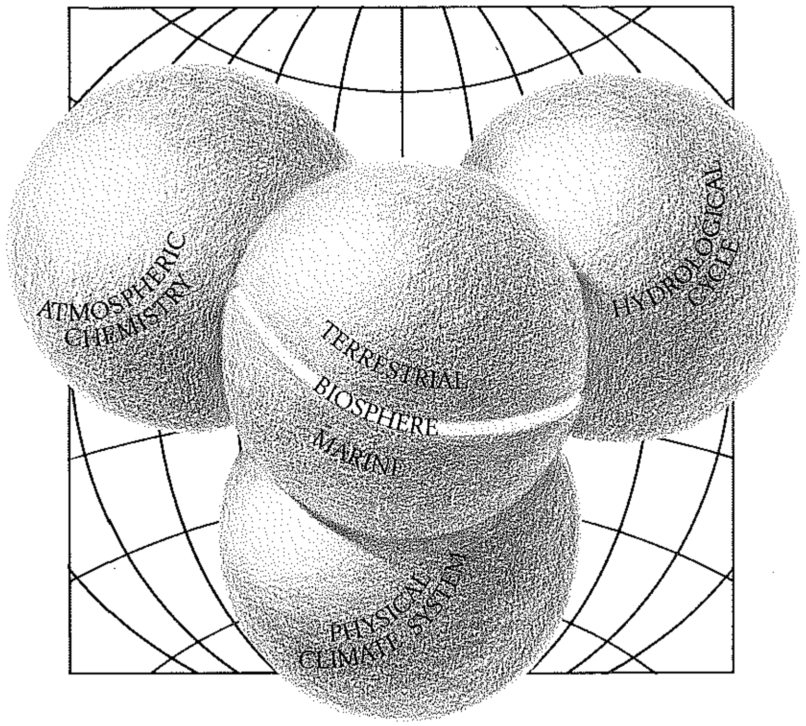
The focus of Coordinating Panels and Working Groups on predictive aspects of global change require that each give serious consideration to:

- Studying sensitive regions in which rapid changes are taking place because of man's exploitation of Earth resources.

- Using our improved knowledge of global change to understand and predict effects at the regional scale.

4

The IGBP


ATMOSPHERIC CHEMISTRY
TERRESTRIAL
BIOSPHERE
MARINE
HYDROLOGICAL CYCLE
PHYSICAL CLIMATE SYSTEM

4.1. Structuring the Programme

In the previous section the underlying themes of the IGBP were outlined. When developing a research programme, however, other considerations are also essential.

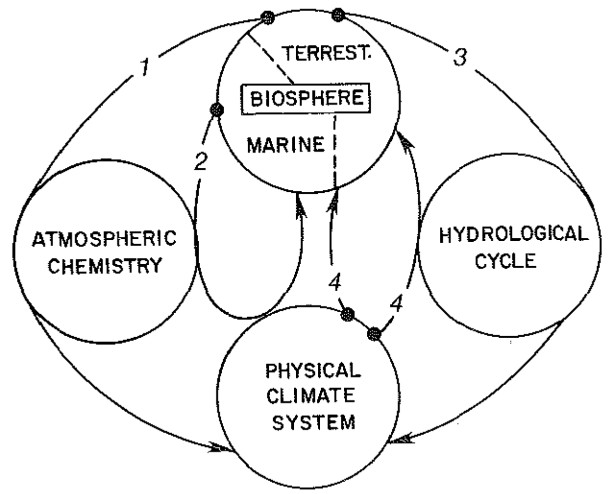
In principle, the IGBP should be viewed as one project: the study of the basic biological, chemical and physical processes and their interactions that regulate the Earth system as well as the linkages between the different parts of the system. The concept of teleconnections is well-recognized in the fields of meteorology and oceanography. For example, weather forecasting beyond 5-7 days is not possible without hemispheric consideration, and any understanding of the Earth's climate, its geographical features, and variation, necessarily involves a global perspective. Similarly, the biogeochemical cycles that are the links of biological and chemical interactions are truly global in nature. In order for the IGBP to be successful, it is most essential that this view of a globally interacting system guides the selection and development of research components of the programme.

The interactive geosphere - biosphere in the global Earth system is extremely complex. For practical reasons it is necessary to structure the programme in a manner that will ensure the development of well-defined core projects that are manageable. Furthermore, there are a number of ongoing international research programmes, the aims and activities of which are of great importance to the IGBP.

The SC-IGBP has identified a number of research areas that are of central importance. These research areas require increased and coordinated research efforts and new initiatives are accordingly needed. For each one of these fields, a Coordinating Panel has been formed. The initial research areas are:

- Terrestrial Biosphere-Atmospheric Chemistry Interactions
- Marine Biosphere-Atmosphere Interactions
- Biospheric Aspects of the Hydrological Cycle
- Effects of Climate Change on Terrestrial Ecosystems.

Proposals for internationally coordinated research efforts and projects are given in Section 5. A schematic presentation of the linkages between these four activities of the IGBP is shown in Figure 4.1.



It should be emphasized that this is not a final outline for the ultimate research programme. Several ongoing programmes, especially the World Climate Research Programme (WCRP), are of fundamental importance to the success of the IGBP. *It is essential that the linkages with* programmes be defined and ways and means identified for effective collaboration further developed. It is clear from Section 5 of this report that such work is already under way. In addition, the formulation of any programme is an evolutionary process. The deliberations of the SAC-IGBP during its first meeting in Stockholm and the further analysis of major components of the IGBP by the Special Committee might well lead to the identification of additional important components, the development of which will require new initiatives.

It is even more important to recognize that the core programme of IGBP will depend on advances in our knowledge of important external forcings such as:

- Variations of solar radiation, its modifications in the upper atmosphere and its variations due to the characteristics of the Earth's orbit around the sun;

- Soild Earth processes (e.g., volcanism) have potential for significant alteration of the geosphere - biosphere on the spatial and temporal scales with which the IGBP are concerned.

There is also a need for continuous monitoring of direct human impact on the geosphere-biosphere system, in the form of emissions of gases and particulate matter to the atmosphere, effluents to lakes, rivers and coastal waters, deforestation and changing land use, and waste management.

The success of the IGBP programme will depend on the full commitment of scientists and national IGBP committees throughout the world. The number of environmental scientists actively working on problems related to the IGBP is comparatively small. Undoubtedly, it will be necessary to extend advanced education and research opportunities, particularly in developing countries, in order to obtain the competent human resources necessary for the research tasks which are emerging.

It is also clear that the planning and organization of a joint international effort will require additional time, although priorities and action plans are already set forth in this report. It appears highly essential that initiatives be taken by *national IGBP committees along the lines* presented in this report. Such pilot studies may significantly increase the rate at which the international programme will be realized.

4.2. Major scientific IGBP components and their interdependencies

In order to emphasize the interactive characteristics of the IGBP components, brief summaries of the present status of planning are given below. These stress the interdependence involved. More details are given in Section 5.

4.2.1. Terrestrial Biosphere-Atmospheric Chemistry Interactions

The issue

The importance of biogenic and anthropogenic trace gases for the chemistry of the atmosphere and for the Earth's climate has been fully recognized for only one to two decades. During this period a reasonable understanding of the basic functioning of and interactions between climate, atmospheric chemistry and biosphere has developed. For example, we have recognized the important role played by tropospheric ozone and ultraviolet radiation, which together with water vapour produce the hydroxyl radicals. Although present in only minute amounts, these radicals are responsible for removing most gases, though not CO_2, that are emitted to the atmosphere by natural biogenic, agricultural, and industrial activities. Biogenic N_2O and CH_4 are important in determining the natural state of the ozone layer. Certain trace gases in the atmosphere contribute to the greenhouse warming effects. This is a result not only from growing atmospheric abundances of CO_2 and H_2O, but also from biogenically and industrially produced CH_4, N_2O and the industrial chlorofluorocarbon gases ($CFCl_3$ and CF_2Cl_2).

Stratospheric ozone concentrations are influenced *by anthropogenic* NO_x *(NO and* NO_2) and especially by ClO_x (Cl, ClO, Cl_2O_2) additions. In recent years additions of these gases have contributed to the rapid development of a deep "ozone hole", especially during September to November, over Antarctica and surroundings.

Priorities for research

There is an urgent need for a better understanding of the importance of the biogenic and anthropogenic processes that regulate the chemical composition of the atmosphere. Of particular interest for the IGBP will be studies on background tropospheric and stratospheric chemistry, stratospheric - tropospheric exchange, and the identification of the key regions and quantification of the exchange rates of the most important biogenic trace gases at the Earth's surface. Key priorities are an understanding of the environmental factors that regulate these exchange rates, and development of predictive models to determine the changes in these factors that are due to natural and, especially, anthropogenic, perturbations. Most important is recommendation of the most efficient international actions necessary to reduce, or prevent, the build-up of chemically and radiatively active trace gases and particulate matter in the atmosphere.

Action plan

The following activities should be urgently pursued to develop IGBP components:

- In cooperation with the CACGP develop an *IGBP project on "Chemical and* Meterological Processes that regulate the Composition of the Global Troposphere". The next IGAC planning meeting in November, 1988, will be an important step towards this goal.

- In cooperation with the SCOPE project on biogenic trace gases, this Coordinating Panel will develop a research project on biological processes, leading to the release and uptake of photochemically or radiatively active important trace gases in terrestrial ecosystems. Interactions with the JGOFS activities will be important to promote studies of chemical air-sea exchanges.

- It is likewise of the greatest importance that strong links are maintained with the proposed activities of the other IGBP Coordinating Panels and Working Groups, so that maximum use can be made of the opportunities which will be provided by these activities with respect to trace-gas exchange studies at the biosphere-atmosphere interphase.

- Of particular interest to the IGBP will be the documentation of land use changes, the role of biomass burning, and the effects of these on trace-gas releases. The IGBP intends to play a leading role in developing this research.

- The IGBP will encourage the development of a strong international research effort on the middle atmosphere, in particular the ozone layer, through the appropriate international organizations.

- When the results of the SCOPE-IUPAB initiative on the biological efforts of UV-B radiation become available, the IGBP will consider the need for direct involvement in the area of research.

4.2.2. Marine Biosphere-Atmosphere Interactions

The issue

Records of the past, as revealed by studies of temperature and the chemical composition of the atmosphere trapped in glacial ice, and in the fossil remains of marine organisms and their *isotopic content buried in deep-sea sediments,* suggest an involvement of ocean biogeochemistry in glacial-interglacial cycles of climate change. The remains of marine organisms and their skeletons in the form of dissolved and particulate organic carbon and calcium carbonate, constitute the major reservoirs of carbon in the biosphere. The carbon in sediments alone is more than one hundred times that presently circulating in the atmosphere, terrestrial biosphere, and the ocean together. Thus, relatively small changes in the fluxes of carbon either to or from these reservoirs can have substantial implications for the relatively small atmospheric reservoir.

Although the capacity of the ocean to absorb carbon dioxide from the atmosphere is primarily determined by temperature and the salinity of the surface ocean, plankton in the upper ocean enhance the transfer of carbon dioxide from the atmosphere to the ocean through photosynthesis.

Although a portion of the carbon fixed by this process is released to the upper ocean via respiration, a certain amount enters the longer lived pool of carbon in the deep ocean or sediments, some sinks or is advected into deep water where it is respired and released to the atmosphere on the time scale of ocean mixing, and some is sequestered for even longer periods in deep-ocean sediments.

Estimations based on model results indicate that about half the carbon dioxide being introduced into the atmosphere via fossil-fuel combustion is being absorbed by the ocean. Moreover, it is evident that the oceans have been important agents in determining the glacial-interglacial cycle of atmospheric carbon dioxide concentration. Ocean models that focus specifically on the high latitude regions, characterized by particularly high rates of water mass sinking, provide scenarios for rapid changes in atmospheric carbon-dioxide concentrations in response to changes in ocean circulation.

Global concern regarding the quality of marine habitats in coastal regions is growing rapidly. Problems associated with pollution, once local in scale, have now reached regional proportions that transcend national boundaries. In many instances, the ability of these habitats to sustain populations of species important to mankind is being jeopardized. We must develop coherent regional programmes that address these issues, fully cognizant of the likelihood that without corrective measures conditions will certainly deteriorate in coming decades.

In addition to carbon dioxide the oceans are also a source of other climatically important biogenic gases, such as N_2O and dimethylsulphide (DMS). The former is probably of greater significance in coastal waters, which are affected by anthropogenic fixed nitrogen inputs, while the latter is more prevalent in open oceanic regions. The strength of source terms and the biogeochemical processes regulating the production and release of these gases to the atmosphere are poorly known. However, there is growing interest in the role of DMS, because of the possibility of feedback loops that involve the formation of cloud condensation nuclei and hence albedo.

Priorities for research

- Characterization of the oceanic carbon cycle and associated links with cycles of other elements known to either limit biological productivity or affect climate.
- Assessment of effects of human activity or climate change that are likely to affect coastal and estuarine biological systems of particular value to humankind.
- Characterization of linkages among biogeochemical cycles and the physical climate system in order to anticipate not only the effects of global change on these cycles but their feedback to climate as well.

Action plan

The priorities relating to the ocean carbon cycle will in large measure be met by the research projects now being planned as the Joint Global Ocean Flux Study (JGOFS of SCOR). The Coordinating Panel should work jointly with SCOR to develop a complementary programme in this area.

Within the next year, the IGBP should initiate planning activities that address priorities relating to both coastal- and estuarine-system issues and modelling aspects of the linkages among biogeochemical cycles and the physical aspects of climate.

4.2.3. Biospheric Aspects of the Hydrological Cycle

The issue

Vegetation plays a fundamental role in the interaction between the biotic system and climate, especially because of its effects on the hydrological cycle. Vegetation is crucial in determining the partitioning of surface energy fluxes into latent and sensible heat. Vegetation is also important in determining transpiration, surface albedo, and roughness, which are key parameters in climate models. The description of interaction between vegetation and the physical climate system in the GCMs is inadequate and needs improvement.

Major changes in vegetation cover (e.g., desertification, clearfelling of tropical forests)

will affect the hydrological cycle and thus albedo water transport to the atmosphere and roughness. The effects of climate change on vegetation (addressed by Coordinating Panel 4, Section 5.4) will thus have a feedback effect on the whole climate system.

Priorities for research

The core programme will concentrate on the interaction of biomes with the hydrological cycle on scales that are compatible with global observation systems (remote sensing) and GCMs. Special emphasis will be given to changes - past, present and future. A hierarchy of models needs to be developed: Models of large river-basin systems based on simple balance calculations of the hydrological cycle in its interaction with vegetation. Remote-sensing will give state-variable information, which, coupled with river discharge data, will provide inputs to GCMs with a realistic description of the role of vegetation. In addition, more detailed models of small river systems need to be developed. Those should include processes in the soil-vegetation-atmosphere interface to evaluate remote-sensing and experimental results. Both of these types of models will depend on more detailed process-related models, which should be simplified to include only those crucial processes which are needed to model the interactions on large spatial scales.

In order to obtain empirical data, field measurements and experiments are needed on various spatial scales. Small-scale, single parameter experiments will be carried out to determine properties such as albedo and directional reflectance that can be resolved in satellite images. Complex experiments should be established for the pixel scale in which ground-truth observations are linked to remote-sensing observations for the development of proper algorithms. Such experiments require studies of water and heat fluxes as well as vegetation properties and can be similar to the FIFE/ISLSCP studies. Satellite measurements also need to be validated over complex terrain and vegetation mosaics on GCM grid scales (200x200 km).

Action plan

It is proposed that a core project be developed by an IGBP Scientific Steering Committee focussing on spatial scales from pixel arrays (hydrotope) to grid nets (GCMs, continent-globe), which will include biogeoclimatic zones (plant communities and biomes/ecosystems). The programme should include an expansion of ISLSCP in consultation with IAMAP and COSPAR as one of the core research projects of the IGBP. Development of interactive soil-vegetation-atmosphere models will be further pursued and a joint planning meeting for this activity will be organized jointly between IGBP and WCRP/GEWEX. This meeting should also consider the spatial and temporal resolution needs of GCMs in order to be useful to the IGBP research programmes on effects of climate change on terrestrial ecosystems. In addition, water-balance studies of specific large river basins should be considered in collaboration with WCP/Water and IHP.

4.2.4. Effects of Climate Change on Terrestrial Ecosystems

The issue

Climate change scenarios predict that we will witness global warming of perhaps 2-5°C over the next 50 years with changes also in the amounts and patterns of precipitation. The chemical composition of the atmosphere is also changing rapidly. Both these factors will have profound effects on all terrestrial ecosystems. Significant alterations in the hydrological and biogeochemical cycles that result from climate-induced ecosystem changes will, through feedback mechanisms, affect the physical climate. Primary effects of climate change on ecosystems will be especially important in relation to primary production, evaporation, and decomposition. It will also affect the hydrological cycle, and thus the transport of essential plant nutrients, due to changes in surface flow and percolation. Through changes in biogeochemical cycles and the hydrological cycle, secondary effects at the ecosystem level will include plant succession, competition and establishment of new species. Taken together, primary and secondary effects on ecosystem processes will affect ecosystem properties, e.g., vegetation type, litter quality and soil characteristics.

Any climate change will alter the basis for agricultural and forestry production. Production levels will change and new species will have to be selected in order to sustain economic outputs.

In order to predict what measures need to be taken, the outputs from GCMs must be matched with the needs of crop production models. For both management and non-management ecosystems, the effects of climate change are probably more closely related to occurrences of extreme events than to mean changes in temperature or precipitation. Global models need to take this into account and also to address the issues of spatial resolution needed by ecologists to predict the effects of climate change.

Priorities for research

It is essential that certain key ecosystem processes and properties are investigated and results interpreted at spatial scales that will allow the results to be incorporated into GCMs or Global Geosphere-Biosphere Models (GBMs). Examples include the effects of vegetation change on roughness and albedo (see also 4.2.3), effects of increased CO_2 concentrations on plant water-use efficiency, primary production/litterfall relationships and litter quality as influenced by climate change affecting decomposition rates. It is also essential to determine how changes in these factors will affect plant community distribution and ecosystem dynamics. In selecting areas for study, special attention should be given to those regions where significant effects of climate change might occur. Statistical models should be used for an initial screening.

There is a need to develop simulation models for major biomes. These models should predict how physical and chemical climate affects vegetation as well as fluxes of biogenic trace gases. Based on such models, appropriate parameterization needs to be carried out to include vegetation in GCMs and in the new generation of GBMs.

Past climate change and its effect on distribution of plant communities and biomes should be studied, and the rare climatic events which are especially important for determining the development of communities and biomes should be identified.

Generic crop and forest models need to be developed and should be tested under a wide range of climatic conditions. Interactions between CO_2 effects and fertilization should be investigated and included in these models.

Action plan

Primary emphasis will be on the development of conceptual models to bridge the gap between the GCMs and existing ecosystem models. A first important step will be the SCOPE Workshop in April 1989. The results from the SCOPE projects on ecosystem experimentation and long-term ecological research will be used as the basis for a proposal for an ecosystem experiment. The experiment will study the effect of changing physical and chemical climate on ecosystem properties. In addition, there is a further need to address the effects of climate change on agriculture and forestry, and the IGBP should initiate additional work on the development of truly international generic production models.

4.3. Common Problems of the IGBP Programme Components

In its deliberations, the SC-IGBP has recognized several problems that are common to all four components of the core programme as presently envisaged. Further analysis of these problems and the development of action plans to stimulate internationally coordinated activities will contribute to close interaction between the four research areas as well as with other ongoing international programmes. These common problem areas are discussed in detail in Section 6.

Brief summaries of these problem areas are given below. These emphasize the interconnections between the different programme components.

4.3.1. Global Geosphere - Biosphere Modelling

The issue

Athough it is presently premature to develop fully coupled global models of the Earth system, it is essential that a programme element of the IGBP be defined with focus on model development. This element should first address the separate components of the system, i.e., the atmosphere, the marine system and the terrestrial biosphere, gradually aiming at the development of models for the Earth system as a whole.

Climate models describe the major physical processes that govern transfer of energy, momentum, and water. These models provide a natural basis when we focus on questions of how biological and chemical processes contribute to the condition of our environment. Key emphasis should be on improved understanding of the global biogeochemical cycles that provide the means for global interactions. Close links between the IGBP and the World Climate Research Programme (WCRP) are most important for this model development.

General circulation models (GCMs) for the atmosphere are well developed and are being used for climatic studies. They are also used for the study of the chemical interactions and transfer of atmospheric trace substances (and water) by air movement. The seasonal variations of atmospheric carbon dioxide have been interpreted quantitatively in terms of interaction of the atmosphere with the terrestrial biota and the ocean. Interactive models are being developed for methane and the chemically more complex interactions between nitrogen, sulphur and chlorine compounds, UV-radiation, ozone and the key atmospheric oxidizing agent, the OH-radical.

The first attempts to use GCMs for studies of the biogeochemistry of the marine system are presently being carried out. For some considerable time, rather simple conceptual models (box-models) will still play an important role in studying the relative role of key chemical interactions in the marine environment.

Modelling the terrestrial ecosystems, and their interactions with the atmosphere has not yet reached the stage where interactive dynamic models are linked to atmospheric general circulation models. We need models that can describe the internal response of the major biomes to changing abiotic conditions as well as those that describe how a transition zone from one ecosystem to another (ecotone) may change due to changing climate conditions.

Action plan

Within the next two years, development of the IGBP will include intensive discussions in the form of workshops between modellers representing different scientific disciplines. These discussions are necessary in order to establish the most feasible approaches to modelling the different subsystems in such a way that they can later be fully integrated. The interactions between the atmosphere and the sea and between the atmosphere and the terrestrial system should also be considered. Several meetings and workshops will consider these aspects of the programme (Section 6.1.6). As a step towards the development of truly global models, an IGBP conference on the modelling of the global carbon cycle will be organized in the summer of 1989. If possible, interactions with other biogeochemical cycles, particularly those of the key nutrients nitrogen and phosphorus, will be dealt with in a simplified manner.

A more penetrative status report on global modelling of the geosphere-biosphere system will be available for discussion at the next SAC-IGBP meeting scheduled for the first part of 1990. This work will also be of considerable value in defining the system of Geosphere-Biosphere observatories (Section 6.4). In order to achieve the goal of interactive global models, it is essential that the scientists from the different fields of importance to the IGBP increase their awareness about key issues in adjacent fields and improve their means for scientific communication and collaboration.

4.3.2. Data and Information Systems

The issue

Systematic efforts to document significant global changes are crucial to the IGBP. The structure of the IGBP and the institutional arrangements must be appropriate not only for obtaining the necessary long-term observations and calibrations but also for the processing and analysis of the collected data. The results from these observations must be made accessible both to scientists and policy makers.

Remotely-sensed data, largely from spacecraft, will constitute a cornerstone in the IGBP observations. In this regard, there is a need for national commitments to achieve international goals.

The information system for IGBP should provide for: acquisition, quality control, and integration of raw data together with associated calibrations and documentation. In developing an information system, it is necessary to strengthen and build upon existing and already planned systems.

Selected data assembly and assessment projects should be started in the near future to provide appropriate experience with global data-management issues.

The scientific needs of the IGBP should guide the establishment of data requirements and priorities. Data sets and associated documentation must be simply constructed so as to be easily accessible.

Data status for IGBP in the areas of solar flux, stratosphere, clouds and earth radiation budget, tropospheric chemistry, role of vegetation in the hydrological cycle, land-surface properties, oceans, sea levels and snow and ice coverage is given in Section 6.2.

The IGBP should also address the existing barriers to free access of data sets, including the poor knowledge of the current existence of some data sets. The mechanisms for data exchange also need improvement, the aim being to make all data freely available to all bona fide scientists.

Action plan

The Working Group membership should be extended to accord with the urgent task of designing an IGBP data-management structure. This should be done in close consultation with other international bodies, such as ICSU-WDC, UNEP and WMO. A pilot data-assembly project should be initiated, e.g., for land cover and management changes.

A pilot assessment of end-to-end performance of existing observation and data systems should be made for one globally significant parameter. Possible collaboration with the Global Information Systems Test of the ISY should be investigated.

The spatial and temporal resolution of the data proposed for collection in IGBP core projects should be specified in collaboration with the IGBP Coordinating Panels.

The SC-IGBP will consider the possible amalgamation of the Working Groups on "Data and Information Systems" and "Geosphere-Biosphere Observatories".

4.3.3. Techniques for Extracting Environmental Data of the Past

The issue

Studies of the physical, chemical, and biological parameters found in "natural archives", such as glacier ice, tree-rings, oceans and lake sediments, have revealed a wealth of information on the behaviour of the Earth system. Through such paleo-studies the general nature of climate change during the past 150,000 years has been observed and the Milankovitch cycles documented. Short-term variations, which might partly be externally forced (sun, volcanoes), have also been studied by means of paleo-records.

Changes in terrestrial vegetation, induced by changes in the physical climate system, have been documented from historical records, and changes in the basic nature of ocean circulation have been linked to significant changes in climate patterns. In addition, variations in the chemical composition of the atmosphere, (e.g., CO_2 and CH_4) as well as a broad spectrum of ions and solid particles have been analyzed from ice cores. These variations reflect changing atmospheric dust content and circulation patterns.

In order to develop a further understanding of changes in past Earth systems, it is necessary to bring together the presently disparate and scattered data sets that describe the past states of the Earth system in terms of essential astronomical, geological, climatological, and oceanic parameters and to formulate common guidelines for future data collection.

Models of the Earth system need to be developed in an attempt to disentangle the system's responses to different external as well as internal natural and anthropogenic forcings.

In doing this, there is also a need to develop methods to decipher the actual meaning of proxy information;, e.g., study the coupling of the atmosphere to polar and mid-latitude glaciers, and environmental and plant physiological effects on the isotopic ratios of C, H, and O in

cellulose. The application of new analytical techniques needs to be explored as well as the identification of new records to further elucidate past changes in Earth system processes.

Action plan

In order to develop a core IGBP project on past environmental changes, an IGBP Scientific Steering Committee (SSC; see Section 7) should be established to plan a core project on "Global Changes of the Past". It is essential that this effort coordinates with other programmes, and new programmes should be designed to fill the gaps.

The development should be cognizant of plans to establish Geosphere-Biosphere Observatories. These will monitor ongoing global changes, but there is also a need to study overlaps of directly measured parameters with those derived from natural archives.

In principle, the project plans developed by the Coordinating Panels should consider past, present and future global changes. It is essential that the proposed Scientific Steering Committee ensures efficient liaison with the Coordinating Panels. It is also important to interface with the climate modellers (WCRP) and geosphere-biosphere modellers (IGBP) to optimize the use of paleo-studies for model development.

The development of new instrumentation and techniques for extracting and analyzing environmental data from the past needs to be stimulated, and the Scientific Steering Committee should encourage this and ensure that appropriate intercalibrations are made between all the different methodologies.

4.3.4. Geosphere-Biosphere Observatories (GBOs)

The issue

The network of GBOs will be designed to facilitate the achievement of the underlying themes of the IGBP. This is necessary in order to identify and decipher global-change phenomena, as distinct from local or regional signals, and to encourage interdisciplinary research in the IGBP. The GBOs will also promote coordination, cooperation, and communication among the participating nations in an attempt to facilitate global-change research. They will serve as focal points for documenting earth-system parameters, process studies, development and validation of models, and ground-truth locations for remote-sensing data.

The development of a GBO network is envisaged as a hierarchical structure consisting of a small number (5-10) of regional research and training centres, which are multinationally supported, interdisciplinary in character, and multi-purpose in function. In addition, cooperating GBO facilities, which are nationally supported and function as sites for experiments and as key monitoring sites will form part of the network. The next level of the hierarchy consists of stations in affiliated networks. These are primarily monitoring sites. In addition, the last level in the hierarchy is referred to as the "tents and rowboats", which are temporally and spatially transient research and monitoring sites that may vary in number at any one period in time.

The GBO Research and Training Centres will provide support for regional educational and training activities that are relevant to ongoing IGBP research. The Centres will focus on the interdisciplinary aspects of research. Equipment and techniques will be state-of-the-art, but the development of simple and reliable techniques to be used in collaborative, international projects will also be pursued. Educational and training activities will ensure that IGBP research developments are made available on a global basis. Process studies ~~and syntheses will also be~~ important ~~activities. These~~ will include experiments, detailed process studies, cross-ecosystem and interdisciplinary comparisons, global comparisons, and global synthesis as identified by the IGBP research programme. Key processes, environmental parameters, or Earth-system components will be routinely monitored or characterized depending on the type of research being conducted. The Research and Training Centres will function as centralized data-storage facilities that will coordinate process studies and synthesize results (e.g., cross-site and interdisciplinary comparisons, global comparisons, and multi-scale modelling studies). They will also serve as support facilities for other GBO facilities in the region.

Action plan

The membership of the Working Group will be extended and the SC-IGBP will consider the relative benefits of two separate or one combined group for "Data and Information Systems" and "Geosphere-Biosphere Observatories".

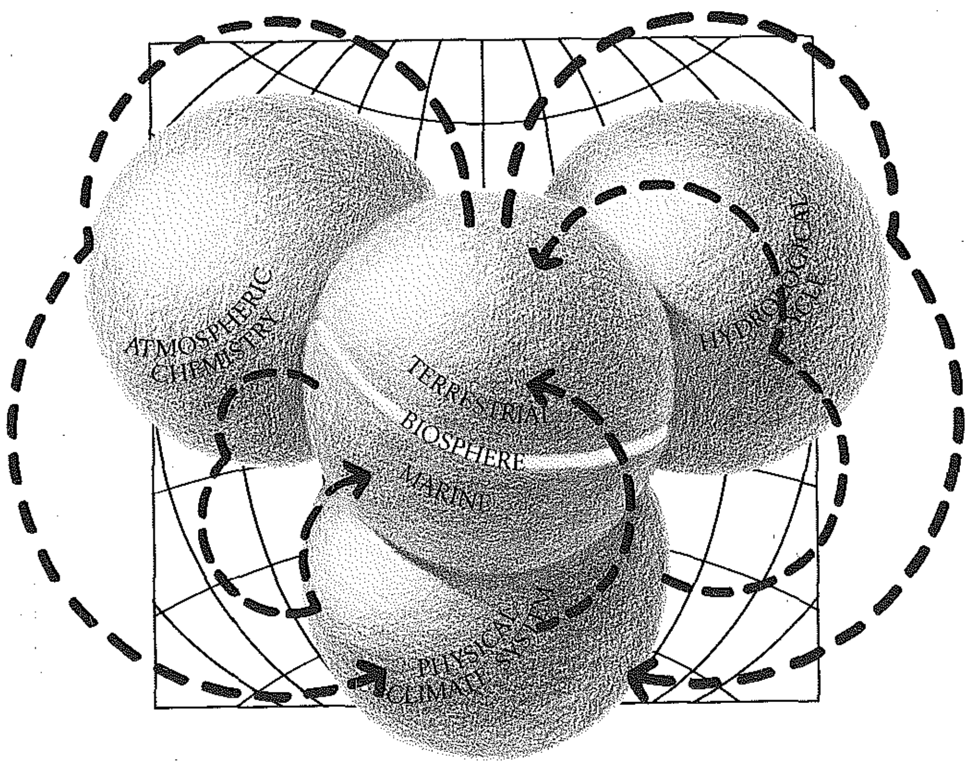
The next IGBP step will be to develop a detailed proposal for the establishment of GBO Research and Training Centres. The proposal will be based on the report to and discussions during the SAC meeting. A rationale for the selection of locations for GBOs should also be worked out. The role of other international organizations will be addressed specifically. Representatives from the IGBP Coordinating Panels will be involved in this process to ensure that the development of an international GBO network will adequately meet the needs of the forthcoming IGBP research projects. Specific attention will also be given to the integration of recommendations from the Working Group on "Data and Information Systems".

A second meeting of the Working Group will be arranged in collaboration with IIASA. This meeting will consist of two parts. The first part will deal with the relationship of the GBOs to existing national, regional and global monitoring systems. The second part of the meeting, which will consist of Working Group members only, will formulate a statement for the GBO network including a funding proposal, an estimation of the costs of developing the Research and Training Centres, and an action plan for way of approaching potential donors.

A third meeting is envisaged for 1989. This meeting will discuss the relationships between a GBO network and the present and future remote-sensing needs for ground-truth observations.

5

Components of a Research Programme



During the first meeting of the SC-IGBP, it was decided to focus the initial planning for the research programme on four specific areas. The selection of these areas took into consideration the five background planning documents presented to the ICSU General Assembly, and the report of the Planning Group. The concept of underlying themes for the Programme, which are to be used in guiding the selection of the research topics (Section 3), emerged from Special Committee discussions.

As the programme is concerned with interactive processes of the total Earth system, it would be counterproductive to select highly distinct topics. One could argue that only one project should be developed; i.e. a project to study the functioning of the interactive biological, chemical and physical processes that regulate the Earth as an ecosystem. For practical reasons this is not feasible, and the programme will need to have to have distinct sub-elements or specific project areas. It is essential that there are close contacts between the four Coordinating Panels that were established to develop research proposals for the IGBP, and to ensure that a coherent picture will emerge, the SC-IGBP decided that only its members would be formal members of the four Coordinating Panels. It is, however, expected that the membership of the groups will be increased after the first SAC-IGBP meeting.

The focus for the planning of research projects in the four Coordinating Panels, and project relationship to the Earth system, is depicted in Figure 5.1. This schematic presentation shows the interactions between the Coordinating Panels and the following four components: The Biosphere (Marine and Terrestrial); The Hydrological Cycle; The Chemistry of the Atmosphere, and the Physical Climate System. A central focus of the IGBP is the biospheric role in the total Earth system and how this affects the chemistry of the atmosphere, and how through biogeochemical cycles (including the hydrological cycle) it interacts with physical processes to produce the climate system of the Earth's.

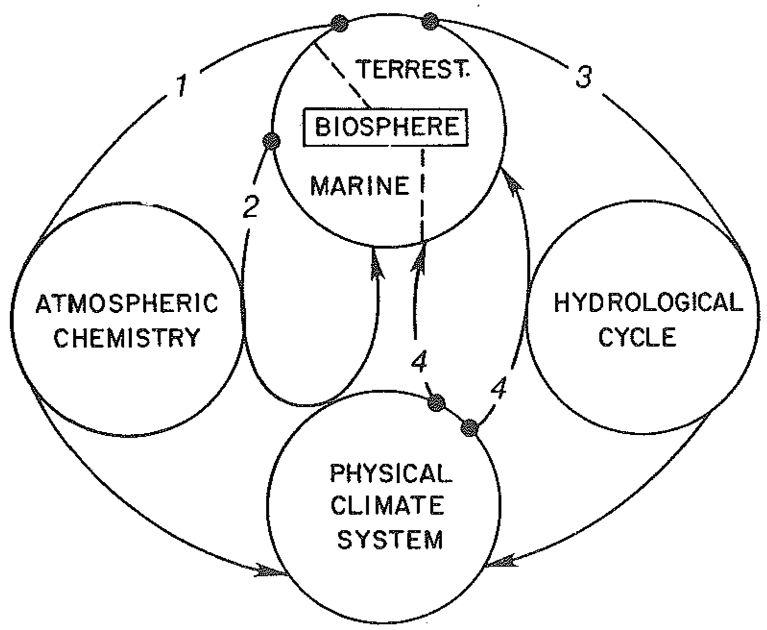
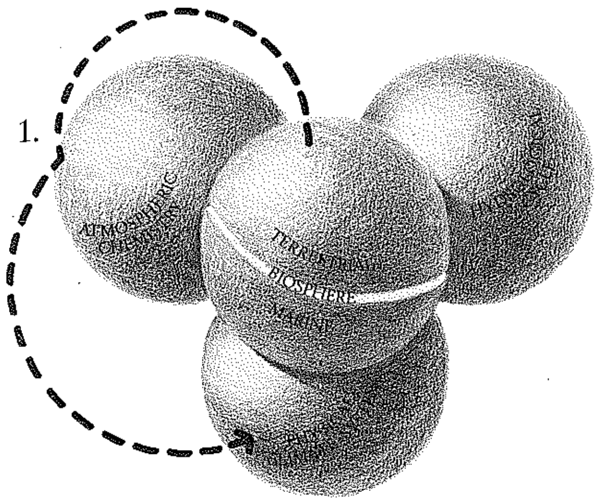


Figure 5.1.

1.



Identification of the significant terrestrial biosphere sources and sinks of green house gases in the atmosphere are important for understanding regional and global chemistry and its impact on climate. The need to study the fundamental processes underlying the emissions from terrestrial ecosystems is driven by the lack of understatnding of these processes and how to parametize these processes in global and regional models of climate. The coupling of the terrestrial ecosystems and the atmospheric chemistry is an important link in the Earth system control of climate.

5.1. Terrestrial Biosphere - Atmospheric Chemistry Interactions

5.1.1. Introduction

Research on the chemistry of the atmosphere developed in the 18th and 19th Centuries with quantitative and interpretative studies by the great chemists Scheele, Lavoisier, Rutherford, Priestley and von Liebig, who were all concerned with the major atmospheric gases O_2, N_2, CO_2, and H_2O and their role in the Earth's life processes. However, despite this early start, it is only during the past few decades that the important role of minor constituents in the cycling and transformations of chemical species through the atmosphere has been discovered. Recent, rapid development in our knowledge of the fundamental processes that regulate the chemistry of the atmosphere, has coincided with the establishment of the important effects of biospheric emissions and waste products from human and industrial activities on the atmospheric composition on all spatial scales.

Only during the past two decades has our understanding developed in regard to the basic chemical reactions that transform the many compounds that are brought into the atmosphere by emissions from the biosphere and by agricultural and industrial activities. However, quantitative knowledge of these important atmospheric chemical processes is still very incomplete. We know now that most atmospheric oxidation and subsequent removal reactions are initiated by the presence in the troposphere of very minute amounts of the hydroxyl radical (OH). Hydroxyl radicals in turn are produced by the photochemical action of solar ultraviolet radiation on tropospheric ozone and water vapour. Only a very small portion of the solar ultraviolet radiation that penetrates to the earth's surface through the stratospheric ozone shield is capable of initiating OH formation by reacting with tropospheric ozone, which constitutes about 10% of all ozone in the atmosphere. This illustrates the importance of the presence of ozone and ultraviolet radiation at the Earth's surface, although too much of either would be damaging to life on Earth.

This is only one example of the sensitive and delicate balances that regulate the functioning of the biospheric and atmospheric environment. Human activities, both industrial and agricultural, are now altering this and other balances. In the troposphere, worldwide concentrations of methane (CH_4) have been increasing by about 1% annually over the past decades. Because methane oxidation leads to carbon mon oxide (CO), and because CO and CH_4 are the main reactant gases of hydroxyl in the background troposphere, atmospheric concentrations of OH may be on the decline. In fact, as both CH_4 and CO are removed mainly by reactions with OH from the atmosphere, there exists the potential for instability in the global atmospheric photochemical system; more CH_4 leading to less OH, less OH leading to more CH_4 and CO, and so on. As a consequence, there is concern that the oxidative power of the atmosphere may gradually decline, leading to the accumulation not only of CH_4 and CO, but also of many other important atmospheric trace gases. The recorded increase in the global background concentrations of CH_4 is primarily due to increased emissions at the Earth's surface by several human-influenced activities (e.g., rice agriculture, cattle-holding, landfilling), but may well be significantly enhanced by the loss of OH radicals.

These effects hold for the background, relatively pristine, troposphere. In atmospheric environments that are influenced by industrial fossil fuel and agricultural biomass burning activities, major emissions of nitric oxide lead to the opposite effect, i.e. enhancements in the concentrations of OH, and especially of ozone (O_3). Indeed, at several observation stations in the northern hemisphere increasing concentrations of ozone of almost 1% per year have been observed over the past decade. Consequently, a gradual transfer of the oxidative power in the atmosphere from pristine, mostly oceanic and tropical environments to more human influenced environments (the mid-latitude zone of the northern hemisphere) has taken place over the past decades. The resulting increases in background ozone concentrations may well have had a negative influence on the productivity of some temperate forest systems. Furthermore, in tropical ecosystems the emissions of NO by biomass burning have been shown to lead to greatly enhanced ozone concentrations.

It is estimated that the enhanced combined climate warming caused by greenhouse gases other than CO_2, especially CH_4, O_3, N_2O, $CFCl_3$, and CF_2Cl_2, will match that of CO_2 in coming decades. Only the increase in the atmospheric burdens of $CFCl_3$ and CF_2Cl_2 can be traced entirely to industrial chemical synthesis and release to the atmosphere. However, in the case of CO_2, CH_4, N_2O and NO, both industrial, agricultural, and other biospheric processes play important roles in establishing emissions to the atmosphere.

The atmospheric concentrations of each of these gases are increasing at significant annual rates: CO_2 by 0.4-0.5%; CH_4 by about 1%; and N_2O by 0.2-0.3%. The industrial input of NO to the atmosphere has risen particularly rapidly over the past three to four decades, such that the global industrial NO source is now comparable to that produced by the combination of all natural sources, such as lightning discharges and soil emissions. In order to be able to estimate future increases in trace gases, and possibly lower their rates of increase, it is important to greatly improve our knowledge of their biogenic, agricultural and industrial sources and sinks. Although current attention is mostly focussed on CO_2 and CH_4, alterations in the atmospheric and biospheric nitrogen cycle are particularly large, and demand strong efforts to acquire a greatly improved understanding of the processes regulating the global biogeochemical nitrogen cycle, especially production of N_2O and NO. On the whole, it is clear that there is still a particularly strong lack of knowledge regarding the biospheric processes that regulate the emissions of these and other chemically important trace gases to the atmosphere. One of the main objectives of the IGBP will be to acquire wider improved knowledge on the response of the biosphere to anticipated atmospheric and climatic perturbations.

Several other human activities influence regional and global chemical processes in the atmosphere. For instance, fossil fuel burning strongly enhances SO_2 emissions, which are now several times larger than natural ones. This may well have a significant effect on cloud albedo in the northern hemisphere. The average cooling of the northern hemisphere, which may have resulted from greater SO_2 concentrations, could have partially counteracted the climatic warming effect due to growing atmospheric burdens of the greenhouse gases CO_2, CH_4, N_2O, O_3, $CFCl_3$, and to CF_2Cl_2 emissons due to human activities.

The oxidation of biogenic N_2O in the stratosphere leads to the production of NO and NO_2, which control the natural stratospheric ozone content by catalytic reactions. Because the atmospheric N_2O content is changing by only 0.2 to 0.3% per year, only slow stratospheric ozone changes would result from these perturbations. However, Mankind is now strongly influencing global stratospheric ozone in another way. Compared to the emissions of many other trace gases, those of the chlorofluorocarbons ($CFCl_3$, CF_2Cl_2, CCl_4, $C_2F_3Cl_3$) are quantitatively small. However, their photochemical dissociation products, Cl and ClO, efficiently break down ozone by catalytic reactions, leading to reductions in stratospheric ozone. The efficiency of these reactions was dramatically manifested by the unexpected rapid development of the Antarctic "ozone hole". Recent scientific studies have not only convincingly shown a clear cause and effect relationship, pointing to chlorofluorocarbon gases as the culprits, but have also unveiled a remarkable chain of positive feedback between dynamic, radiative, and photochemical processes. There feedback processes have led to a sudden system instability. Although, still far less dramatic than over Antarctica, total ozone depletions have now been observed at middle to high latitudes in the northern hemisphere, indicating perhaps a potential for substantial future ozone depletions.

Loss of total ozone will result in enhanced ultraviolet radiation at the Earth's surface and possibly, significant damage to the biosphere. Studies on the effects of increasing ultraviolet solar radiation intensities in the biosphere have so far been very limited. At the suggestion of IGBP, SCOPE has contacted IUPAB with a proposal for a joint exploratory study on the effects of increased UV-radiation on biological systems. On the basis of this study, IGBP will later consider possible research on this topic.

5.1.2. Proposed IGBP Activities

The chemical composition of the atmosphere is rapidy changing, mainly due to anthropogenic causes. These changes will have profound effects on the global system and need to be better understood, especially in their relation to the physical climate system and to the feedback mechanisms that affect production of biogenic trace gases. For the IGBP, the following research areas are especially important:

- Chemical and meteorological processes that regulate the composition of the troposphere.
- Biological processes leading to the release or uptake of photochemically or climatically important atmospheric trace gases.
- Global studies of the photochemistry and dynamics of the middle atmosphere (stratosphere and mesosphere), including its interactions with the troposphere and lower thermosphere.

Chemical and meteorological processes that regulate the composition of the global troposphere.

Although a broad picture has developed in regard to the most important processes which regulate chemical composition and transformations in the atmosphere, much remains to be done to acquire the necessary quantitative information that will lead to an understanding of atmospheric chemistry, its interactions with the biosphere, and its influence on climate.

Some important initiatives have already been taken by the Global Atmospheric Chemistry Panel of the U.S. National Research Council and by the IAMAP Commission on Atmospheric Chemistry and Global Pollution (CACGP) to develop an international research programme in global atmospheric chemistry. The latter organisation, building on the U.S. report, is in the process of defining the International Global Atmospheric Chemistry (IGAC) programme as a contribution to the IGBP. A partial list of recommendations so far agreed upon by is presented below:

- Develop international intercomparison, intercalibration and standardisation programmes for atmospheric chemical measurements. Promote the development of novel instrumentation, and the transfer of technical know-how to the research community.
- In order to detect more reliably the trends of trace gases and to derive exchange fluxes at the Earth's surface, current background measurement networks of radiatively and chemically important trace gases (CO_2, CH_4, N_2O, O_3) need to be expanded to include more stations in the networks, especially on or near continents. Vertical profiling of the chemical constituents should be conducted and the suite of gases should be extended, in the first place with observations of CO and NOx.
- Improve and expand the worldwide chemical precipitation network.

- Intensify studies on the exchange of trace gases and particulate matter at the Earth's surface and on their meteorological and biological regulation mechanisms.

- Conduct intensive and comprehensive measurement programmes in selected, ecological or atmospheric - chemically important regions of the Earth to test photochemical theory and to investigate regional chemistry and its relation to the global system, with full consideration given to the role of meteorological, atmospheric - chemical (gas and multiphase) processes and biospheric interactions. Some of the most interesting regions that have been identified are the dry and wet tropics, Southeast Asia and China, the North Atlantic, the Pacific, and the Arctic.

- Conduct laboratory investigations of key atmospheric chemical reactions, both in the gas and aqueous phase, and with particulate matter, to derive reaction-rate coefficients and mechanisms, as well as product yields. Emphasis should be on NO-poor conditions.

- Develop worldwide industrial emission scenarios for photochemically and radiatively important trace gases.

- Develop comprehensive, regional and global models of atmospheric chemistry and its interactions with the biosphere. By making use of the measurements obtained at the global background stations apply these models to derive fluxes of important trace gases at the Earth's surface.

The development of an IGAC programme is of crucial importance to the IGBP. A core IGBP Project should be developed together with CACGP to ensure that in the planning of the programme proper recognition is given to the links between the atmosphere and the biosphere.

Biological processes leading to the release or uptake of photochemically or climatically active trace gases.

To a large extent the biosphere determines the composition and photochemistry of the atmosphere through the emission and absorption of trace gases and particulate matter at the Earth's surface. Rapidly expanding human activities cause major changes in the biosphere. These changes influence atmospheric chemistry and climate. These in turn influence the various atmospheric constituents of the biosphere, whose concentrations are changing. So far, CO_2 is by far the best studied example. Nevertheless, despite many years of research efforts many unknowns remain, especially regarding the net biospheric sources and sinks due to tropical land-use changes, effects of fertilization by CO_2 and other atmospheric nutrients on the total biomass, air pollution effects, uptake in the oceans as sinks for atmospheric CO_2, and so on. The current lack of sufficient knowledge on CO_2 net-exchange rates between atmosphere and biosphere is reflected in significant uncertainty about the "airborne CO_2 fraction". This introduces substantial uncertainties in the projections of atmospheric CO_2 content.

Within the IGBP, studies of CO_2 uptake and release by the biosphere will be considered in connection with studies proposed by the Coordinating Panels on "Marine Biosphere-Atmosphere Interactions" (Section 5.2), "Biospheric Aspects of the Hydrological Cycle" (Section 5.3) and "Effects of Climate Change on Terrestrial Ecosystems" (Section 5.4). Furthermore, long-term observations and active experiments are planned to be conducted at the Geosphere-Biosphere Observatories (Section 6.4). Among other things, these studies should shed light on the important exchange of CO_2 between biosphere and atmosphere. Studies on the exchange of trace gases other than CO_2 will be the main responsibility of this Panel and will profit from close interactions with and participation in the activities which are planned within other sections of the IGBP, as well as several other ongoing or planned international activities.

The most important biogenic trace gases after CO_2, contributing to global change are CH_4, CO, NO_x, and N_2O. All of these are strongly affected by both industrial and agricultural activities and play important roles in establishing the ozone and hydroxyl concentration fields in the atmosphere. A coordinated research effort will be necessary to identify the most important source regions for these trace gases, to establish their source strengths and to develop prediction capabilities for future emissions. This will be a major task of the IGBP in collaboration with CACGP and SCOPE. The multidisciplinary collaboration that is required to accomplish these tasks has only been recently developed. Collaboration involves atmospheric chemists, boundary layer

meteorologists, terrestrial ecologists, and microbiologists.

An important contribution to the definition of IGBP projects in this area is the project on "Trace Gas Exchange between Terrestrial Ecosystems and the Atmosphere" of the Scientific Committee on Problems of the Environment (SCOPE). The following broad objectives have been defined for the SCOPE project:

- Assess our understanding of the controls and interactions in the plant-microorganism-soil-water system which regulate trace-gas exchange within the atmosphere.

- Assess the status of current techniques to derive fluxes of trace gases, and explore the possibilities for the development of new sensors and novel approaches to flux measurements. Also, assess measurements on large spatial scales, such as aircraft-based techniques and approaches, using remote-sensing.

- Develop high quality global and regional data sets of important atmospheric trace gases to derive exchange fluxes at the Earth's surface with the aid of photochemical-meteorological models.

- Develop a foundation for the design of diagnostic and predictive models to describe the exchange of trace gases between the biosphere and the atmosphere. Such models form a critical link between the small scales (in time and space) on which measurements are conducted and the long-term scales that are of interest for a scientific understanding of the exchange of gases between the biosphere and the atmosphere. These range from the microscopic scale, at which microbiological production and consumption of gases take place, to the regional and global scales relevant for atmospheric chemistry and climate.

The first SCOPE Project activity will be a Dahlem Workshop (February 1989). This meeting will provide a state-of-the-art review of scientific knowledge to advance interactions between disciplines. The meeting will concentrate on the processes which control the exchange fluxes of CH_4, N_2O and NO_x between the biosphere and troposphere and measurements of these gases. The following is a partial list of questions that will be addressed at the Dahlem Workshop:

- What are the relative roles of biological and environmental variables in regulating production and consumption of trace gases in ecosystems?

- How should we extrapolate small-scale flux measurements to regional and global scales?

- What are the physiological and biochemical processes controlling the fluxes of trace gases between terrestrial ecosystems and the atmosphere, and how do we best measure these fluxes?

- How does trace-gas exchange interact with chemical and physical climate? Do geophysiological regulation mechanisms exist?

The SCOPE Project, in collaboration with IGBP, will also organize a larger conference on "Trace Gas Exchange between Terrestrial Ecosystems and the Atmosphere" in February 1990. This conference will deal with biospheric sources and sinks of important trace gases other than those discussed by the first SCOPE meeting, such as carbon monoxide, the reactive hydrocarbons emitted from vegetation and anthropogenic activities, and the reduced sulphur and organic halogen gases, emitted by land and ocean sources. Strong emphasis will be given to the relationship between field experiments and modelling, especially with regard to the problem of extrapolation from local and field measurements to large-scale exchange estimates. This conference will, therefore, provide another important step for the IGBP toward developing a comprehensive research effort on trace-gas fluxes.

Discussions leading to the development of an IGBP project on biogenic fluxes of the Earth's surface, will also take place at the International Soil Reference and Information Center (ISRIC) Conference on "The Effects of Changing Soils and Land-Use on Emissions of Greenhouse Gases, Evaporation and Albedo" (August 1989).

Of particular interest to this panel will be worldwide analyses of biomass burning and land-use changes (e.g., tropical deforestation), since these not only affect the exchange of CO_2 between biosphere and atmosphere, but also affect other important trace gases, such as the reactive hydrocarbons, CH_4, CO, NO, and N_2O. Research over the past decade has shown that the common and widespread practice of biomass burning in the tropics can be a major source of many important atmospheric trace gases, in par with, and in some cases exceeding, industrial sources.

Studies on the exchange of N_2O, and of the organic sulphur and halogen gases between the biosphere and the atmosphere should be intensified in collaboration with the oceanic research community, e.g., by making use of the opportunities that are offered by JGOFS. Coordination with the activities of the IGBP Coordinating Panel on "Marine Biosphere-Atmosphere Interactions" (Section 5.2) is also essential. The increasing disturbance of the coastal nitrogen cycle and the possibility of substantially enhanced release of N_2O will be important topics for future research efforts.

It is important to start IGBP field research and modelling projects on trace gas exchanges between the biosphere and atmosphere as soon as possible. Several pilot programmes are already being conducted on national and multinational levels. The experience gained by these field projects will be of the utmost importance in the development of future IGBP projects.

Although knowledge about source-sink relationships of relevant biogenic trace gases can only be gained from studies on current ecosystems, substantial additional information about the globally integrated sources and sinks of trace gases and particulate matter can be obtained by considering environmental and climatic changes of the past, as obtained from ice core, tree ring and sediment analyses. In this effort, strong interaction with IGBP Working Group 3 (Section 6.3) will be necessary.

The IGBP will also address the potential role of satellite-borne instrumentation for global studies of tropospheric trace-gas distributions (Section 6.2), and the modelling of global atmospheric chemistry (Section 6.1), including material exchange processes at the Earth's surface. Optimum communication among scientists and exchange of research data obtained within the IGBP will be of the utmost importance for the success of the IGBP (Sections 6.2 and 6.4).

Finally, an important task for this Coordinating Panel will be to advise on the choice of sites for the Geosphere-Biosphere Observatories (GBOs) (Section 6.4), and the types of meteorological and chemical observations, and field experiments, to be carried out at the GBOs, including active ecosystem experimentations.

Global studies of the photochemistry and dynamics of the middle atmosphere, including interactions with the troposphere and lower thermosphere.

The chemistry and dynamics of the middle atmosphere, extending in altitude between the tropopause and about 100 km, is controlled by both natural (e.g., solar and volcanic) and anthropogenic forcings. An important role in the chemistry of the stratospheric ozone layer is also played by the largely biogenic gases, N_2O and CO_2.

The serious concern about the alterations which may occur in the middle atmosphere is, in large part, related to the stability of the ozone layer, which serves as a natural filter against the solar ultraviolet radiation that can damage organisms. Together with carbon dioxide and water vapour, ozone is also responsible for the temperature structure of the atmosphere and may therefore have an impact on long-term climate changes. However, while CO_2 is essentially chemically inert in the atmosphere, the spatial and temporal distribution of ozone is the result of a large number of photochemical and physical interactions, involving the action of variable solar ultraviolet radiation, the transport of minor constituents of both natural and man-made origin, as well as sporadic influences arising from volcanic eruptions and solar proton events. The absorption of solar ultraviolet radiation creates temperature gradients which drive the wind fields in the middle atmosphere, with possible consequence also for tropospheric climate. In addition, the temperature and wind structure of the stratosphere determines the vertical propagation and deposition of wave evergy in the middle atmosphere, providing an immediate connection between tropospheric and middle atmospheric processes.

An important component of the underlying themes for the IGBP is the external forcing by solar radiation (see Section 3). One question that arises is how deep into the atmosphere the impact of solar variability can penetrate. A recently discovered association between solar ultraviolet flux, the phase of the Quasi-Biennial-Oscillation (QBO), and the dynamic structure of the atmosphere may point to an influence of middle-atmospheric processes on the Geosphere-Biosphere system.

Due to this complex set of interactions, the accurate prediction of climatic changes, which could occur under the combined effects of variations in solar activity, atmospheric circulation, and inputs of anthropogenic active chemical constituents, is fraught with many uncertainties. The natural variability of the middle atmosphere on various temporal and spatial scales is not yet understood.

The sudden appearance of the Antarctic "ozone hole", a drop in total ozone by about 50 percent during the period September-November, over the past 5-10 years, has dramatically demonstrated how human activities can strongly disturb critical atmospheric properties in unexpected and nonlinear ways. In response to this environmental problem, research efforts have been intensified in a number of European countries and in North America. However, the ozone layer is a common resource, and ozone depletion represents a global problem. Consequently, it is of the utmost importance that enhanced, truly international research efforts are developed to monitor and study the physics and chemistry of the middle atmosphere. Of special importance will be improved and enhanced *in situ* and remote-sensing observations of the temporal and spatial distributions of temperatures and winds, of ozone, and of chemical species that affect ozone as well as of both the optical and physicochemical properties of stratospheric particulate matter. The latter has been shown to be of great importance for the development of the Antarctic "ozone hole", by providing reaction sites for surface catalyzed reactions that create active chlorine gases. These gases destroy ozone by catalytic gas-phase photochemical reactions. Changes in ozone due to anthropogenic influences, especially the continued release of the chlorofluorocarbons, will be at the centre of interest. However, in order to disentangle these from natural variations, enhanced long-term observations and related studies must also be devoted to factors such as variability in the ouput of solar ultraviolet radiation with the appropriate spectral resolution. Studies of dynamical and chemical-exchange processes with the troposphere are not well understood. These will, therefore, be of fundamental importance, as future climatic changes may well alter tropopause structure and temperatures in such ways that substantial effects on the lower stratosphere, and vice versa, may result. As the thermosphere may supply significant quantities of NO and NO_2 to the ozone layer, chemical and dynamic linkages between the lower thermosphere (100-150 km), the mesosphere and the stratosphere should likewise be subject to middle-atmosphere research. Finally, large short-term disturbances of the chemistry and meteorology of the stratosphere may be expected because of sporadic phenomena such as solar proton events and volcanic eruptions. As these phenomena are related to solar variability and magnetospheric and geospheric processes, close links must be established with the research efforts that are planned for these processes. However, these may not necessarily become part of the core programme of the IGBP.

5.1.3. Action plan

The IGBP will cooperate with the CACGP in developing an IGBP project on "Chemical and Meteorological Processes that Regulate the Composition of the Global Troposphere". The next IGAC planning meeting of the CACGP in Melbourne on 7-11 November, 1988, will be an important step in this direction.

On the basis of the recommendations of the SCOPE project on biogenic trace gases, the IGBP will develop research projects on "Biological Processes Leading to the Release and Uptake of Photochemically or Climatically Important Trace Gases". The Scientific Advisory Committee of the SCOPE project and representatives from the IGBP Coordinating Panel will hold a meeting, immediately following the Dahlem Workshop, in order to draft an outline of a research plan for trace-gas exchange studies within the IGBP. In addition, this will be discussed with JGOFS to ensure that research is promoted not only in terrestrial but also in marine systems. In 1990, SCOPE and IGBP will jointly organize a review conference on "Trace Gas Exchange between Ecosystems and the Atmosphere".

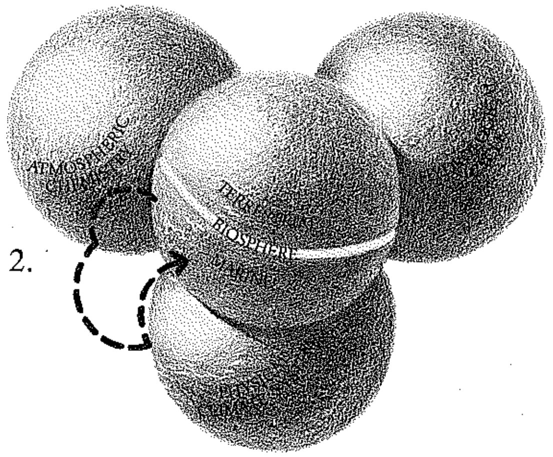
The documentation of land-use changes, the role of biomass burning, and the effects of these activities on trace-gas releases are of central importance and will be further developed by the IGBP.

IGBP will encourage the development of a strongly enhanced international research programme on the middle atmosphere through the appropriate international organizations.

After the results of the SCOPE-IUPAB Study on the biological effects of UV-B radiation have become available, the IGBP will evaluate its own role in this area of research.

Finally, it is understood that close links should be maintained with the other three Coordinating Panels to ensure that questions related to the exchange of CO_2 are adequately covered.

2.



The feedback among climate, ocean primary production and ocean CO_2 storage depends on global as well as regional characteristics of the biogeochemical cycles of carbon, nutrients and key trace elements and on the climate control of the physical environment in the euphotic zone. A much better knowledge of the basic processes that couple physics, chemistry and biology in the sea, based upon in situ and remote-sensing methods of observation, is needed to make it possible to understand and to model this coupled marine - climate system. It is important to know the consequences of these climate-induced changes on euphotic zone physics and their effects on global biogeochemical cycles, including feedback to atmospheric concentrations of radiatively active trace gases of biogenic origin.

5.2. Marine Biosphere - Atmosphere Interactions

5.2.1. Introduction

The role of oceanic biota in the global carbon cycle is generally understood. Marine plankton in the sunlit upper portion of the ocean extract inorganic carbon from water through the process of photosynthesis. The largest portion of the organic carbon product, perhaps 90%, is respired during its transfer through the food web in the upper layer of the ocean. The residual organic matter, along with associated inorganic components of the organisms' skeletons, such as calcite, aragonite and opal, settle to greater depths, with a small fraction ultimately committed to long-term burial in deep sediments. In the absence of biological consumption and release of inorganic carbon, the content of dissolved inorganic carbon in oceanic surface waters, for specific temperature and salinity, will be determined by the partial pressure of CO_2 of the proximal atmosphere. Thus, to the degree that carbon exported to depth reduces the surface water content below the air/sea equilibrium value, it is replaced by CO_2 from the atmosphere. Over time these linked processes have resulted in substantial reservoirs of inorganic and organic carbon in deep-sea sediments; more than 100 times those presently circulating in the atmosphere, terrestrial biosphere, and ocean.

Seasonal fluctuations in atmospheric CO_2 concentration result from seasonality in terrestrial and marine primary production and respiration. They range from about 2 ppm at the South Pole to about 15 ppm near the Arctic Circle. Their magnitudes and phases are primarily influenced by terrestrial biological processes, but are also indicative of the general pattern for the seasonal flux of CO_2 between the atmosphere and ocean. The bulk quantity of CO_2 invading the ocean can be calculated, but for any ocean basin the rates of exchange are highly variable on time and space scales that reflect the scales of physical mixing and biological activity. Whereas the seasonal CO_2 signal is dominated by terrestrial processes, the annually averaged trend in atmospheric CO_2 is a function of marine processes. This difference is in part a consequence of the fundamental differences in the biological processing of carbon in these two systems.

It can be calculated that about 40-50% of the fossil fuel combusted since the industrial revolution has been absorbed by the ocean. However, our sparse data base for ocean carbon chemistry and biological production prevents us from knowing the response characteristics of these processes either on a global spatial scale or time scales of several decades to many centuries. Results of studies of the ancient atmosphere, in ice cores and carbon isotope ratios in deep-sea sediments, provide clues as to the response time for change in the atmospheric CO_2 and marine-carbon reservoirs over long periods of natural climate change. In addition we do not adequately know the fate of the incremental anthropogenic CO_2 that is being absorbed by the ocean. It would in no way directly stimulate biological primary productivity, and thus must be accumulating in the non-living carbon reservoirs (dissolved and particulate, organic and inorganic). Regrettably, there is no data base for this major global reservoir analagous to that obtained for the atmospheric CO_2 content over the last thirty years.

Models of ocean-atmospheric interaction predict that as the lower troposphere warms in response to increased concentrations of atmospheric greenhouse gases, there will be a general warming and diminished seasonal cooling of surface ocean waters, particularly in temperate and high-latitude regions. The resulting increase in stratification in the upper ocean might diminish upward fluxes of critical nutrients from deep water and thus lead to reduced seasonal maxima for biological productivity. Consequent changes in food webs could affect commercially exploited fisheries, alter the flux of carbon, both organic and inorganic, to the deep sea, and also influence the exchange of CO_2 between the ocean and the atmosphere.

Changes in the rates of oceanic production and the species composition of the plankton could also affect the marine production of organo-sulphur compounds such as dimethylsulphide (DMS), which, on release to the atmosphere, are thought to be important in atmospheric chemistry and physics via the production of cloud condensation nuclei. Certain groups of plankton, especially coccolithophorids, are more active than others in these processes. It is important that we obtain a closer understanding of the processes and conditions responsible for the distribution of these organisms, and determine how their abundance and rates of activity may change in response to change in climate. The processes responsible for the formation of DMS and its fate in the sea, including its release to the atmosphere, need to be better understood (see Section 5.1). A feedback loop between the release of DMS and climate change has been hypothesized, the sign and strength of which needs to be assessed quantitatively.

Our knowledge of the regional and seasonal patterns for both primary production and the fluxes of biogenic particles to the deep sea are poorly known for any of the ocean basins. Equally incomplete is our documentation of the seasonally varying physical processes responsible for the transport of plant nutrients from the deep ocean to the sunlit surface waters, and the mixing of biogenic particles to the deep ocean. Improved understanding of these processes will require extensive new observations on the distributions of inorganic and organic carbon, organisms, nutrients, and physical properties in the oceans.

Recent evidence on the availability of iron in seawater has led to hypotheses that the windborne delivery of continental dust may play a more important role than previously realized in regulating the rate of marine primary production. Evidence from the contemporary distribution of excess major nutrients and iron support this hypothesis, and it raises intriguing questions regarding feedback loops between climate and ocean production via continental aridity and atmospheric transport of dust.

Although considerations of global-scale change in climate require that we focus much of our attention on the vast domain of the open ocean, global change in both climate and land-use practices have potential for significant impact in coastal and estuarine regions as well. The rate of sea-level rise associated with global warming (thermal expansion of ocean waters and the melting of ice now positioned on land) has important implications for estuarine and coastal flood-plain environments. Habitats critical for the food webs supporting commercially valuable species of fishes, mollusks, crustaceans, seaweeds, etc., may be altered in ways that reduce the yield of products that are of most value to mankind. Although there is a tendency to think of these problems as being local or regional in scope, their solution requires a global perspective for certain critical phenomena.

The coastal and estuarine domain extending to the shelf-break also consitute a poorly studied source term for materials of biological importance in the open ocean. Although rivers deliver the products of continental weathering to the oceans, such as essential nutrients for marine biological processes, e.g., phosphate, it is unlikely that even dramatic changes in the quality or quantity of riverine discharge associated with climate or land-use changes in the watershed would have an effect on open-ocean biological processes on time scales of decades to centuries. Such changes could, however, have profound effects on the coastal regions.

Increased rates of nitrogen delivery to this domain could result in increased rates of N_2O release to the atmosphere. Biostimulatory and biotoxic materials certainly have the potential to alter plankton community composition, and there are indications that such perturbations could be contributing to the increased frequency and intensity of toxic plankton blooms in coastal waters.

Arguably, changes in climate and land use that contribute to regional changes in patterns of aridity and atmospheric circulation have potential to influence coastal and oceanic biological production via the wind transport of mineral material. The biological significance of this pathway for delivering trace quantities of essential nutrients needs to be evaluated.

There are, thus, many interdisciplinary problems in the domain of marine biosphere-atmosphere interactions, which are clearly global, and critical in understanding the linkages between biogeochemical cycles and the physical climate. These must be better understood if we are to predict the effects of atmospheric change, especially tropospheric warming, on the biotic system.

Part of the background information considered by this panel was the Working Group report on this general topic that was commissioned in 1986 by the ICSU Ad Hoc Planning Committee for the IGBP. That report outlined the case to be made for a Global Ocean Euphotic Zone Study. The long-term goal of such a study would be to predict the potential impact of increasing tropospheric concentrations of radiatively active trace gases on physical processes in the atmosphere and the ocean, and consequent effects on ocean biogeochemical cycles that have significant potential for feedback on climate on time scales of decades to centuries.

The earlier working group that addressed this topic concluded that there existed a suite of unresolved and scientifically challenging issues relating to marine biosphere-atmosphere interactions that were particularly relevant to the climate change now anticipated as a consequence of increasing tropospheric concentrations of radiatively active trace gases. It was recognized that some aspects of this general problem would be addressed by existing and planned large-scale research programmes that were focussing on physical, chemical, and biogeochemical aspects of atmosphere-oceans interaction. However, it was also concluded that key aspects of the coupling of physical-climate processes and biogeochemical cycles were unlikely to be addressed satisfactorily by the programmes that could be identified.

In the two years since this report was written, our understanding of these linkages has been strengthened by the results of studies relating to marine production and its fate, new observations regarding the role of marine plankton in the production of volatile organo-sulphur compounds, and the products of models that link ocean biogeochemical processes to climate.

Certain recently initiated programmes of the World Climate Research Programme (WCRP), such as Tropical Ocean and Global Atmosphere (TOGA) Programme and the World Ocean Circulation Experiment (WOCE), are highly relevant to this topic. Furthermore, the Panel is cognizant of recent developments of SCOR that have led to the initiation of the Joint Global Ocean Flux Study (JGOFS), of the Joint Scientific Committee of the WCRP relating to the role of radiatively active gases in the context of climate change, and of the planning for the International Global Atmospheric Chemistry (IGAC) Programme (of CACGP).

5.2.2. Proposed IGBP activities

- Characterization of the oceanic carbon cycle, and associated links with cycles of other elements known to be either limiting to biological productivity or of significance to climate.

- Studies of effects of global change that are likely to affect coastal and estuarine systems of particular value to mankind.

- Examination of linkages among biogeochemical cycles and the physical climate system that require characterization in order to anticipate not only the effects of global change on these cycles but also their feedback to climate.

Oceanic carbon cycle

Much progress has been made in this area in recent years, and it points clearly to the need for international cooperation in order to mount global scale observations and process studies in the following areas:

- Seasonal and regional distribution for the constituents of the CO_2 system and partial pressure of other radiatively active biogenic gases in both the upper-sunlit, and deeper depths of the ocean, and the exchange of these gases with the atmosphere,

- Seasonal and regional distribution of plankton biomass and associated biogenic materials (calcite, aragonite, and opal) as well as their rates of producton,

- Roles of physical, chemical, and biological processes in regulating the distribution of inorganic and organic carbon in the upper ocean,

- Roles of gravitational settling and physical mixing in transporting biogenic particles from shallow to deep water.

- Effects of anticipated climate change on the airborne supply of continental dust to oceanic regions, where primary production is influenced by the availability of micronutrients, such as iron, which are otherwise scarce in seawater.

Some of these topics are under consideration by CCCO and SCOR, and it now appears that they will be considered in the context of the newly established Joint Global Ocean Flux Study (JGOFS). This programme will depend on data from ocean-sensing satellites, especially for measuring ocean colour, which is used as a proxy for plankton distribution. In addition, it would seem reasonable that the portions of this work requiring a global survey of ocean properties be done in conjunction with the global hydrographic survey of the World Ocean Circulation Experiment (WOCE of WCRP).

Coastal and estuarine systems

Historically, the scientific problems in this domain have been dealt with as matters of local or regional interest. In large measure, this is because many serious perturbations to these habitats have resulted from riverine or other point-source introductions of domestic and industrial wastes and, except for very large rivers, the effects are typically contained within national boundaries. With growing urbanization in the world's coastal regions, what have been local effects (some toxic for desirable organisms and others stimulatory for undesirable forms such as red tide organisms) are bound to spread to larger geographic regions.

Potential consequences of a global sea-level rise (a few to several tens of centimeters in the next several decades) for coastal and estuarine habitats are only just now being contemplated. Serious consideration should be given to the research needs in the following areas:

- Long-term trends and regional patterns in the eutrophication of coastal waters related to urbanization, industrialization, agricultural development, and other land-use practices in the watersheds of the world's major rivers.

- Effects of anticipated climate change on watershed hydrological cycles (see also 5.3) that can influence riverine delivery of suspended sediment and dissolved nutrient materials to estuarine and coastal habitats.

- Effects of global sea-level rise on estuarine and coastal wetland habitats and its implications.

The regional aspects of these issues need to be assessed in a global context, and recommendations formulated for studies that will enhance our ability to predict the consequences of large-scale changes in land-use practices and climate on some habitats. Many existing national and multinational programmes should be brought to bear on this subject.

In addition, international efforts should be directed towards focussing investigations on some of the world's largest rivers, where the implications for global change will be the most wide-reaching.

Biogeochemical cycles and physical climate linkages

The ice-core and deep-sea sediment records provide evidence that the global carbon cycle underwent significant changes with the ice-age fluctuations in climate. The marine biosphere is clearly involved in these cycles in a significant way, and there are profound implications for the nitrogen and phosphorus and perhaps sulphur cycles as well.

Additional effort needs to be devoted to a more complete interpretation of the record of the past (see also 6.3). The anthropogenic increment to the greenhouse-gas effect is now predicted to cause an increase in the mean temperature of the planet's atmosphere, perhaps exceeding within the next century the same increment of warming experienced since the last glacial maximum 18,000 years ago. It is, however, unknown whether the feedbacks that operated among physical climate processes and biogeochemical cycles in the past will function similarly in the near future.

To a considerable degree, progress in this area will benefit from data sets likely to emerge from studies such as the WOCE, TOGA, JGOFS, and IGAC. There are, however, several aspects of this problem that could benefit from modelling activities in anticipation of data sets from currently planned ocean and atmosphere studies. This is particularly evident in three areas: (i) Physics of the upper ocean, (ii) Air-sea gas exchange, and (iii) Interactive roles of physical, chemical, and biological processes.

The objective of the upper-ocean physical effort would be to provide explicit treatment of processes that affect primary production such as penetration of solar radiation into the sea, seasonal variation in the depth of the upper ocean mixed layer, upwelling processes, and annual deep vertical mixing. With respect to gas exchange, we need to improve our capability to compute rates of exchange across the air-water interface for large areas of the ocean under a wide range of natural conditions. Finally, much more sophistication is needed in modelling interactions that regulate the distribution of dissolved inorganic and organic carbon in the ocean. Parameterization of these relationships will be needed to develop useful predictions of the effects of climate change on marine biogeochemical cycles for entire oceans, and to assess quantitatively the potential for feedback to climate.

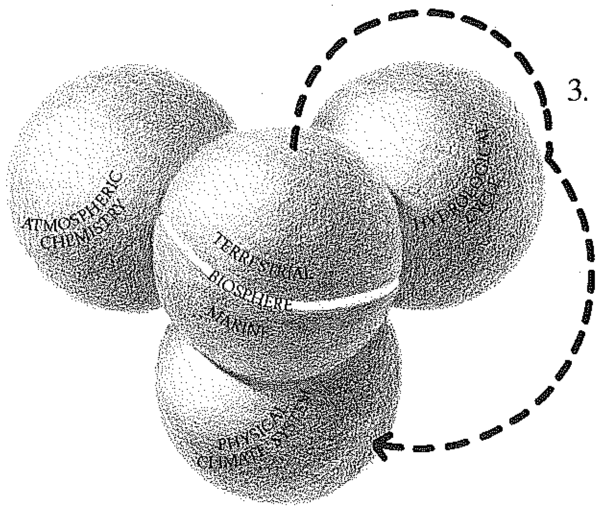
5.2.4. Action plan

In one of the areas identified for initial IGBP emphasis, the oceanic carbon cycle, JGOFS is now laying plans for major contributions through field studies, remote-sensing, and modelling. Discussions are underway regarding collaborative activities between JGOFS and IGBP, and we anticipate the development of a close working relationship in this area.

However, in the other two, those relating to coastal and estuarine biological systems and linkages among biogeochemical cycles and the physical climate system, no coordinated programmes of the scale envisaged are either in place or likely to be planned as part of other international programmes in the near future. Thus, the IGBP must take the lead in organizing these efforts.

In the near future, discussions will be initiated with experts from the scientific community to develop consensus on how to proceed in the latter two areas. In each case, input will be provided to the IGBP Working Groups on "Geosphere-Biosphere Modelling"; "Data and Information Systems"; "Techniques for Extracting Environmental of the Past"; and "Geosphere-Biosphere Observatories". Discussions at the SAC meeting will be important in identifying potential international partners in these studies, as well as to assess the interest of national members of IGBP.

With respect to observatories, it could be argued that numerous coastal and perhaps even oceanic locations are appropriate candidates as observatory sites. Perhaps, though, a singularly strong case could be made for the Southern Ocean. There is increasing evidence that this region is of unusual significance in the marine carbon cycle. Its intense seasonality, complicated biological interaction with seasonal pack ice, great sensitivity to global climate change and remoteness from many of the nations with global oceanographic capability leave us with a suboptimal observing capability. A land-based observatory on one of the adjacent continents could help to better focus oceanographic activities in this region. It could be of great value in staging field operations, conducting controlled experiments, and providing a focus for international scientific exchange of data. In cooperation with the Working Group on Geosphere-Biosphere Observatories, the IGBP will engage SCAR in discussions to assess the possibilities for joint activities in this area.



3.

The climate and land surface systems are dynamically coupled through the physical processes of energy and water supply, transformation, and transport at the land-atmosphere interface. The biosphere works in concert with these physical processes to further modify this coupling. Large-scale patterns of climate are influenced by regional variablity of the surface processes of the water cycle. Present physically based models need developments which reflect the dynamic coupling in the climate-soil-vegetation system.

5.3. Biospheric Aspects of the Hydrological Cycle

5.3.1. Introduction

The hydrological cycle is crucial to the planet's ability to sustain life. It is governed by a complex of physical and biological processes, the interactions of which are not very well understood, especially at the global level. The Earth system has undergone continuous changes from natural processes and will continue to do so in the future. What is new is that human activities are causing further changes in the atmosphere, lands, oceans, and biological systems that in many instances are larger and more rapid than the processes of natural change. These changes also affect the hydrological cycle in several major ways. Research is needed to provide the scientific understanding required to predict what changes might occur in the distribution and transport pathways of water. The impact of such changes should be addressed and possible measures be proposed to reduce them or at least mitigate their most undesirable effects.

Models of the global system potentially provide the tools needed to construct self-consistent descriptions of the coupled physical and biological processes, to test hypotheses, and to predict future changes. The most complete and advanced models of the global physical-climate system are the General Circulation Models (GCMs). Through simulation of the large-scale weather systems, these GCMs reconstruct the atmospheric component of the hydrological cycle, including mainly evapotranspiration and precipitation. The closing component of the hydrological cycle at the land surface is represented by the storage of water as soil moisture and snow cover and by runoff. This modelling framework provides the opportunity for describing and quantifying the present state of and future changes in the hydrological processes on the land surface, which account for the major portion of water resources available to man and to the terrestrial biosphere in general. However, the GCMs can now incorporate the land-surface hydrological processes only in a very simple and limited fashion, especially with regard to the representation of the key role of vegetation in the land-surface part of the hydrological cycle. GCMs are also weak in representing the time and space characteristics of rainfall. Since rainfall is a key ecosystem variable, frequency, intensity and spatial distribution characteristics must be specified.

Vegetation is crucial to determining the partitioning of surface energy fluxes into latent (water) and sensible heat. It does this by intercepting a fraction of incident precipitation, accessing soil water through its root systems, offering resistance to the flow of water from the soil through stomatal control, and by providing surface albedo and roughness. Large-scale patterns of climate are influenced by regional variability of the surface processes of the water cycle. We have to treat both the underlying physical determinism and the uncertainty in the elements of the water balance in order to better understand the interactions between the climate system and the hydrological cycle and how this might change in the future.

Major alteration of the vegetative cover of the land surface by humans affects both global atmospheric composition (Section 5.1) and the regional energy and water balances, especially evapotranspiration and runoff. Since the hydrological cycle in a drainage basin is usually regulated by radiation energy, changes in radiation balance will significantly affect rates of evapotranspiration, and alter the water-balance components. It is, therefore, very important to assess the response of evapotranspiration to changes in net radiation as a result of vegetation change.

How can we use current knowledge about vegetation (biomass, plant functional types, etc.) to assess time and space averages of actual evapotranspiration at scales compatible with the GCMs? Studies of past land use, climate, vegetation, and hydrology, provide the ranges of past fluctuations and insights into the dynamics of hydrological and vegetation systems (Section 6.3). The results from paleo-studies challenge the models to describe a wide range of processes to the extent that models can be developed to simulate past states on the basis of fundamental physical processes. As these models are refined, confidence will be developed in the ability of models to predict future states of these processes.

The dynamic interactions between climate forcing, vegetation, soil hydrology, and ecosystems suggest questions of system equilibrium and abrupt changes that must be addressed. For example, how stable are regional hydrological systems interacting with tropical forests or savannas or their margins? What would be the mechanisms and time scales of change?

How can we account for the wide range of temporal and spatial scales involved in land processes and parameterize the small scales in terms of variables of global models?

A main goal for the IGBP is to better understand how to quantify the role of vegetation in the hydrological cycle for the purpose of modelling its linkage to global climatic change on regional to continental scales. To understand the dynamics of and the synergism among soils, vegetation and atmosphere on the small scale and their integrated effects on the macro or grid scale there is an urgent need to

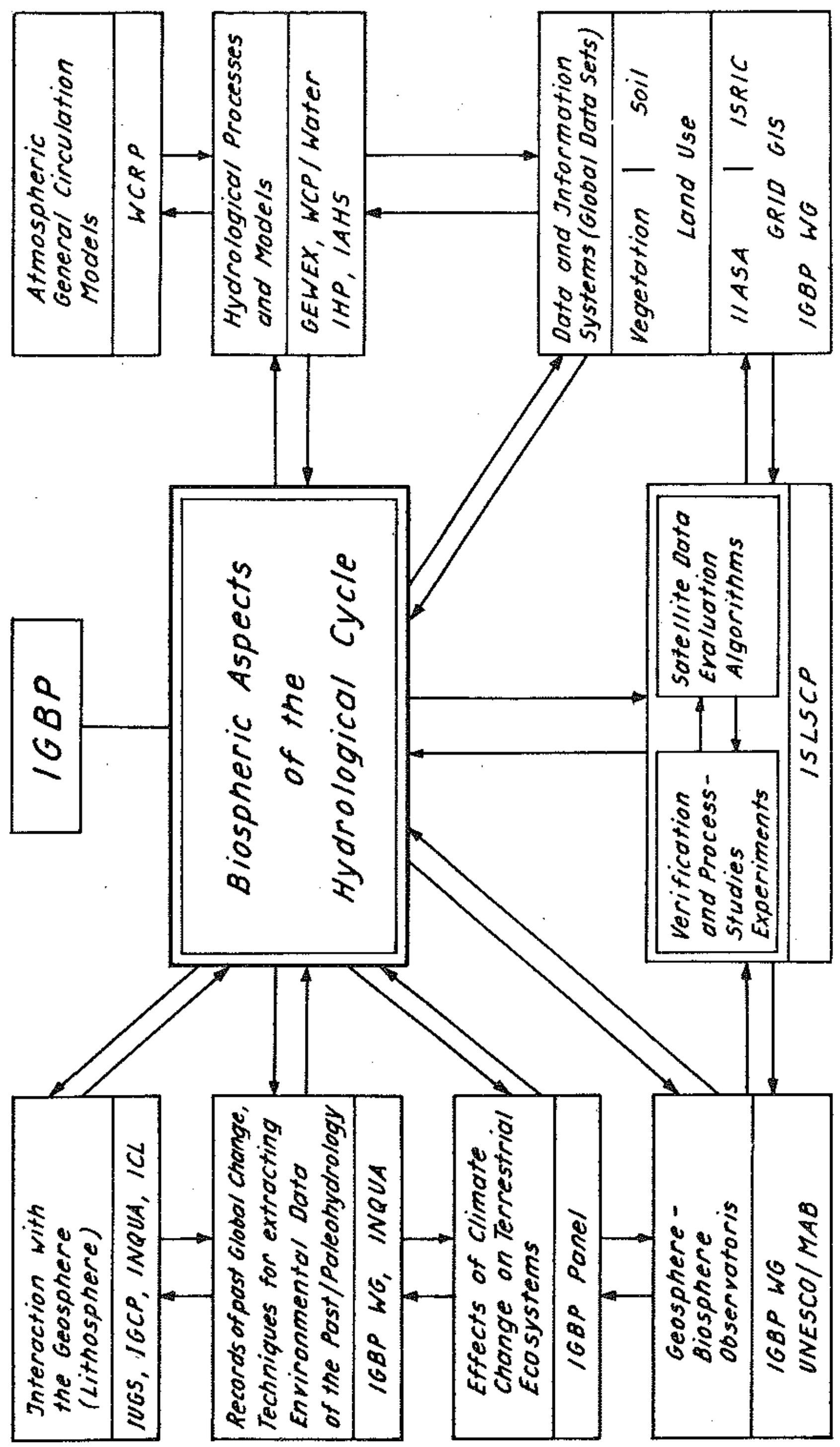
- study the regional distribution of energy, moisture and momentum sinks and sources over the land surface and their seasonal variability, especially the role of the biosphere in controlling these fluxes at various scales,
- explore, by experiments and models, whether our understanding of surface hydrology involving vegetation on the small scale can be rigorously integrated over space to describe interactions appropriate to scales of global models, and whether such processes can be quantified, individually as well as in their integrated effects, by remote-sensing.

On all time scales, non-linearity, non-stationarity and threshold processes play a fundamental role in the time evolution of hydrological systems (both surface and groundwater). Deterministic methods are suited to deal with processes far from bifurcations. Stochastic methods and synergetics offer tools for dealing with the dynamics in the vicinity of bifurcations of the non-linear deterministic differential equations. Situations under which fluctuations deeply influence the further development of hydrological systems are indicated not only by the theory of stability and bifurcations, but also by thermodynamic stability criteria.

5.3.2. Other Relevant Research Programmes

Because of the current recognition of the crucial role of the hydrological cycle in the global climate system and for human economics, a number of related programmes have recently been initiated or are currently being developed.

Figure 5.3.1.



Interaction of the "Biospheric Aspects of the Hydrological Cycle" — Programme with other Activities or Projects

The interaction between the IGBP and other related activities is shown in Fig. 5.3.1.

Four key programmes which are closely linked to IGBP objectives are the Global Energy and Water Cycle Experiment (GEWEX) of WCRP, the WCP/Water, the International Satellite Land-Surface Climatology Project (ISLSCP), the proposed Land-Surface, Atmosphere and Vegetation Interaction Programme (LAVIP) of IAMAP, and portions of Unesco's IHP-IV programme.

The study of the hydrological cycle is a major focus of the World Climate Research Programme. The primary hydrological research programme is being developed in the GEWEX. This research programme has four objectives:

- To determine the hydrological cycle and energy fluxes by means of global measurements of observable atmospheric and surface properties.

- To model the global hydrological cycle and its impacts on the atmosphere and the ocean.

- To develop the ability to predict the variations of global and regional hydrological processes and water resources, and their response to environmental change.

- To foster the development of observing techniques, data management and assimilation systems suitable for operational application to long-range weather forecasts, hydrology and climate predictions.

In the GEWEX scientific strategy, to be built upon the next-generation Earth-observing satellite systems, a comprehensive model development programme of the global atmospheric flow, upper ocean and land-surface processes is planned. This aims to expand the range of interactive physical and chemical processes taken into account in atmospheric climate simulations, especially in regard to exchanges through the air-sea and atmosphere-land interfaces. The coupling between the biotic and the hydrological component is not a major research component of the GEWEX.

The World Climate Impact Studies Programme (WCIP), one of four components of the WCP, is planned to study the impact of climate change on the hydrological cycle through WCP/Water. The projects are oriented to collect information relative to global runoff values and global energy balance. This programme will also make use of physical climate models coupled to hydrological models to simulate precipitation and runoff levels for large areas.

The Joint Scientific Committee (JSC) for the WCRP has established a Research Programme on Land-Surface Processes and Climate (PLSPC) for the purpose of maintaining an effective dialogue between the hydrological and the atmospheric community, and offering scientific guidance for the conduct of observational projects in the field.

The development of new satellite-observation technology to determine land-surface parameters of importance to the hydrological cycle is now under way in the ISLSCP project initiated by COSPAR and IAMAP. Results from this project will be essential for the understanding of land-surface parameters in controlling water flux from various ecosystems and regions.

The proposed draft plan for the fourth phase of the Unesco International Hydrological Programme (IHP-IV, 1990-1995), "Hydrology and Water Resources for Sustainable Development in a Changing Environment", places special emphasis on the adaptation of the hydrological sciences in order to cope with the expected changes in climate and environmental conditions. The sub-programme "Hydrology in a Changing Environment" includes three relevant themes:

1) Interface processes between atmosphere, land and water systems, including two projects;

   - Review of the scientific aspects of the interface processes of water transport through the atmosphere-vegetation-soil system at an elementary catchment and grid scale size.

   - Study of erosion, river-bed deformation and sediment transport in river basins as related to natural and man-made changes.

2) Relationship between climate variability (and expected change) and hydrological systems, including three projects:

   - Study of the relationship between climate changes and hydrological regimes.

   - Study of the hydrological effects of possible changes in sea levels.

   - Study of effects of extraordinary rainfall and snowmelt floods on rivers of the world.

3) Hydrological research and water resources management strategies in the humid tropics and in arid and semi-arid regions.

5.3.3. Proposed IGBP activities

Introduction

The hydrological-exchange processes in which vegetation is involved are extremely complex. On the one hand, the interaction between the system consisting of the vegetation and upper soil layer down to the root zone with lower water-conducting layers of the lithosphere, and on the other hand interaction between the soil surface, vegetation and atmosphere, have to be considered. In order to understand the biospheric interactions in the hydrological cycle and to determine the controls and constraints of this system, a cross-disciplinary programme is needed. This programme must include aspects of the hydrological watershed system, water pathways in the ground, vegetation properties, planetary boundary layer problems as well as monitoring and archiving of changes (Table 5.3.1). In developing this section, the experiences from ISLSCP and the available LAVIP plans have been taken into consideration. Components of an IGBP research programme should include:

- Models that combine more than one of the research areas.

- Remote-sensing (from space and from the surface).

- Field experiments to validate specific hypotheses, methodologies, area averaging parameterizations and inferred data sets.

- Long-term *in situ* observations at and around Geosphere-Biosphere Observatories.

Consequently, it is proposed to follow an interdisciplinary approach, and this section of the report is organized accordingly. Table 5.3.1 constitutes an effort to present the matrix that evolved during discussions in a readily overviewable manner, without any claim to being complete. In a second step, it would be necessary to define more precisely the single steps in each of these areas and their interactions.

A core project should be developed to investigate the interaction of plant communities and biomes with the hydrological environment, on scales that are compatible with global observation systems, and the interrelated effects that are due to changes in one or the other system (Table 5.3.2).

This investigation should include an inventory of knowledge and knowledge gaps, as well as documentation of case histories of environmental changes, and the conditions during which they occurred.

Modelling

A hierarchy of models should be developed to study the interaction of different processes in the soil-vegetation-atmosphere system. This should be based on physical processes and observable data on a global scale. These models should be developed for various time and space scales. Specifically:

- Models of large river-basin systems. These simplified balance models would use: atmospheric inputs from GCMs; information from remote-sensing systems about state variables and observational data of river discharge as a calibration quantity. They would provide inputs to GCMs. As simplified balance models they are also adaptable to other areal geometry used in grid networks.

- More complex models of small river basin systems. These models would include more knowledge about the single processes, especially concerning the soil-vegetation-atmosphere interface. They should use remote-sensing data and field experimental results and be capable of estimating evapotranspiration and other hydrological components as responses to changes in state

Table 5.3.1.

Scale			single leaf	single plant	agricultural field forest stand group of species	biogeoclimatic (vegetational) subzones plant communities	biogeoclimatic (vegetational) zones biomes	Activity areas in hydrology
Pixel	Hydrotope	micro α	x	x				Single process studies
Pixel array	Hydrotope	micro β		x	x			Simulation of elementary hydrological processes
Sub grid / Grid	Landscape River basin	meso				x		Simulation of interaction of different processes in a simplified form
Grid net	Region	macro				x	x	Water balances
Grid net	Continent Globe	macro					x	Water balances

Core Program

Table 5.3.2.

Parameter	Resolution: max.	min.	opt.	Frequency: max.	min.	opt.	Accuracy: max.	min.	opt.
Precipitation	100 m	10 km	1 km	5 min	1 M	1 h	10%	30%	20%
Snow depth	30 m	10 km	1 km	12 h	1 M.	24 h	2 cm	10 cm	5 cm
Ice cover	10 m	1 km	25 m	12 h	7 d	24 h	1%	20%	10 %
Glaciers	10 m	500 m	25 m	1 y	10 y	2 y	1%	5%	2%
Surface water areal extent	10 m	100 m	30 m	12 h	7 d	24 h	1%	5%	3%
Groundwater aquifer maps	50 m	1 km	100 m	1 y	5 y	3 y	5 m	30 m	10 m
Evaporation	100 m	10 km	1 km	12 h	10 d	1 d	10%	30%	20%
Water quality – turbidity	30 m	300 m	100 m	3 h	24 h	6 h	10%	50%	20%
Drainage – drainage area	10 m	100 m	20 m	3 y	10 y	5 y	0.1%	1%	0.5%

Frequency: h = hour; d = day; M = month; y = year.

Feasibility: [box] = Requirement can be generally met by existing satellite(s)

—— = Requirement should be generally met by near future satellite(s)

Note: Where a value is neither boxed nor underlined the observational requirement cannot generally be met either by existing or firmly expected future satellites, given the present state of the art.

Hydrological observational requirements, after Barrett et al. 1988

variables supporting the large-scale models. The models are needed to evaluate remote-sensing data or experimental results.

- Models for the most important processes governing the interactions between the components of the soil-vegetation-atmosphere systems. These models should relate physical process parameters to observational parameters of remote-sensing systems, calculating the reactions of the single systems to state changes on an interactive basis. Processes and systems to be included are: (i) Infiltration and runoff formation including soil moisture fluxes under the influence of changing vegetation, (ii) Interaction of radiation with the plant canopy, and (iii) Vegetation development and responses (root model, stomatal control, photosynthesis under different influences, transpiration and interception).

Role of satellite measurements

Definition of global hydrological balances requires measurement of three key hydrologically active components: The climate as a forcing function; the soil as storage function; and the vegetation as a partitioning point for interception versus throughfall, and as a consumption function for evapotranspiration. For global-scale research the first general variable is studied by the GCM, which may be able to define the Earth in approximately 200 x 200 km cells. For this purpose large-scale satellites can provide an important, and in many cases the only, means of data collection.

Certain surface meteorological conditions can be directly calculated from optical satellite sensors, including albedo, shortwave and longwave radiation balance, surface temperature, surface dew point and surface wetness. Satellites can provide an important extrapolation of point measurements, particularly of precipitation. ISLSCP was designed to measure these variables, first in FIFE on a grassland, with a second experiment being planned for a boreal forest.

The most hydrologically important surface variables measurable by satellite are topography (best done with stereo SPOT data or Landsat TM), vegetation cover, and snow cover. Highest spatial detail in a static condition can be achieved with SPOT or TM data. However, temporal dynamics at 1 km resolution are best done with AVHRR or the next EOS generation MODIS sensor at 250 m - 500 m with twice daily overpasses. Current satellite NDVI products may provide very good measures of seasonal vegetation phenology, but must be calibrated for the differing bidirectional reflectance properties of different biome types (e. g., forest vs. grassland). Soil physical parameters or rooting parameters of interest are not readily measured by optical sensors, and active radar sensors provide soil-surface penetration of only a few centimetres.

A current research need is the incorporation of these variables directly measurable by satellite into hydrological models on a GCM cell scale. Snowmelt models could incorporate repetitive snow-cover data with surface temperature and radiation conditions. Vegetative canopy partitioning into interception (and evaporation) or throughfall and soil storage could be modelled using satellite vegetation indices to estimate leaf-area index, and precipitation periodicity from Doppler radar. Evapotranspiration (ET) could be modelled using the satellite vegetation indices with the appropriate surface meteorological conditions (incident solar radiation, vapour pressure deficit) to drive an evapotranspiration equation (e.g., Penman-Monteith equation). New studies suggest that a satellite derived surface resistance factor may also be entered into the equation of evapotranspiration. These simple satellite driven models must be validated with "point" measurement and mechanistic soil-plant-atmosphere models. If precipitation and ET can be calculated adequately at GCM cell scales, reasonable estimates of runoff, or hydrological discharge, would be possible if the basin storage could be assessed.

A number of important variables for routine monitoring of the global hydrological balance can be sensed by satellite. Coastal sea levels, lake levels and wetland levels can be repetitively measured over large areas by definition of boundaries, especially with radar. Glacier, snowpack and ocean icepacks are easily monitored over large areas. The spatial shift in hydrologically defined biome ecotones, such as the savanna-desert boundary of the African Sahel, are already being monitored.

Other important variables that cannot be sensed directly, such as river discharge, soil moisture and groundwater depletion, may be efficiently monitored by automated ground stations transmitting through a satellite to a central data bank.

At some future time, efficient testing and operation of these capabilities will demand a computerized global GIS to organize available surface meteorology, topography, vegetation cover, soils and other data, at least to GCM grid spatial detail. Aggregation of homogeneous landscape units is possible, but probably is unwarranted beyond the 200 x 200 km GCM cell size.

Perceived needs for future advancement in satellite measurement have been classified in terms of the feasibilities of meeting the needs with existing or firmly planned remote-sensing data from satellites. A summary of hydrological observational requirements is presented in Table 5.3.3. The "Resolution" and "Frequency" columns demonstrate that many observational requirements will only be met if new sensor systems and satellites are developed for application in hydrology. The "Accuracy" column confirms that further algorithm development is also necessary. Using joint criteria importance and likelihood of achieving useful goals in the foreseeable future for satellite application in hydrology the following priority items are proposed: rainfall monitoring, surface-water monitoring and inventory (e.g., of rivers, lakes, marshes, reservoirs); snow mapping, measurements and monitoring; soil-moisture measurement, though mainly for un- or sparsely-vegetated areas; evapotranspiration estimation and monitoring; extremes of surface water presence or availability, i.e., through floods or droughts; and groundwater mapping and assessment, and discharge measurements.

Field experiments

The study of the general problems identified above requires an integrated programme of research that combines satellite observations with carefully selected experimental work that has to be done on the "ground". The principal goals for the field experiments are (i) to provide the information which is necessary for the interpretation of the satellite observation data, and (ii) to provide the biophysical parameterization of land-surface processes necessary for the different types of models in order to understand the interaction between vegetation and the hydrological cycle. To facilitate the interpretation of satellite data three types of experiments will be performed:

Single-parameter experiments on a small scale. These experiments take place over an area comparable with the pixel size of satellite observations and are concerned with essentially one or a few parameters neglecting the interrelations between them. They can be carried out by single and relatively small independently working research groups. The goal of such experiments is, e. g., to determine the albedo and directional reflectance of a homogeneous area that can be resolved in satellite images. With simultaneous measurements of the state of the atmosphere (spectral transmittance, water/vapour amount), which allow for a correction of atmospheric effects, it is possible to reduce the signals measured by the satellite-borne instruments to the quantities measurable at the surface. By comparison with the directly determined quantities, it is then possible to validate the remote-sensing data.

Complex experiments on pixel-array scale. If evaluation models or more elaborate products deduced from satellite observations are to be validated, much more complex experiments are necessary. For instance, if the evapotranspiration is to be inferred from temperature, vegetation index, and perhaps, microwave measurements, then ground measurements must determine not only these primary quantities but also the fluxes to be inferred from them. Such a complete boundary-layer experiment requires additional measurements of the heat and moisture fluxes as well as vegetation properties. In such experiments, a number of groups with different specialties must participate. In order to survey the whole site and to interpolate correctly between the surface measurements, aircrafts are essential.

Grid-scale experiments. The results of global models and the measurements made from satellites must be validated over a complex terrain. It is advisable to perform such experiments in areas that include a whole drainage basin, so that detailed runoff data are also available. In this case, the equipment used for pixel-scale measurements has to be multiplied and distributed over the large area of up to 200 km x 200 km. These experiments cannot be carried out without aircraft equipped with heat-flux measuring and remote-sensing

devices. Remote-sensing devices operated from the ground to determine the structure of the boundary layer are also useful. Thus, this type of experiment especially stimulates the application of modern technology and basic considerations of how to overcome the sampling problem.

These different types of experiments that reflect three different levels of complexities have to be combined with the study of the physiological behaviour of the major plant components in order to understand the interaction between soil, plants, and atmospheric conditions. When considering any interrelations between vegetation, lithosphere and atmosphere, the basic information must be derived from experimental evidence on the behaviour of entire plant stands or communities. Such knowledge cannot be estimated by simple extrapolation from the physiological response of single plants or leaves (with very rare exceptions), because a closed plant community has to cope with its own specific system of interactions; e. g., competition for water and nutrient uptake within the soil and competition for light and CO_2 above ground. Similar principles are valid for the interaction between single types of plant communities and higher associations on different global scales, as well as between single processes at one site and integrated processes on a large scale.

For this purpose it is necessary to perform simultaneous measurements of the micrometeorological variables, soil conditions and plant physiological processes. In this context, measurement variables and experiments should take into account the following processes in the soil-plant-atmosphere continuum: radiation absorption as affected by spectral properties of leaves and canopies; biophysical control of evapotranspiration, and in particular the degree of stomatal regulation of water losses at a leaf and entire canopy level; momentum transfer and its effect on sensible and latent heat transport; soil moisture availability including the depth and density of the root systems; resistance in the liquid phase to the transport of water from the bulk of the soil to the leaf surface; and the water-use efficiency of the plant components.

In order to study these processes the following physical and physiological characteristics should be investigated:

Root system. Depth of rooting zone, vertical distribution of roots, root resistance per unit root length, root density, and volume of root per unit volume of soil for each soil layer; root resistance in comparison to the resistance to water flow through the soil; interaction between hydraulic conductivity of the soil and vegetation. Since physical details for large-scale models are unlikely to be available, simplifications appear necessary.

Stomatal resistance (no water stress). Minimum and maximum stomatal resistance, functional form for dependence on solar radiation, temperature dependent factor implying stomatal closure for freezing temperatures, vapour pressure deficit term, variability of dependence of stomatal resistance on water-vapour deficit and on the content of trace gases in the air between species.

Stomatal resistance dependence on water stress. Dependence of stomatal resistance on leaf water potential and hence on plant, root, and soil resistance to flow; water stress factor. Since dependence of stomatal resistance on root resistance is complicated, simplifications seem necessary. Dependence of stomatal resistance on trace gases.

Radiation model. Dependence of canopy average stomatal resistance on solar radiation. Attenuation of incident visible solar radiation. Leaf orientation, Albedo for visible and near-infrared fluxes for each land type, zenith dependencies.

Leaf boundary-layer resistance. Heat and moisture transport from leaf surface to air within the canopy. Leaf-surface conductances, leaf-area index (LAI), eddy diffusion description of momentum deposition within the canopy, position of the canopy source height.

Canopy and soil aerodynamic resistances. Transfer of heat and moisture from vegetated ground or from bare soil surfaces; wind-dependent eddy diffusion coefficient profile within the canopy, canopy density, roughness height, displacement height; fraction of area covered by vegetation, in canopy and above-canopy wind.

Interception. Interception reservoir capacity, fraction of throughfall, LAI, partial wetting of leaves, temperature of wet and dry fraction of leaves. additional interception by ground cover.

Sensitivity studies are needed with evapotranspiration models of different complexity to discover which parameters are most important. These studies should be performed in selected vegetation types that constitute the main components of the terrestrial ecosystems. For studies of water movement from the soil through the plant cover to the atmosphere, the use of stable isotope techniques could be very useful for identifying the seasonal versus permanent underground water table, levels of absorption within the soil profile, and the contribution of transpired water to the atmospheric water vapour within and near the vegetation canopy.

The concept of monitoring and of a system of observatories for research of biosphere hydrological cycle changes

In accordance with the Geosphere-Biosphere Observatory network an observatory system is essential to the investigation of changes of biosphere-hydrological cycle interactions. Such a system must be applied to the purposes of modelling of changing interactions among geological structure, soil, vegetation and atmosphere. This system must also be able to gather information with the specific goal of a better understanding of the processes of the hydrological cycle. Monitoring and observatory systems must be capable of quantifying changes at different temporal and spatial scales.

The observatories for hydrological cycle changes need to be located in river basins that are representative of main geographical zones, biomes and geological structures. In addition, they must be established in accordance with river network hierarchy and economic infrastructure. The most important aspect is the locating of the stations and observatories to territories that are indicative and most sensitive to global change. Such localities might be: closed lake basins in semiarid and arid zones, glaciated mountain basins, delta and estuarine reaches of large rivers, upper swamp basins in humid zones, river basins on the southern border of the permafrost zone, etc.

Observatories and stations (see Section 6.4) should be able to describe the hydrological systems and their interaction with vegetation and the atmosphere in the representative river basins.

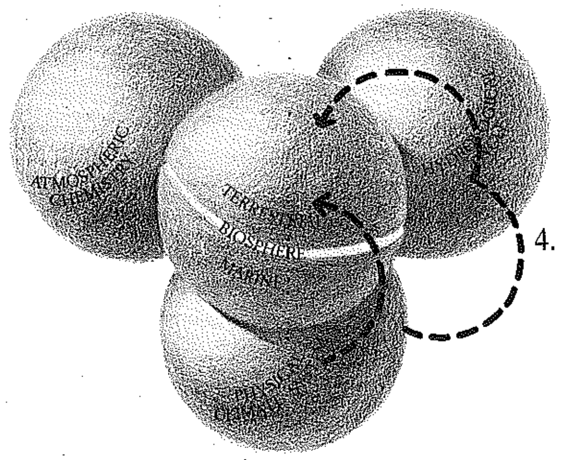
5.3.4. Action plan

It is suggested that the IGBP, in consultation with IAMAP and COSPAR, develop a core project on hydrological aspects of soil-vegetation-atmosphere interactions. This should be done through the appointment of an IGBP Scientific Steering Committee. The project development should fully utilize the experiences of ISLSCP.

The IGBP will invite GEWEX/WRCP for detailed discussions on how the programmes can best complement and support each other. Such consultations should focus on modelling aspects both for linking the results from future IGBP projects to GCMs. IGBP and GEWEX should also address questions related to temporal and spatial resolutions of climatic variable outputs from present models in relation to the needs of the planning for IGBP projects on the evaluation of the effects of changing climate on terrestrial ecosystems.

The need for water-balance studies in large river systems should be evaluated in consultation with IHP and WCP/Water. The effects of changes in water balance and its effects on river transport and estuarine and coastal areas will be evaluated in collaboration with the IGBP Coordinating Panel on "Marine Biosphere - Atmospheric Interactions" (Section 5.2).

In collaboration with the Coordinating Panel on "Terrestrial Biosphere - Atmospheric Chemistry Interactions" the Coordinating Panel will consider how questions of vegetation as a CO_2 sink might be handled during the planning phase of the IGBP. Consideration will also be given to the role of vegetation as a source for reactive hydrocarbons (Section 5.1).



There is a need to understand the effects of climate change on the soil, vegetation structure and species composition of terrestrial ecosystems, both directly and through changes in ecosystem processes (e.g., nutrient cycling, primary productivity) and demographic processes. The rates of ecosystem change will vary among different regions of the world. It will become necessary to understand the mechanisms that determine the lag times in the responses of ecosystems to various types of climate change. Such studies of change in ecosystems should focus on the properties of vegetation and soil which will feedback to the global environment (for example though changes in the fluxes of water and biogenic trace gases). It is necessary to consider both natural ecosystems and those affected by man.

5.4. Effects of Climate Change on Terrestrial Ecosystems

5.4.1. Introduction

The overall objective is to develop a research programme which will generate a predictive understanding of the effects of climate, and therefore of climate change, on terrestrial ecosystems. This capacity is primarily required to forecast the consequences of climate-driven ecosystem change for land use and biotic conservation and, secondarily, to determine the potential feedback of these changes on further climate change. The direct effects of climate change will be considered initially in four parts: (i) landscapes and soils, (ii) vegetation function, (iii) vegetation dynamics and distribution, and (iv) higher trophic levels.

The implications of climate change for the maintenance of biological diversity and, very briefly, for agriculture and managed forest crops, will then be considered.

5.4.2. Direct effects of climate change

Landscapes and soils

Processes. The topographic characteristics of landscapes (ruggedness, dissection, etc.) control the spatial and temporal patterns of soil and water distribution, solar radiation and consequently plant composition and plant productivity. The spatial patterns of water, soil and nutrient distribution span several orders of magnitude of scale; from the topographic controls of drainage on scales of 10^4m or so, to the very local scales that determine and affect individual plants. Landscapes can therefore be viewed as determining a basic, characteristic spatial patterning in the distribution of water, resources (soil and nutrients) and plant community composition and productivity. The distribution and productivity of higher trophic levels are coupled to this pattern; the strength of this coupling being higher in arid than in more mesic environments.

The processes of water distribution (runoff/run-on) and concomitant relocation of soil materials and solutes (erosion/deposition) are controlled by climatic factors (most strongly by rainfall and to a lesser extent by temperature and wind) and the feedbacks of vegetation cover on runoff, which vary in sign, strength, and influence according to characteristics of the rainfall regime. Changes in the intensity and duration of rainfall characteristics will eventually lead to changes in vegetation cover and thence to changes in the temporal pattern of infiltration, runoff, etc. Therefore, climatic changes which involve changes in rainfall regime will result in changes in the spatial and temporal patterns of hydrological processes and biological productivity.

With respect to possible soil changes, climate directly influences soil zonation, texture differentiation, and the role of organic matter in soil formation.

Scientific issues. The research issues related to the effects of climate change on landscapes are:

- Field hydrological/ecological investigations need to recognize explicitly, and account for implicitly, the spatial scaling imposed by the landscape at any one site.

- Any stratification of the landscape must be made at some recognized level within the hierarchy of landscape functioning, e.g., catchments, erosion cells, canopy drip zone, etc.

- The temporal scaling and extrapolation of hydrological and ecological investigations will be determined by the frequency distribution of the key processes of run-on/runoff and erosion/deposition.

With regard to soils, the response times of the properties and profiles of most soils to climate change are estimated to be very slow compared with the landscape processes of runoff, etc., or the biological species and community responses discussed below. There is, however, some uncertainty concerning this general conclusion. Labile soils, such as the forest-savanna transition zones of Eastern Africa, may well exhibit far more rapid change under changing climate conditions. Northern and Southern Hemisphere soil assemblages are distinctively different from each other, but very little information is available on soil responses to climatic change. It is to be expected, however, that the nature of the response would differ between soil types.

Even though some soil properties will respond more rapidly than others, few will respond in the short term and thus are not of immediate concern to the IGBP, even though pedogenic inertia will cause different time-lags and response rates for different soil types.

Changes in climate and atmospheric chemistry are predicted to exert an important effect on soil processes such as litter accession, decomposition, organic-matter turnover; proton/nitrogen accession from the atmosphere, leaching, exchange chemistry, relocation of salts and bases; groundwater recharge; erosion/deposition regimes.

Vegetation function

Processes. Vegetation function represents the combined effects of individual plants in capturing and releasing resources. To understand and predict the effects of climatic change on vegetation function, some general propositions relating to the processes involved in vegetation/atmosphere exchanges need to be examined. Production and general growth patterns are mainly the result of average climatic conditions (means), whereas survival (presence/absence) of any particular species is mainly determined by extremes. The process is thus modified by past production patterns and the frequency of extremes.

A particular vegetation type occurs within a climatic envelope, the limits of which may be readily defined by the limits of tolerance of the vegetation to extremes of low temperature and to the balance of precipitation and evapotranspiration. Climatic change will immediately affect the occurrence and degree of extremes of low temperature, and therefore, the geographical limits of a vegetation type. The hydrological balance will also respond immediately to climatic change. In addition, transpiration will be sensitive to changes in the atmospheric concentration of CO_2. The limits of

vegetation distribution and functioning will therefore be most sensitive to climatic change.

The response time of vegetation functioning will be dependent on the growth and developmental responses of individual plants. These responses are measured as the fluxes of entities between the atmosphere and vegetation (irradiance, water vapour, heat, CO_2) and the soil and vegetation (water, nutrients). Fluxes of entities (e.g., water vapour, heat, CO_2) between vegetation and the atmosphere are determined by the vegetation type as well as by atmospheric conditions. Studies of such fluxes must take place within large areas of vegetation, avoiding edges (see Section 5.3).

Owing to vegetation-level processes (e.g., microclimatic modification, competition), the responses to environmental factors of individual, isolated plants will be poor predictors of vegetation responses.

Scientific issues. Photosynthesis is the primary process involved in vegetation growth and the factors governing this process are well known. Additional research on photosynthesis *per se*, as a biochemical process, or at leaf level, is of low priority compared to possible changes in climate and their effects on vegetation. For IGBP purposes, attention should be confined to the effects of atmospheric and climatic factors on processes at the plant community and ecosystem level.

The factors which will likely undergo significant change in the next few decades are atmospheric CO_2, temperature, plant available moisture (PAM), nutrients and, perhaps, light.

On a global scale it is important to determine how vegetation change will affect albedo (especially hot, water-limited environments and cold, snow/tundra environments; see also Section 5.3). Current predictions of greater temperature change at the poles have ignored albedo changes at low latitudes.

Increasing CO_2 concentrations and climate change will have effects on carbon storage in ecosystems. This in turn will affect C/N ratios of the plant material with possible effects on decomposition cycles. This problem is being investigated for boreal forests and grasslands within a SCOPE project. This project also addresses the question of which models would be appropriate for forecasting such changes. Changed climate will also affect the characteristics of cloudiness and ultimately evaporative demand (see Section 5.3).

Different biomes will respond differently to changes in temperature regimes. This fact needs to be considered in relation to the effects of feedback mechanisms on climate (evaporation, albedo and roughness, Section 5.3) as well as on fluxes of biogenic trace gases, especially N_2O, NO_x and CH_4 (Section 5.1).

At regional levels the response of major vegetation types to increased CO_2 concentrations should be determined within large areas. Extreme events, e.g., prolonged droughts, intense rainstorms, early frosts, will affect regional-scale changes in vegetation function, and thus should be investigated in relation to genetic variability.

At local (community) levels mechanisms of CO_2 interaction with water, light, nutrients and temperature should be investigated, and the effects integrated, to quantify the effects of CO_2 increases on biomass production and community composition.

In turn, the effect on community composition will depend on how plant populations respond to CO_2 enrichment at all stages of their life cycle. The mechanisms of response of different life forms and the reasons for genotypic differences in CO_2 responsiveness need to be understood if we are to make predictions of the effects of CO_2 increases at the plant-community level.

Vegetation dynamics and distribution

Climate-induced changes in vegetation dynamics and distribution will raise concern about individual species and about vegetation community structure as a whole. The latter may therefore involve treating vegetation in different ways; as a single unit, as a community of plant functional types (PFTs) or guilds, or as selected species. Whichever approach is adopted, changes in community composition are brought about by changes in a number of processes.

Processes. Five processes (in phenological sequence) determine the dynamics of vegetation on a site, and therefore the changes which occur in the distribution of plant species and communities:

- Germination and establishment (G/E)
  . in the presence of established vegetation
  . in gaps or extensive bare areas following mortality of established vegetation.
- Growth and competition (G/C)
- Seed production (SP) (including dormancy and seed longevity).
- Dispersal or removal of seeds or other propagules (D)
- Mortality (M)
  . age-specific mortality
  . age-independent mortality

Scientific issues.

Determinants of community dynamics. The primary issue is to determine how climate and ultimately climate change influence the five processes in either individual species or in plant functional types (PFTs). This results in the establishment of the following four relationships. These express the five processes as functions of climatic and other variables, which together determine the rates or levels of the processes concerned:

i) G/E and M = f_1 {1. absolute limiting conditions (e.g., min/max temperatures, threshold levels of nutrients)
2. time for which plant available moisture (PAM) = 0}

In addition, other variables will also be affected by a change in climate and will, in turn, influence G/E and M. Three such variables which will need to be taken into account are:

3. Fire frequency and intensity.
4. Herbivores, pathogens and seed predators/dispersers.
5. Influence of CO_2 on all of the above, especially 1 and 2.

This model must include the interactive effects, because these define the nature of particular events or combinations of conditions which result in significant, episodic change. The "minimum sufficient model" is a key phrase and the major challenge for the IGBP. In order to avoid including too many complex factors, we must ask: "What is the single most important factor to introduce into existing models, to improve them?"

ii) G/C = f_2 {1. PAM, CO_2, light, temperature
2. soil nutrients
3. herbivores and pathogens}

iii) SP = f_3 {season length, temperature, light, CO_2 ?}

iv) D = f_4 {animals and microorganisms, i.e. vectors, predators and pathogens, as well as wind and surface hydrology}. Dispersal will also be strongly influenced by barriers induced through land-use changes.

In determining these four relationships, problems and questions arise for the different levels, from global to continental/regional, to landscape, and finally, to the community level. The importance of the variables in each of the equations varies and, fortunately, not all variables need be included in each analysis. Again the emphasis must be on keeping complexity to a minimum.

Initial screening and the use of statistical models. An initial screening procedure is needed to simplify the problem, by identifying places/vegetation types where change is likely to be great or easy to determine. The screening should utilize the relationship between present day distributions of species or PFTs and present climate, to make projections of the changes in their distributions that will result as a consequence of future climate scenarios. These statistical models include no ecological or biological mechanisms. It is possible that in some places, and for some questions at particular scales, a simple correlative model will be all that is required to provide a satisfactory prediction of vegetation change.

There are various correlative models which relate either species groups or vegetation types to sets of climatic parameters. They all suffer from the following major limiting assumptions:

- The difference between realized and fundamental (or potential) niches of species is ignored.

- Assumption of equilibrium. There are no time lag effects built into such models, and a major factor in determining whether particular species or PFTs will persist on a site or be able to move to new sites, will be the rate of change in climate relative to such attributes as longevity and dispersal. We need to understand nature of the the transients in order to predict the impact of climate change.

- The direct effects of increased CO_2 on , e.g., plant water-use efficiency are ignored. If present, these potential effects will alter existing statistical relationships.

- The scale of most models of plant distribution is such that differences in soil type are ignored. Where soil is important it will be necessary to predict a set of plant community mixes, the number in the set being equal to the number ecologically distinct soil types.

- Analogues of the new environmental conditions may not exist, either because of the new climatic combinations which may occur, or because of secondary effects such as new fire regimes.

Few in-depth attempts have been made to resolve the issue of how much complexity needs to be incorporated in the statistical models, i.e., how many, and which, climatic variables should be used to predict vegetation change, what source of climatic data should be used, how should the data be corrected for regional/local variation, and how many state variables should one attempt to predict within a single model?

There is probably a need to improve techniques for statistical-models. This involves two highly complementary approaches; improved statistical methods,and improved estimation of the independent variables that incorporate/summarize relevant processes.

The first of these approaches requires substitution of methods like generalized linear modelling for simple linear least squares regression, incorporation of factors, variables and their interaction; use of CART procedures (Classification and Regression Trees) for recognition of threshold effects; the use of non-linear methods rather than linear methods; and the incorporation of methods to estimate the statistical frequency distributions including their extreme values.

The second approach requires the substitution of process-oriented indices (e.g., annual evaporation/annual rainfall) for simple-state variables that have no necessary physiological relevance, such as mean annual rainfall, altitude, etc. Similarly, biological processes must be incorporated, e.g., competition, role of nitrogen fixing organisms and pathogens, by using summary indices based on processes which are biologically more relevant than abundance of other species or life forms.

An alternative view is that we should restrict ourselves to rapid screening, using the already existing models, and then proceed immediately to the process models which deal with particular parts of the world.

Classification of plant functional types. It is necessary to establish whether, for IGBP purposes, there is a need for a PFT classification. For the feedback effect of vegetation on climate, it is likely that a fairly broad classification of Vegetation Functional Types (as opposed to plant types) is all that is necessary. The research requirement would be, firstly, to establish the minimum set of such types that would adequately represent the feedback effect (albedo, surface roughness, evapotranspiration and CO_2 and other biogenic trace-gas fluxes) and, secondly, to determine the conditions required for an alteration in vegetation from one type to another.

For the effects of climate on vegetation, it may be necessary to develop a PFT classification. However, alternatively, it may be more useful, and more efficient to disregard the PFT step and to develop instead a "classification" of the characteristic features of plants, which enable them to respond via the five processes described above, to a shift in climate variables (particularly PAM and T). Given this information, it would be possible to proceed directly from a change in climate in any one region to a forecast of the species which would be likely to increase, decrease, or remain unaffected. This forecast would be based on sets of the characteristic features of the species and that climate shifts would not significantly alter the nature of the species interactions.

Mechanistic models of dynamics and distribution. In view of the serious limitations of statistical models, beyond their use for intitial screening, there is a growing need to develop appropriate mechanistic models. There are two main approaches to this issue.

i) Generally applicable (mechanistic) models. Generic models, or generally applicable models, should be developed for the major biomes and perhaps for the global scale (e.g., the Universal Vegetation Model, UVM, currently being developed at IIASA; see also Section 6.1). These models should incorporate the minimum, but sufficient, set of biological and ecological mechanisms required to predict changes in vegetation within a defined set of possible rates and magnitudes of change in climatic conditions.

There are already a number of models which may provide a framework for IGBP models, such as the FORET model and the Vital Attributes model. Existing models will need to be modified when a decision has been taken on exactly what they are required to predict. Careful peer review and acceptance will be a necessary step in this process. Research needs to be coordinated with the activities of other groups working in this area, such as the SCOPE Scientific Advisory Committee on "The Effects of Climate Change on Production and Decomposition in Coniferous Forests and Grasslands", and the IIASA programme on "Modelling Global Vegetation Change".

In developing these models it is important to note that two levels need to be considered: individual community models; and models at the landscape level. The latter include a mosaic of patches (communities) and take into account the relationships between the patches that dictate landscape-level properties e.g., total species, biomass, etc. These relationships may be vulnerable to climate change, just as they are to human interference.

In considering the synthesis and further development of existing models, there is a need to pay particular attention to demographic aspects and associated time lags (possible rates of change), and the identification of 'extreme' events or event-driven processes (G/E, M) in the biome concerned. These should include *combinations of climatic features* (such as potential and actual rainfall) and secondary effects such as changes in fire regimes, insect eruptions.

ii) Paleo-ecological models. A considerable advance in developing a predictive understanding of vegetation change in response to climate can be obtained by investigating past biotic and climatic change (see also Section 6.3). Examples of appropriate methods to achieve this are:

- Collect and analyse appropriate fossil-leaf data of stomatal densities and of stable isotope composition at fine resolution to determine CO_2 responses of the pre-industrial period.
- Construct international tree-ring data sets to define pre-industrial climate-growth and CO_2-growth relationships. An international tree-ring data set is gradually being collected, collated and maintained at the University of Arizona Tree Ring Laboratory.
- Identify and analyse new tree-ring series from seasonally dry tropical locations which are free from atmospheric pollution.
- Continue development of accelerator mass spectrometry for C^{14} dating and develop the ^{32}Si dating method.
- Document at fine resolution vegetational and climatic change in high sedimentation sites in tropical lowlands and at very high latitudes *near climatically sensitive ecological* boundaries. In order to document frequencies of rare events and long-term characteristics of transient responses by vegetation communities concentration should be on the Holocene with special emphasis on the past 6,000 years.
- Collect parallel tree-ring and weather data from sites which include the entire circumpolar boreal forest. These data can be used to modify and verify growth models and to document temperature versus CO_2 induced growth changes. These high-latitude forests are likely to be impacted heavily by CO_2 concentration changes and by climate change and forest structure and composition are simple enough to allow modelling of transient climate effects with mechanistic models. This initial boreal forest research would serve as a test-bed for modelling the more complex vegetation at low latitudes.

High trophic levels

Processes. Climate has two main direct effects on animals. It influences their energetics, and therefore determines which kinds of animals

(size, shape, metabolism) will survive and/or prosper; and it influences their reproduction. The combined effects determine the potential distribution of animal species, and interactions with other species determine their actual distribution and abundance. The influence of a climate change on a species will therefore be both direct and indirect, depending on the influence on other species.

Changing weather patterns will therefore have no readily identifiable effect upon the dynamics and distribution of animal species. The geographical ranges of some species will expand and those of others will contract. Data bases such as the CSIRO CLIMEX are available to model projected distributional changes where sufficient biological data are available.

The geographical ranges of the majority of animal species reflect specific habitats. For some the nature of the habitat is the overwhelming determinant of their performance and distribution, and prediction of the fate of the species is a simple corollary of the fate of the plant communities upon which they depend. No additional prediction is required in these cases.

Scientific issues. There are three kinds of issues concerning the changes in higher trophic levels in response to climate change:

The conservation of adversely affected species, especially those with restricted geographical ranges and narrow climatic tolerance and habitat requirements. The consequences to one sub-set of such species, the topographically stranded relicts on mountain tops, can be predicted as a group; most of these will become extinct as mean temperatures continue to rise.

The dynamics of pest species. These will exhibit no general reaction to a change in climate. Their inconvenience to people will be amplified in some cases and diminished in others. Some species, not presently viewed as pests, will undoubtedly become so when their climatic ranges are changed. The ecology of a large number of economically important pest species is presently sufficiently known to allow specificatioan of the probable effects of climate change on their dynamics and distribution. Where this type of knowledge is not available it can be obtained by standard ecological research. The specification of climatic change leading to a prediction of biological outcome must, however, be more precise than simple statements like "mean temperature will rise by 3°C and precipitation by 10%". As emphasized in the section on vegetation dynamics, the specification must include at least additional projections such as changes in seasonality and in year-to-year variability in weather conditions.

Animals as "early-warning" indicators of the speed and direction of climate change. This issue has generated much controversy and two strongly contested views have emerged. One group of scientists is firmly convinced that confounding factors other than climate will be too great, and that our ability to measure climate change directly is more than adequate. The other group, the proponents of the notion, suggests that the ranges of a carefully chosen sub-set of animal species should be used as "early warning" indicators of the speed and direction of change of the biologically meaningful components of climate. Indicator species would thus be used as bio-assay agents, the movement of their range boundaries integrating these shifts in weather patterns. These range boundaries are likely to be considerably more sensitive to biologically important shifts in climate than time series analysis on standard weather records. Standard weather stations do not record data that allow detection of changes in, for example, diurnal distribution of precipitation, diurnal distribution of temperature, and intensity of rainfall events. Such changes have important biological consequences and can be detected early on from movements in the range boundaries of indicator species. These movements can be interpreted and used to identify the component(s) of climate involved.

5.4.3 Implications of climate change

Maintenance of biological diversity

Scientific issues. Biological diversity will probably change in unknown ways in response to climate change. Species will move at different rates, altering their present distributions, and some will be altered genetically, at least ecotypically. Because the once continuous ranges of many species are now fragmented, and especially in the light of the relatively fast rate at which climate change will occur, it is likely that some species will be left in climatically

Research needs. It is necessary to document the current distribution and abundance of species and to assess species' response to climate change, by assessing movement and evolution. Will effects of land-use change override effects due to climatic change alone? It is also necessary to consider where reserves should be sited to encompass the greatest number of species, now and in the future. Are there widely applicable guidelines for off-reserve management to maintain species diversity?

The research needs are considered in relation to these questions. This is developed fully in the main report from the meeting of the Coordinating Panel, which will be published separately.

Agriculture and managed forest crops

The implications of climate change for agriculture, including silviculture, have not yet been considered in any detail. The topic is obviously of very great significance, and must be *treated as an issue in its own right.* The expertise at the Coordinating Panel meeting was, by design, largely centred on the areas related to natural ecosystems.

5.4.4 Predictive understanding: modelling and scaling

The functioning of the geosphere-biosphere is characterized by scale-dependent processes. The issues involved in modelling and scaling have been considered at some length by both ecologists and climatologists. The central role of scaling in the design, integration and synthesis of field experiments in the forthcoming IGBP is acknowledged, but no useful, widely applicable theory presents itself. A functional approach is required and we believe the following will contribute to such an approach.

Scaling down

Scaling down includes all of the steps involved in the application and interpretation of the output variables, from GCMs to terrestrial ecosystems. This is the most pressing issue in the whole modelling process because it is only from the GCMs that quantitative forecasts of future weather and climate regimes will emerge. Without a quantitative and dynamic link to this forecasting capacity, future research on and, more importantly, management of terrestrial ecosystems will be obstructed. The output of GCMs must be coupled to ecological models that are scaled to the landscape and/or management levels. If this is not done, the substantial scientific investments in global modelling will have no influence on the direction of terrestrial ecosystem research.

The problems involved in linking GCMs to ecosystem or landscape models derive from the great disparities in scale that currently characterize each research field. Because of computational limits, existing GCMs are run on an appreciably coarser scale than most ecological models. Typical spatial cell sizes which might be achieved (200 km on a side) are meaningless in terms of the linkages to ecosystem or landscape models.

Rainfall, which is a key ecosystem variable, provides a good illustration of the mismatch between GCM forecasts and basic ecological requirements. For almost all biomes the *ecological and management consequences* of a given rainfall will be determined by its time (frequency and intensity) and space (patchiness) characteristics. However, rainfall within GCMs is currently generated and represented as a 'uniform drizzle' - a space/time rainfall pattern that does not, in fact, occur. Thus, forecasts of the ecological effect of this modelled rainfall smeared over a GCM cell are meaningless for most of the world's landscapes.

The problems of scaling down can only be solved by practical considerations. In other words, terrestrial ecologists must specify for the climate modellers exactly what is required to interface the output of GCMs to realistically scaled ecosystem models. This should be discussed together with GEWEX/WCRP (see Section 5.3).

Scaling up

Scaling up includes all the steps required to parameterize the land surface in order to provide the interactive feed-back link between it and GCMs. The surface parameters currently required by GCMs are albedo, evapotranspiration, surface (aerodynamic) roughness and CO_2 flux (productivity and decomposition). The question that must be faced by both terrestrial ecologists and climate modellers is how to represent accurately landscapes aggregated over a cell size of 200 x 200 km. The recommendations provided in the main report are derived from very pragmatic considerations. It is recognized that these empirical suggestions are just a beginning, but *the beginning is all important. The sooner* realistic parameterization of landscapes is incorporated into GCMs, the sooner the strength and dynamics of the feedback loop, and the relative contributions of surface components to this loop, will be studied.

5.4.5 Proposed IGBP activities

The following is a summary of the research needs and recommendations that warrant the immediate attention of the IGBP. Additional important recommendations are listed in the full report from the meeting of the Coordinating Panel.

There is no body of ecological theory that adequately integrates environment, energetics, dynamics, distribution, and abundance. The gap looms large in both plant and animal ecology, and it hinders our general understanding of the effects of climate change on the distribution and dynamics of populations. High priority should be given to the development of such a theory, using existing data, and to testing and refining the theory experimentally.

With regard to the effects of climate change on *landscape and soils the rate of change in the* following soil properties (those that determine plant growth) should be assessed: (i) magnitude of soil nutrients/chemistry pools and rates of transfer exchange pools - CEC/cations, anions on clay and organic matter, organic pools of N, P, S; (ii) soil-water regime and groundwater recharge/salinity; and (iii) soil structure.

The requirements for models of organic matter/accession/decomposition/turnover that could predict levels of N, P, S exchange chemistry and pH under climate change need to be specified. Existing models, which can serve as starting points, should be identified. This is partly the case for an ongoing SCOPE project on boreal forests and grasslands (see above). Given climate change data, existing water-balance models should be further developed to *predict water regime/groundwater recharge/* salinity. What modifications do these models require for IGBP purposes? This question is partly considered in Section 5.3. The existing minimum data sets needed for such models must be specified and identified.

An important preliminary requirement is to establish, *for the major biomes of the Earth,* the degree to which a given change in vegetation structure/composition will affect albedo and surface roughness. It is then necessary to establish the sensitivity of global circulation models to such changes (see Section 5.3).

Models should be developed for the major biomes. These models should have the capability to predict how changes in atmospheric composition and climate, and concomitant changes in vegetation, will influence exchanges of CO_2, H_2O and N, and perhaps P and S, between the biosphere and the atmosphere (see Sections 5.1 and 5.3).

There is a need to determine, at the landscape or at least the community level, and within a representative set of vegetation types, the influence of increased atmospheric CO_2 on (i) soil organic matter and litter decomposition, (ii) water-use efficiency and the effect of this on evapotranspiration (in collaboration with the Coordinating Panel on "Biospheric Aspects of the Hydrological Cycle", Section 5.3), and (iii) primary productivity and litter fall.

It is necessary to develop the most efficient hierarchical structure of interlinked statistical and *mechanistic models on vegetation dynamics and* distribution. Together these should provide an adequate predictive capability for assessing changes in vegetation due to climate change on both global and other levels.

Existing models that are appropriate for incorporation into the IGBP model structure should be identified and their applicability in an IGBP context should be assessed at the forthcoming IGBP meeting on global modelling (Section 6.1). Existing statistical models should be evaluated and new models developed, including some which will deal with transients (as functions), and situations where analogues of the new environmental conditions do not exist. This will require more mechanistic models.

There is a need to establish the availability of, and *further requirements* for, data sets appropriate for statistical modelling. There is also a need to develop coordinated data-bases of climate, soil and biotic data, from the same localities (see Section 6.2). The lack of appropriate data-bases is more limiting for current modelling efforts than the model development step. Development in both these fields will eventually have to be coordinated.

Statistical models should be used to indicate important areas in which the most significant effects of climatic change may occur and where more detailed process-oriented work should be concentrated. These should include the influence of secondary effects such as changed fire regimes. In this context, the most appropriate classification of Vegetation Functional Types needs to be established for the feedback effect of vegetation on climate, to determine the conditions required for change in vegetation type. It should be established whether there is a need for a classification of Plant Functional Types, or if it is sufficient to establish the plant features that determine plant response to climate change. There is undoubtedly a need to establish the most appropriate classification for IGBP purposes.

Vegetation will perceive climate change as a change in frequency of rare and/or extreme events. Consequently, IGBP models must include this as a primary determinant of vegetation composition. Research needs to identify and characterize such events, and decide how to include them in models, in ways that allow validation of the models.

With respect to past climate/vegetation changes, periods of past climate variation and vegetation response should be defined, which coincide with those expected in the future. Can we adequately test models of long-term ecosystem behaviour, and if so, what are the features of paleo-ecological records we require? Fossil pollen and tree-ring chronologies from tropical lowland areas should be developed with enough precision and spatial comprehensiveness to define past relationships of climate and vegetation variance. The possibility of documenting effects of CO_2 fertilization during prehistoric periods of known CO_2 variance (e.g., full glacial atmospheric CO_2 concentrations of 180-200 ppmv) should be explored. To achieve this we need to examine late Quaternary single species leaf-macrofossil data (e.g., stomatal densities, stable isotopes, etc); (see also Section 6.3).

What specific types of rare events do we expect to be both of interest in vegetation response to climate change, and recorded in fossil pollen and tree-ring records (i.e., frost frequency and drought frequency in tree rings; volcanism and flood intensity in fossil pollen records), and what is the "paleo-ecological fingerprint" of each? Research is needed to define the measurement characteristics of these paleo-ecological tools.

Research effort related to agricultural crops and managed forests should concentrate on the development of generic growth and yield models for all of the major crops (and varieties), including forest species. The models should be tested across the full range of existing climatic conditions under which they are cultivated. The effect of increased CO_2 levels on the performance of different crops (and therefore on the predicted model outputs under changed climates) needs to be experimentally determined under field conditions, at an appropriate level. The results obtained should be incorporated in the generic growth and yield models. The period of significant climate change may correspond with the period when current developments in genetic engineering reach the phase of application in crop breeding. Activities should interact strongly, and research should incorporate developments from both these areas.

The influence of secondary effects on rangelands should be determined. Where the primary effect of climate and CO_2 change is increased production (through increased precipitation and increased water-use efficiency), the secondary effects of changed fire regimes are likely to strongly re-inforce even quite small changes in vegetation. Before including such effects in models of rangelands, it is necessary to assess the role of man in controlling fire regimes. The changes in vegetation on rangelands should be related to their importance for livestock production. A shift from predominantly winter to predominantly summer rainfall in semi-arid rangelands would probably induce a vegetation shift from shrubs to perennial grasses. The former favours sheep, the latter cattle.

In order to achieve a predictive understanding we need to use models to address scaling issues. For areas equivalent to a GCM cell size, i.e., 200 x 200 km, the average class/frequency rainfall distributions for time intervals (months) and rainfall types (convective vs frontal system)

should be determined using existing recording stations. The representativeness of field sites needs to be addressed in relation to grid sizes (see also Section 6.4). Within the area of a GCM cell, the most appropriate measure of spatial variability or patterning that can be applied to rainfall events should be determined; e.g., the equivalent to the beta-diversity index used by ecologists.

While the importance of extremes or rare events is recognized by terrestrial ecologists, it remains largely a qualitative appreciation that cannot yet be explored with the output of GCMs. The topic requires special consideration in order to define the specific research recommendations that would enable, within a GCM cell and for any biome, quantitative determination of what constitutes an (ecologically) extreme event in terms of P, T, and the coincidence of P and T, and the consequences of such an event.

For scaling up, it is necessary to refine, or develop and test, models that will forecast the primary productivity of landscapes from P and T, for the major biomes. Readily available satellite data can be used as part of this modelling process. The derived estimate of CO_2 flux should then be included in GCM sensitivity analyses, to determine which parts of the world, or which biomes (if any), will require further refinement of these estimates.

5.4.6 Action plan

A meeting of an expanded Coordinating Panel is tentatively scheduled to be held in conjunction with a SCOPE workshop on "The Effects of Climate Change on Production and Decomposition" (Woods Hole, MA, April 1989). A second SCOPE workshop will be held in early 1990 (possibly in Oxford, UK). It is anticipated that a draft plan for a core IGBP project on the effects of climate change on forest and grassland ecosystems will be worked out together with the IGBP Coordinating Panel at this meeting. The SCOPE project will continue to develop forest and grassland models to define climate conditions, the aim being to design diagnostic and predictive models that can describe the effects of climate change.

The Coordinating Panel will arrange a small workshop on requirements for and appropriate structure of models to predict, at a global scale, major changes in vegetation structure and composition as a consequence of climate change and how such changes will affect albedo and surface roughness. The results from the IIASA project will also be of direct relevance in this context, and the possibility for a joint IGBP-IIASA activity should be explored. The IGBP modelling will also be considered in relation to global models of the atmosphere and oceans during a workshop arranged by the IGBP Working Group on Geosphere-Biosphere Modelling in mid-1989 (see Section 6.1).
The interaction between soils and vegetation in relation to albedo and greenhouse gases will be considered at a meeting arranged by ISRIC in Wageningen, The Netherlands, in August 1989 (Section 5.1).

The IGBP will host a workshop on modelling local and regional vegetation dynamics in response to climate change. This meeting will also consider the importance of extreme and/or rare events and how these can be incorporated in experiments and models.

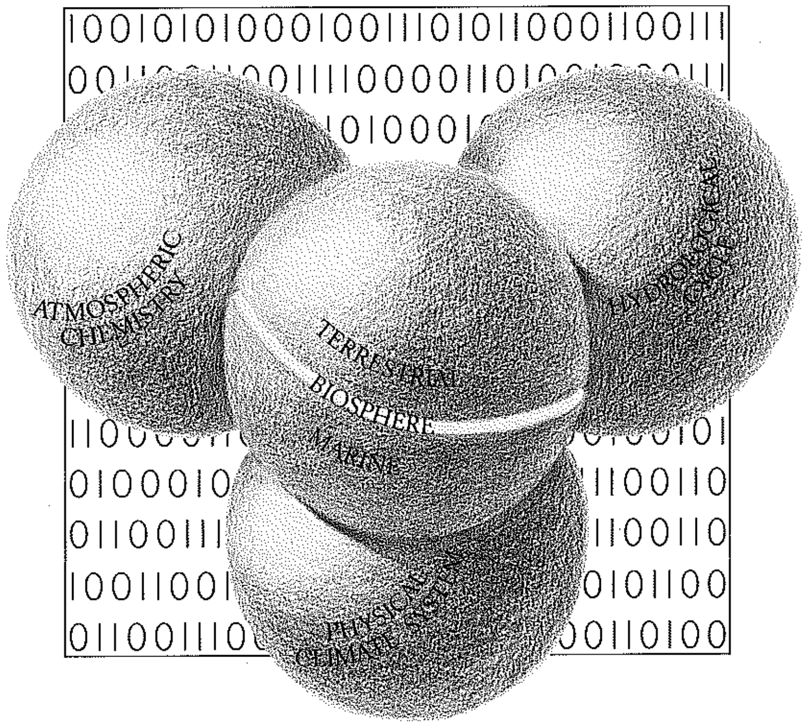
The further developments of generic models for agricultural crops will be addressed in consultation, with, e.g., FAO, IBSRAM, and IBSNAT.

The IGBP should discuss with IUCN the future needs related to climate change and conservation issues.

In early 1990, a core research programme will be presented for discussion at the second SAC-IGBP. The development of such a proposal will not only depend on the two SCOPE modelling workshop outputs, but also on the results of a recently held SCOPE meeting on ecosystem experiments.

6

Some Common Problems

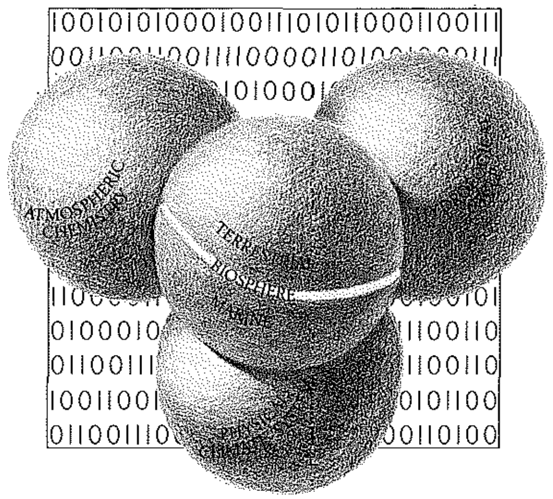


At the first SC-IGBP meeting, it was decided to set up four Working Groups, which would assess current status of knowledge and future prospects for Programme activities (through, e.g., Study Conferences) in areas of interest to the IGBP. The Working Groups cut across the project planning activities of the Coordinating Panels and are concerned with all aspects of the IGBP (Fig. 6.1). Problems related to data collection, data storage, data handling and logistic matters in relation to the securements of long observations series are crucial to the Programme development (W.G. 2 and 4). In view of the importance of these activities to the success of the IGBP, planning activities have already been taking place. It is, however, essential that this planning is guided by the needs of the research projects as developed by the Coordinating Panels, and the SC-IGBP has ensured that efficient exchange between the Panels and these two groups occur. The SC-IGBP will consider whether these two Working Groups should be merged during the next phase of the planning activities, as a set of permanent observation stations, as suggested by the Working Group on "Geosphere-Biosphere Observatories" (section 6.4), would be dependent on an efficient data and information system, as discussed by Section 6.2.

The use of numerical, dynamic models will be a key to the success of the IGBP, and it is expected that modelling activities will be important in all IGBP research projects. There is, however, a need to view global modelling from a holistic perspective, and a special Working Group was set up to discuss issues of global modelling, and especially how present General Circulation Models (GCMs) could be expanded to take chemical and biological processes into account, as these interactions are corner stones of the IGBP.

Future global changes can only be predicted through an understanding of past changes. A Working Group (W.G. 3) has addressed "Techniques for Extracting Environmental Data of the Past". The report from that group recommends that the Special Committee considers the establishment of a Scientific Steering Committee on "Past Global Change". Although there are strong reasons to integrate past, present and future changes into each of the existing Coordinating Panels, there are compelling reasons to treat past changes as a separate project as outlined in Section 6.3.

The activities of the Working Groups will ensure that there is an integration between the planning activities of the Coordinating Panels with the ultimate goal of understanding the crucial processes that regulate the functioning of Planet Earth as a whole.



Models of present characteristics of essential linkages between the geosphere and the biosphere and those changes in transfer rates of energy and matter resulting from natural and anthropogenically induced global change will be essential in the process of developing the IGBP. They will, in a long-term perspective, be fundamental for the synthesis of research achievements of the IGBP. Furthermore, they will be of importance both with regard to scientific understanding and for increasing knowledge of how to assess possible future environmental changes both on global and regional scales.

6.1. Global Geosphere-Biosphere Modelling

6.1.1. Introduction

To advance our understanding of the structure and behaviour of the global geosphere-biosphere system in a systematic and orderly manner, it is essential to develop both conceptual and simulation models for the components as well as for the system as a whole. Such attempts will have to be crude and incomplete to begin with, but will gradually increase in complexity with regard to their capability to describe the system, as our understanding of basic processes increases and data become more plentiful. The necessity of setting priorities when formulating a feasible programme will be assisted in this way and data requirements can be specified more consistantly. The IGBP Coordinating Panels and Working Groups all emphasize the importance of model development both for interpretation of presently available and forthcoming data as well as for the continuous conduct of the programme. It is essential to address the problems of modelling early in the course of IGBP development and that a well-conceived model component be defined.

The interactive processes that characterize the global geosphere-biosphere system regulate the transfers of energy and matter involving chemical and biological transformations. Current global climate models describe the primary physical processes that govern transfer of energy, momentum and water through the global environment, and provide starting pointers, as we now begin to focus on chemical and biological processes. For example, the hydrological cycle has so far been treated almost exclusively as a physical process in climate models, and the processes of evapotranspiration are usually formulated in terms of simple physical analogues (e.g. the "bucket"-method). The IGBP must additionally address the mutual interaction of terrestrial biota and water transfer. The development of global geosphere-biosphere models means an extension of global climate models to include the transfer of chemical compounds and key chemical and biological reactions and transformation. It is necessary to provide the theoretical basis for the study of biogeochemical cycles and their interaction and provide means for extending the results of local and regional process studies and observations to provide understanding at greater spatial and temporal scales.

6.1.2. Basic characteristics of climate models

Climate models are today remarkably sophisticated, although in many regards they still imply considerable simplifications of the physics of the global system. They are basically developments of weather forecasting models, but with less spatial resolution. The derivation of a climatic steady state requires the integration of the forecasting model over long periods of time subject to the external forcing which is being considered. Because of the computational demands a spatial resolution of 200 km or less does not permit sufficient numerical experimentation and a resolution of merely 300 to 500 km is therefore common. Another complication then arises; few satisfactory general ocean circulation models using even a coarse spatial resolution are available. Future development of more powerful computors will, however, reduce this technical limitation.

Global Climate models in use today (General Circulation Models, GCMs) include the following features:

1) A large scale dynamic GCM of the atmosphere with submodels accounting for: (i) vertical radiative transfer, (ii) condensation of water vapour and cloud formation when the relative humidity reaches a prescribed value (which usually is less than 100% in order to describe cloud assemblies rather than individual clouds), (iii) vertical overturning and mixing when convection occurs as a result of vertical instability, (iv) precipitation formation, deposition, and evaporation of clouds and of falling precipitation, and (v) vertical turbulent transfer of energy, momentum and water vapor in the boundary layer next to the Earth's surface and exchange of these properties with the underlying surface.

2) A land surface model accounting for (i) the dependence of soil moisture on precipitation and evaporation, exclusive of the dynamics of the terrestrial ecosystems and possible feedbacks with the atmosphere, (ii) snow and ice accumulation or melting, as dependent on temperature changes at the Earth's surface and associated changes of the albedo of the Earth's surface, and (iii) transfer of excess water from land to sea by rivers.

3) A large scale ocean circulation model (OCM) with sub-models accounting for (i) vertical overturning and mixing when the density distribution becomes unstable, (ii) vertical turbulent transfer with exchange of energy and momentum between the top layers of the ocean and the atmosphere and between the deeper layers and the sea-bed, (iii) formation and melting of sea-ice, and (iv) change of albedo as dependent on the state of the sea and the presence or absence of sea-ice.

Note, however, that many current climate models include only a simplified sub-model of the oceans.

6.1.3. Geosphere-biosphere models

Fully coupled geosphere-biosphere models based on present status of climate modelling have not yet been developed. Our knowledge of the more detailed features of key processes in all subsystems is inadequate at present for such attempts. On-going modelling efforts of key subsystems can be summarized as follows.

The atmosphere

General circulation models for the atmosphere are well developed and are used for studies of the interplay between transfer of water and atmospheric trace substances by air motions and their mutual chemical interactions. Particularly important is to try to assess how spatial and temporal variations of trace substances can be used to deduce seasonal variations of natural sources and sinks due to exchange with the terrestrial and marine system, and due to human activities. Few experiments have been made, in which the relevant set of chemical reactions have been explicitly introduced into a general circulation model. It has rather been common to extract from GCMs (or from observations of winds and precipitation) the statistics needed to determine horizontal and vertical transfer, which

are then used in conjunction with a model for chemical transformation.

Seasonal and spatial variations of atmospheric carbon dioxide have in this way been interpreted in terms of changes of photosynthesis and respiration of terrestrial ecosystems and the annual exchange of carbon dioxide between the atmosphere and the sea. In this case no chemical reactions in the atmosphere need be accounted for.

Similar studies of methane, including its isotopic composition, are being attempted. The data base is, however, still minimal. It is difficult to determine the distribution of sources and sinks of methane from observations. The use of models and available observations greatly aids our understanding of the spatial and temporal variations of methane in the atmosphere. Simulations will be fundamental to assessing the role of human activities over the last few hundred years, causing an observed increase from 0.7 to 1.7 ppm(v) which has occurred during the last few hundred years. Attempts to model the behaviour of some other long-lived compounds in the atmosphere (nitrous oxide and chlorofluorocarbons (CFCs)) have also been made and have aided the interpretation of ongoing man-induced changes.

The atmospheric components of the nitrogen and sulphur cycles are much more complex than that for the carbon cycle. They are difficult to model because of more intricate chemical reactions, which lead to the formation of a large number of chemical compounds, and also because of the short life times of several of these compounds in the atmosphere. Consequently, the N and S compounds have very variable concentration fields.

Several research groups are presently engaged in developing global models for the chemistry of the atmosphere by making use of atmospheric GCMs. Their goal is to study the simultaneous interactions of a large number of chemical compounds in the atmosphere. This is necessary in order to understand the oxidation paths for different compounds that are established as a result of the formation of excited oxygen by UV solar radiation, and the generation of the prime atmospheric oxidation agent, the OH-radical (see Section 5.1).

The marine system

General circulation models for the oceans have recently been employed for studies of the biogeochemistry of the sea. While rather good data sets are available to verify general atmospheric circulation models, this is not true for the oceans. As a matter of fact, the distribution of chemical compounds, and not least their isotopic composition, may become of basic importance for assessing how well the physical process that are included in such models describe reality. There is a long way to go, however, and much better knowledge about the chemistry and biology of the sea is required.

Present modelling efforts center around (i) problems of how to formulate the biological/chemical processes to permit their inclusion into ocean circulation models, and (ii) the development and analysis of simple conceptual models that make it possible to qualitatively judge the importance of key processes. These efforts are important preparations for the more general application of general circulation models at a later stage of the IGBP.

For some time to come simple box-models will still be of considerable importance for the analysis of the limited data sets that are available for even key compounds in intermediate and deep waters. It is most important in this context that several interacting trace compounds are studied simultaneously because of the further constraints that thereby are introduced in the process of validation and interpretation of the models being advanced.

We are confronted with the need to quantify the photosynthetic process in the surface layer as dependent on the physical-chemical state of the sea. The problem is difficult because of the presumably important role played by both spatial and temporal small-scale features of the surface mixed layer. A number of ocean models have been developed in recent years. These need further elaboration and testing against data. It is important to include simplified, well-conceived, and tested mixed layer models for study of the biogeochemistry of the sea using global ocean circulation models.

The terrestrial system

There is a fundamental difference between the development of models for the terrestrial sub-system and the formulation of basic models for the atmospheric and marine subsystems. In the latter cases the transfer due to air or water motions can be defined using basic hydro-dynamical principles, and serve as a basis for the biogeochemical model formulation. The terrestrial system, on the other hand, is geographically stationary to a first approximation. In studies of global changes, however, the slow modifications of terrestrial ecosystems that occurred in the past centuries and millenia, and that are now accelerating due to human activities, must be dealt with carefully. Considerable modelling efforts will be required to achieve this. Such a development implies much more than defining state variables that will describe terrestrial ecosystems on the same scale of resolution employed in atmospheric circulation models. This has been attempted in studies of the static role of the terrestrial system. Further development of two different kinds of terrestrial sub-models are needed (see also Section 5.4):

- The internal response of homogeneous biomes (grassland, boreal forest, tundra, etc.) to changing abiotic conditions. The result from such studies could presumably be formulated in a simplified manner and be used in attempting to describe the mutual interplay between atmospheric and terrestrial processes in the interior of the major biomes on Earth. It should further be noted that such models of grasslands with modifications also can be used to model most croplands.

- The dynamics of ecotones. How will a transition from one major ecosystem to another change due to change in abiotic conditions, such as climate change? Models of this kind must address changes in species composition in marginal areas of key biomes and migration rates of species into regions not previously inhabited by them when abiotic conditions change. Statistical methods have been advanced but cannot easily be used for analysis of factors that determine rate of change.

6.1.4. The problem of process parameterization

A fundamental problem in climate model development has been parameterization. We must learn how to simply describe processes on smaller spatial and temporal scales than those resolved by current large-scale models. We must resolve how small-scale processes interact with large-scale processes, thereby influencing the development and maintenance of the regional and global features of the geosphere-biosphere system. Climate models include a number of such parameterizations, e.g., the role of clouds for water and energy transfer in the atmosphere, the importance of boundary layers for transfer of energy, momentum and water between the atmosphere and the land and ocean surfaces, and the role of small scale features of the ocean circulation for the large-scale transfer processes. When concerned with the development of geosphere-biosphere models, we encounter the same difficulties of how to describe the sub-grid scale features of terrestrial and marine biota and of chemical reactions in the atmosphere in a manner that incorporates those features that are of importance when trying to understand regional and global interactions. The model development envisaged for the terrestrial ecosystem might be considered as a way of describing ecosystem behaviour in a simplified manner (parameterization) for inclusion into global biosphere-geosphere models. Similarly, we need to address the problems of how to include the role of clouds and precipitation for vertical transfer, chemical transformation rain-out and wash-out of chemical compounds in the atmosphere and how microbial processes in the soil represent a source for trace gases in the atmosphere. Parameterization of these sub-grid scale processes is a research field of central importance for the development of global geosphere-biosphere models.

6.1.5. Strategy of approach

The scientific community is not yet ready to develop fully coupled global models based on GCMs for the atmosphere and the sea to study the global biogeochemical cycles and their interactions. Simple box models will continue to be important both to more complete studies

using climate models and to provide consistancy when interpreting available data. It is, however,

becoming increasingly clear that the use of models that permit more detailed and comprehensive studies of the fundamental biogeochemical cycles must be of central concern in the formulation of the IGBP.

Since data are most plentiful for the distribution of carbon compounds in our environment, the processes involved in their transformation are comparatively simple, and because increasing atmospheric carbon dioxide concentrations represent a key issue, it seems appropriate initially to focus the attention for formulation of fully coupled models on the development of global models of the carbon cycle. Because of the close interplay between the carbon cycle and other biogeochemical cycles, particularly the major nutrient cycles, as well as with the hydrological cycle, such a priority at this stage of the development of the IGBP will be of general importance.

Global modelling of the biosphere-geosphere system will be dependent on the further development of climate models. Close interaction between the IGBP and the World Climate Research Programme is therefore essential.

Although global models are the ultimate aim, much work is required in order to improve our fundamental understanding of the role of the chemical and biological processes that are of central importance for the functioning of the Earth's system. Undoubtedly, a number of modelling efforts are required in order to clarify how to formulate these in quantitative terms and how to incorporate them into global models. Sub-models need to be developed that will help in this context, both to grasp the most essential processes and to parameterize their roles in a global context. The discussion above suggests three areas requiring attention:

Atmospheric chemistry, considering both homogeneous gas reactions and multiple phase reactions including the role of aerosols, clouds and precipitation as well as exchange processes between the atmosphere, marine and terrestrial ecosystems.

Terrestrial biogeochemistry, particularly addressing questions of how different ecosystems respond to changing abiotic factors, both naturally induced and caused by man.

Marine biogeochemistry, particularly the importance of ocean circulation and as assessment of the natural chemical state of the oceans, as well as the effects of pollution. The interplay between processes in the coastal zone, on the continental shelves and in the open sea needs to be addressed.

6.1.6 Action plan

Workshops will be the media through which extensive preparation for the IGBP modelling effort will develop, as discussed in Section 4.3.1. The following workshops have been planned:

The atmospheric subsystem. A SCOPE-supported Dahlem conference on trace gases in the atmosphere (particularly methane and nitrogen oxides), including modelling, will be held in February 1989. A second meeting, jointly organized by SCOPE and the IGBP, is planned for the spring of 1990. On this occasion a more complete set of trace gases will be dealt with and problems of modelling will be further pursued.

The marine subsystem. A workshop on mixed layer modelling, with particular regard to the interplay between physical, biological and chemical process, will be hosted by the IGBP in the summer of 1989 in collaboration with the Royal Society, UK. JGOFS will be invited to join the IGBP as an organizer of this workshop.

The terrestrial subsystem. A workshop "The effects of Climate Change on Production and Decomposition" will be hosted by SCOPE in April 1989, with a second meeting planned for 1990. Both these meetings will address terrestrial ecosystem modelling issues (see Section 5.4). Results from an ongoing IIASA project on terrestrial modelling will also be of relevance.

Global modelling. The IGBP will organize an international workshop on the global carbon cycle in August 1989. Key problems to be discussed will be:

-How to describe terrestrial ecosystem processes in a simple manner to permit a resolution compatible with presently available climate models.

-Which key features of the air-sea exchange of carbon dioxide are of importance for modelling the global carbon cycle?

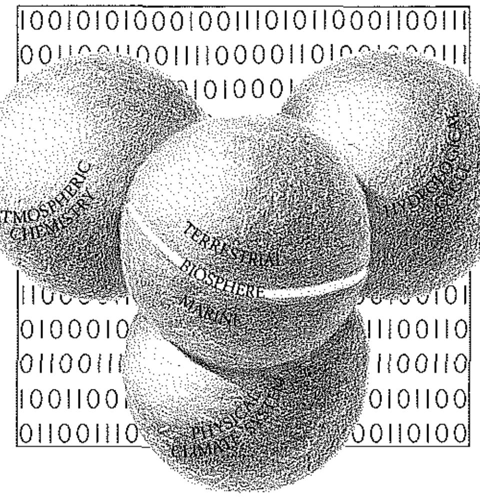
-What do the spatial and temporal variations of carbon isotopes tell us about the relative importance of key processes?

-In the light of new and more accurate observations on dissolved organic carbon in the sea, how dynamic and of what importance is its role in the global carbon cycle?

-How do we assess the impact of fossil fuel emissions, deforestation and changing land use on the carbon cycle and how well are we able to project its future changes, given certain assumptions regarding the rates of human interventions?

-What can we learn about the behaviour of the carbon cycle by studies of the nitrogen and phosphorus cycles?

The outcome of these meetings and workshops should be used for better specifying the data needs for modelling. Results from ongoing modelling activities and observational studies such as JGOFS, ISLSCP and WOCE should serve as a basis for defining a project plan for the IGBP in 1990.



An important theme of the IGBP is that of documenting global change, both in real time and through the reconstruction of past changes in the global environment. One measure of the success of the Programme will be whether scientists in 20 or 30 years time will have available to them the essential records (such as that of the global changes in atmospheric CO_2, in ozone and land use) that will be necessary to document significant global changes in the geosphere-biosphere which, have occurred and are occurring. This task will consider aspects of planning, data collection (from space and on the ground and on the sea, as well as historical records), quality control, and data storage and dissemination.

6.2. Data Management and Information Systems

6.2.1. Introduction

The international arrangements for the IGBP will have to be responsive to a number of challenges that transcend previous experience with collaborative scientific programmes. These challenges are presented by the range of disciplines involved, the need to blend new technology with traditional observational techniques on a world-wide scale, the need to plan and sustain a coordinated research and documentation effort over many decades, and the need to systematize and present in a timely manner both the conclusions and the basis for them on complex issues of substantial and growing public concern. Of particular importance are mechanisms relating to measurements and information systems.

At the core of the IGBP must be a systematic effort to document the significant changes on a global scale over the coming decades. This effort overlaps with, but is distinct from, research initiatives aimed at elucidating key processes involved in such changes and examination of the record of the past to put these changes in context. All these activities are necessary to develop and test quantitative models of how the entire Earth system functions on time scales of decades to centuries. The programme structure and institutional arrangements must be appropriate not only to obtain the necessary observations and calibrations but to process and analyze them in order to extract the required information, and to assemble this information and make it accessible both to scientists and policy makers worldwide. The scientific knowledge and understanding to be gained from the IGBP, and the data collection systems and their resulting data banks, will be the heritage we leave to our descendants.

An obvious high priority need of the IGBP is that of securing remotely-sensed data, largely from spacecraft, of a critical suite of global parameters. These include physical and chemical properties of the land, ocean and ice cover, land-use changes, indices of primary biological production over land and oceans, tropospheric and stratospheric distributions of trace gases, and significant solar inputs to the Earth system. Some of these data can be taken from aircraft, balloons, rockets and ships, but others demand a coordinated, international effort from space.

These needs imply long-lead times, careful planning to include data handling systems and end-to-end performance checks. They demand, as well, national commitments for international good.

It is essential that scientists in all countries of the world have the opportunity to participate in developing and carrying out all aspects of the IGBP programme.

Cooperation with ICSU scientific members early in the planning process is also essential to assure that the larger interested scientific community is involved. The International Geographical Union has already initiated a Global Database Planning Project, of which the first meeting resulted in many useful inputs to the IGBP planning. Many data systems are already in place. The IGBP should assess them and then promote their use.

To make a start on meeting these challenges, the Working Group on Data and Information Systems, in collaboration with the ICSU Panel on World Data Centres, and the Soviet Geophysical Committee, organized a Study Conference to which were invited scientists working in several research areas of IGBP along with data experts experienced in a wide variety of data and information extraction techniques.

This report contains a number of recommendations that are preliminary in the sense that the IGBP core programmes are in the early stage of development. However, the report contains proposals for some priority actions to be undertaken immediately.

6.2.2. Guiding principles for the evolution of an IGBP information system

A number of general guiding principles have been identified as a framework in which to make specific recommendations.

The information systems for IGBP should provide for: acquisition, quality control and integration of raw data together with associated calibrations and documentation; acquisition and making available higher order data products including model simulations; and a knowledgeable and effective interface with the IGBP research community. It is recognized that the information system should also serve the needs of research into past climates and into human dimensions of global change. These aspects have not been discussed in depth.

This functionality should be provided by using, strengthening and building upon existing and already planned systems. It should draw upon the experience gathered in existing and past international disciplinary programmes. In addition, selected data assembly and assessment projects should be started in the near future, as the initial steps in an evolutionary process, to focus attention on and provide experience with data management issues.

The system has to serve the immediate needs of the IGBP research initiatives, while at the same time building the base of data and information necessary for future modelling and diagnostic studies. Thus, immediate activities should be designed so as also to strengthen long-term (beyond A.D. 2000) capability. Particular attention should be paid to the "end-to-end performance" of long-term measurement systems for the purposes of documenting global change. End-to-end performance here means everything that leads to a global analysis of satisfactory quality, including all aspects of the observation, data management and analysis process.

Scientific expertise must be involved in establishing data requirements and priorities, and likewise data experts must be involved early in the planning of research projects. Data sets and associated documentation must be constructed so as to be accessible, with due regard to the probable frequency of use. The goal is to provide data access in a timely manner free of charge or at minimal cost of duplication. Bona fide scientists should be distinguished, if necessary, from commercial users.

6.2.3. Status of data for IGBP and associated preliminary recommendations

Solar flux

Accurate measurements of solar flux density at the top of the atmosphere have been made for about a decade from three different satellites, and these show a small change over this period. The changes appear to be well documented. It is important that these measurements be continued for at least a full 22-year solar cycle.

Stratosphere and above

Data necessary for studies of coupling of processes in the middle atmosphere, stratosphere and troposphere remain to be determined by the relevant scientific planning groups. It is also required that relevant ground-based validation data be merged with the satellite data before the data sets are released for use. This will be facilitated if the validation data are routinely supplied to the data banks as part of the data management process. The planning for the SCOSTEP "Solar-Terrestrial Energy Programme", for example, includes a panel on "Informatics".

Some action items include: establishment of a small disciplinary committee to guide data acquisition and the additional planning and processing needed to optimize data utility; inclusion of data from the relevant satellite instruments (at least 11 in number) and atmospheric absorption and emission spectra, vertical atmospheric profiles, and NOAA temperature data; acquisition of ozone data from the WMO Toronto Data Centre; reprocessing of these data as necessary; addition of balloon and aircraft data; acquisition of ground-based microwave observations of ozone and other stratospheric constituents such as chlorine oxide, and lidar measurements of temperature, ozone and aerosols; and arrangements to add to the archiving of those data from station networks for detection of stratospheric long-term trends.

Clouds and Earth radiation budget

After intensive effort and many years of planning, the International Satellite Cloud Climatology Project (ISCCP) has begun to produce valuable global data sets of a number of cloud-related variables along with regional and global estimates of components of the Earth's radiation budget. In many ways e.g., organization, international collaboration, data managment plan), ISCCP can be one model for how data sets for IGBP should be produced.

Tropospheric chemistry

The IGBP programme in tropospheric chemistry is being developed by the Coordinating Panel on Terrestrial - Atmospheric Chemistry Interactions (see Section 5.1). Some knowledge has already been gained of the increase in tropospheric ozone, methane and nitrous oxide. Moreover, there are some routine surface pollution and chemical observations that will be of relevance to this portion of the IGBP, e.g., the WMO/UNEP Background Air Pollution Monitoring (BAPMON) programme and the USA Global Monitoring for Climatic Change (GMCC) programme, the Australian background station at Cape Grim, Tasmania, and the German-South African station in Cape Town. These programmes, however, do not explicitly address the role of vegetation and soils for uptake and production of atmospheric constituents.

Some questions relating to these networks include: is there an integration procedure to determine area-averaged data on concentrations, ranging from small scale to global measuring systems? How representative are aggregated station data for global concentrations? How good is the sampling for the purpose of obtaining global data sets? Can the source strengths for key gas species be estimated from major ecosystems, and these derived quantities be integrated over the globe on the basis of maps of the worldwide distributions of ecosystems? What information is missing and has to be supplemented by the IGBP Geosphere-Biosphere Observatories (GBOs) (Section 6.4) and other activities?

Further questions are: How are the global data sets compiled? What quality-control procedures are applied? How are individual instruments intercalibrated and maintained? How do the data compare to high-quality national network data?

Have GEMS and regional data sets been analyzed with respect to changes? How large are any changes detected thus far? What is the measurement accuracy, and are the spatial and temporal sampling frequencies enough to assess changes. The potential role of satellite observations in determining global tropospheric trace gas distributions should be explored.

Role of vegetation in the hydrological cycle

As a starting point, it is assumed that vegetation and soil maps are to some extent available but the spatial resolution is probably not adequate for IGBP needs; there is a radiation flux network; irradiance maps can be derived from satellite observations; and many individual measurements are available of energy fluxes.

Then, how useful are existing data collections for: (i) descriptions of the soil-vegetation-planetary boundary layer (PBL) system in terms of physical quantities that can be used directly in models; (ii) assessment of changes in this system by means of satellite surveys, ground based data and additional information from the GBOs; and (iii) modelling of the soil-vegetation-PBL system with predictive capability? Who compiles the data on vegetation types, and how can the required averaged quantities of plant communities be deduced from individual plant characteristics? Who develops a new map contrasting the distribution of plants utilizing the two photosynthesis pathways (C_3 and C_4-plants), together with relevant temperature dependent transfer resistances? Is the radiative flux measurement network adequate to determine the necessary input for evapotranspiration calculations?

In the more general sense of the hydrological cycle, the IGBP needs better quantitative estimates of precipitation, evapotranspiration and run-off. Water balance computations show gross discrepancies even on a continental scale. The WCRP Global Energy and Water Cycle Experiment (GEWEX) is designed to obtain better estimates of these quantities. The IGBP requirements need to be specified.

Land surface

Global observations of land surface properties and their changes at different resolutions are needed for three of the four priority areas of the IGBP: Terrestrial Biosphere-Atmospheric Chemistry Interactions (Section 5.1); Biospheric Aspects of the Hydrological Cycle (Section 5.3); and the Effects of Climate Change on Terrestrial Ecosystems (Section 5.4). Probably the largest single factor influencing these three areas is the direct impact of changing human use of the land including the effects of biomass burning. Other critical variables include the organic content and physical properties of the soil.

Regional estimates of changes in land cover using *in situ* data from various sources or satellite data have produced different results. The IGBP should set up a group to study a stratified sampling design using both satellite data and ground based observations for consistency and validation. This design should provide a baseline from which changes can be measured, and should be capable of expansion to cover the globe. The group should include both theoretical and empirical scientists. Among other international organizations, UNEP's GEMS should be approached to co-sponsor this activity.

Pilot projects are under way to produce a digitized data base for soil properties at a resolution of 1-5 km. IGBP should examine the suitability of this data base for studies in the three priority areas listed above, and, if appropriate, seek ways to modify and accelerate its development. The results of both this and the preceeding project should be of immediate interest to the participating countries.

A satellite-derived vegetation index is operationally available at 25 km resolution for the entire earth surface. A strong worldwide programme of field experiments and theoretical studies to assist in interpretation is under way. Arrangements need to be made for the long-term archive of the validation data sets.

Geographic Information Systems (GIS) are proving to be a powerful tool for integrating and making accessible Earth land-based data of diverse types. Further technical development should be encouraged, particularly of the ability to efficiently handle time-varying spatial data.

Oceans

Three projects are being carried out under the auspices of the WCRP that are expected to provide scientific guidelines for future ocean monitoring systems. The data management plan for the Tropical Ocean-Global Atmosphere Programme (TOGA) has already resulted in specification of some of the data sets to be produced by analysis centres and stored in the WDCs. A TOGA Data Management Conference will be held in late October 1988, to address the topics of additional sets as well as the publishing of some TOGA data sets on CD-ROMs.

The data management plan for the World Ocean Circulation Experiment (WOCE) is under development, and a prototype on-line system has been developed to provide the data catalogue, search and sample data set capability, and provision for ordering data sets. Data management plans for the Joint Global Ocean Flux Study (JGOFS) is also under development.

The IGBP needs to work with these three projects to ensure that data collected are put in suitable forms for marine biosphere-atmosphere interaction studies (Section 5.2). The IGBP should also collaborate with these projects on the design and implementation of general data management systems.

Sea level

Sea level observations are collected by the Permanent Service on Mean Sea Level. Note should also be taken of the newly developed global sea level programme which isorganized under the auspices of the Intergovernmental Oceanographic Commission (IOC) of Unesco.

Snow and ice

Global data of snow cover and sea ice extent exist from the late 1960s based on 1-5 km resolution, both on visible and infrared satellite imagery. Year-long coverage by low-resolution (50 km) passive microwave radiometry began in 1973. Arrangements need to be implemented for their continued long-term archival.

6.2.4. General Considerations

There are a number of barriers to full availability and applications of data sets:

- The locations of many existing data sets are not widely known. The IGBP should prepare, in collaboration with appropriate other organizations, an inventory of major existing data banks relevant to IGBP objectives, indexed by subject. Such an inventory would draw on existing compilations of Earth science centralized data holdings. However, significant scientific input would be required in selecting subject classifications and judging the relevance of material.

- Poor mechanisms for data exchange. The IGBP can help to define format standards for exchange where none exist at present. The IGBP should initiate discussions with other international programmes of relevance to global change studies with the objective of arriving at standardized formats and procedures for data exchange.

- Various charging policies. IGBP should encourage exchange of data at no or marginal cost. IGBP should seek to define categories of use that are clearly distinguishable from commercial, military or other proprietary applications.

- Copyright restrictions. The IGBP should help to create a climate of free access of relevant global change data to bona fide scientists without restrictions.

- In many cases governments have been reluctant to release geophysical data because of national security concerns. In the context of the IGBP there may be overriding benefits for making such data freely available to scientists. The IGBP should stress the importance of free access to remotely sensed data relevant to understanding the Earth system.

- Much data is poorly reduced and unchecked. The IGBP should encourage end-to-end processing, including some older data sets (see Section 6.2.2).

Major opportunities are presented for the evolving IGBP data and information systems by the newer technological opportunities for easy and cost-effective dissemination of data to users. Such technologies include the publication of data and other information on CD-ROMs for use with personal computers, and on-line electronic libraries.

6.2.5. Action plan

Development of a design for the IGBP data management structure for measurements relating to the land surface needs to be initiated urgently. The roles and responsibilities of international agencies and organizations (ICSU's World Data Centre, UNEP, WMO, FAO, World Bank, Unesco) should be clarified. Land surface data are frequently collected by some agencies for other purposes than research. Hence, in this process of clarification, attention should be paid to the ability of those agencies effectively to coordinate international data exchange between the relevant operating agencies of national governments.

The IGBP should design a pilot data assembly project, including an assessment of the quality of the end product. An excellent candidate is the project on land cover change described in Section 6.2.3. Other possibilities include a global soil database and a project in the paleoclimate area (Section 6.3). The latter should include historical records, bio-components (dendro- and pollen studies, etc.) and geo-components (ice cores, sediments, etc.). The sites for pilot studies relating to the land surface should be coordinated with the placement of Geosphere-Biosphere Observatories (Section 6.4) and their associated data systems.

An assessment of the end-to-end performance of existing observations and data systems for long-term measurements should be made for at least one global variable important to the IGBP. This is necessary because understanding global change requires, by definition, precise data on the magnitude and direction of the change, and there is no assurance that present data collection efforts are adequate for this purpose. This assessment is a large endeavor and mechanisms need to be developed to undertake it systematically. A pilot study should be started in collaboration with the Global Information Systems Test, which has been proposed as part of the International Space Year (ISY) in 1992.

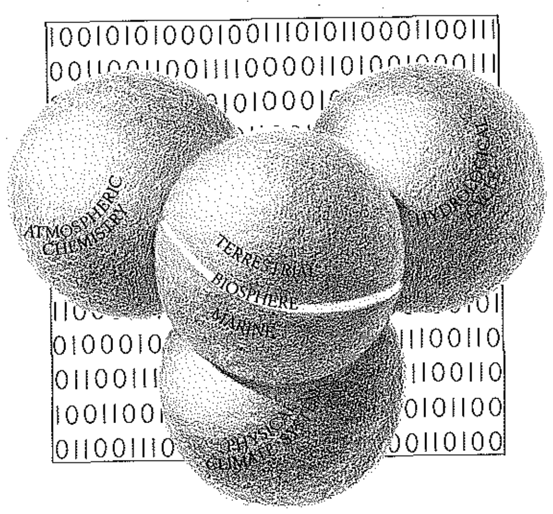
The IGBP Coordinating Panels and Scientific Steering Committees should be encouraged to specifically address the needed temporal and spatial resolution of data collected in the IGBP core projects.

In addition, to facilitate communications among the individuals involved in planning the IGBP, the following should be implemented as soon as possible:

- Establish fully-automated low-cost electronic mail connections over one or more existing networks.

- A newsletter information service about data availability. This might eventually evolve into an electronic bulletin board. An early task would be to distribute a listing of available directories of data relevant to the IGBP.

Finally, in order to proceed rapidly with implementation of these tasks and those of sections 6.2.2 through 6.2.4, and to maintain adequate and continuous contact with the Coordinating Panels and other Working Groups of the IGBP, with the expertise in the constituent ICSU unions, and with other international agencies and organizations, the membership of the Working Group on Data and Information Systems needs to be expanded. This expanded group should overview all activities relating to the design of the IGBP Information System. The design of any pilot projects should be overseen jointly with the appropriate Coordinating Panels. It is anticipated that this activity can be accomplished within available international resources, supplemented by national contributions for specific tasks. The possibility of establishing a joint Working Group on "Data and Information Systems / Geosphere-Biosphere Observatories" should be considered.



Knowledge of the past history of the Earth's environment can greatly aid the study of current global changes. Abiotic and biotic processes contribute to the formation and preservation of information in ice cores, tree rings and sediments that can reveal past change in the Earth environment on time scales of days to thousands of years. These natural records include information on solar variations, volcanism and global ice volume, from which inference can be drawn relating to physical climate dynamics and biogeochemical processes. There is a need to assess the present state of the art and anticipated technological developments, which will extend and refine these reconstructions, to assist in the implementation of new technologies, and to assist in the interpretation of the history of the geosphere-biosphere.

6.3. Techniques for Extracting Environmental Data of the Past

6.3.1. Introduction

Studies of the physical, chemical and biological parameters found in natural archives such as ice cores and tree-rings, as well as in ocean, lake and terrestrial sediments, have revealed a wealth of information on both the "natural" and perturbed behaviour of the coupled Earth system. Breakthroughs in this area, more than in any other, have been responsible for the dawn of Earth system science. Quantitative information on global changes of the past can be used to put observed trends in contemporary data in broader context, to evaluate Earth system models, and to identify unknown and often important interconnections between physical, chemical and biological processes. These findings document the internal and external forcing mechanisms, biogeochemical feedbacks and the general response of the geosphere-biosphere system.

Of special significance is the fact that the four classes of Earth-system interactions defined in the IGBP Coordinating Panels owe much of their impetus to findings of past global changes that were derived from the study of ice and ocean cores. There can be little doubt that new information yet to be found in these and other natural archives will continue to drive the directions of research in Earth system science, and continue to provide critical tests of analytical models.

6.3.2. Present techniques

Environmental data of the past are preserved in natural archives of many types. The principal sources are listed in Table 6.3.1, with optimum temporal precision, length of record, and an indication of the environmental parameters that have been derived. Table 6.3.2 summarizes the techniques presently used to glean Earth system information from these records.

6.3.3. Recommended programme emphases

Seven themes have been developed for recommended emphasis in the IGBP:

Table 6.3.1. Characteristics of Natural Archives

Archive	Temporal precision	Extent	Derived parameters
Tree-rings	yr/season	10^4yrs	T H C_A B V M L S
Lake sediments	yr	10^4-10^6	T B M
Polar ice cores	yr	10^5	T H C_A B V M S
Mid-latitude ice cores	yr	10^3	T H B V M S
Coral deposits	yr	10^5	T C_W L
Loess	10 yr	10^6	H C_S B M
Ocean cores	100 yr	10^7	T C_W B M
Pollen	1000 yr	10^5	T H B
Paleosoils	100 yr	10^5	T H C_S V
Sedimentary rock	2 yr	10^7	H C_S V M L
Historical records	day/hr	10^3	T H B V M L S

T = temperature
H = humidity or precipitation
C = chemical composition of the air (a), water (w) or soils (s)
B = information on biomass, as in pollen samples
V = volcanic eruptions
M = geomagnetic field
L = sea level
S = solar activity

- Year-to-year, decadal and century-scale changes
- Paleo-records of ENSO phenomena
- Past effects of man on climate and environment
- Global changes in the Holocene
- The last 150,000 years: Global changes through glacial-interglacial cycles
- Needs in oceanic and terrestrial data
- Requirements for modelling past data

These are developed briefly below. As noted in Section 6.3.1, these themes are intimately connected to related programme initiatives in "Terrestrial Biosphere-Atmospheric Chemistry Interactions", "Marine Biosphere-Atmosphere Interactions", "Biospheric Aspects of the Hydrological Cycle", and "Effects of Climate Change on Terrestrial Ecosystems", and were chosen with these basic programme directions in mind. They bear as well upon broader areas of "Geosphere-Biosphere Modelling" and on "Data and Information Systems" needs for the IGBP. It is obvious that an IGBP initiative in "Global Changes in the Past" must be developed in parallel and close contact with *all* of these other areas of emphasis.

Year-to-year, Decadal and Century-Scale Changes

Problem statement: The following questions now limit our understanding and need to be addressed:

- How well can climate variability on sub-century time scales be characterized in the space, time and frequency domains?
- To what extent can such year-to-year, decadal and century-scale variability be accounted for by identifiable forcing factors?
- Which of the trends and forcing factors are global in scale?

Table 6.3.2.

	Ice				Sediments/peat				Tree-rings	
	^2H ^{18}O (H_2O)	Dust/Chem.	Gases	Radio Isotopes	comp.	faunal	plants	isotopes	struct.	isotopes
Sun		x		xx						xx
Atmosphere										
aerosols		xx			xx			xx		
circulation	x	xx		xx	x			xx		
gas composition			xx					xx		xx
humidity	xx	xx		xx	x			x	xx	x
temperature	xx							xx	xx	x
Ocean										
circulation	xx	xx	xx	xx	xx			xx		xx
bio-pump		x	xx	x	xx			xx		x
sea level	xx	x	x		xx			xx		x
sea ice	x	x	x		xx			xx		x
Biosphere										
vegetation		xx	xx	x	x	xx	xx		xx	xx
Lithosphere										
volcanoes erosion		xx	x	x	xx					
Biogeochemical C.										
carbon, N, S		xx	xx	xx	x		x	xx	xx	xx
Ice sheets										
mass, height, sea ice	xx	xx	x	xx	xx			xx		
Anthrosphere	x	xx	xx	xx	xx	x	x		x	xx
Dating	xx	xx	xx	xx	xx	xx	xx	xx		xx

Background. Substantial climatic variance is found on widely different time scales. Decadal and century scale variations, including extreme events such as volcanism, flooding, protracted drought and severe storms, are part of the natural background against which the climatic influence of greenhouse gases have to be measured.

The nature and causes of interannual and decadal climatic variability are not well known and constitute an obvious gap in our understanding of the climate system. Surely the best known feature of decadal change is the global warming that has occurred in the last 100 years. Beyond this global trend, little more is known with certainty about even the last century. No one source of data can provide the geographic coverage or climate sensitivity to study global patterns of multivariate climate change. The spatial and temporal applicability of the various records, coupled with their often complex or ill-defined responses to climate, must all be recognized. A strategy for reconstructing short-term climate must:

- be based on as many different kinds of record as possible, to allow cross-validation;
- incorporate or encourage improvements in understanding the responses of the various records to climate change, e.g., biological mechanisms in the cases of corals or tree-rings, and
- involve specialists in synoptic climatology and climate modelling at every stage to ensure that the data taken are applicable to tractable mechanistic problems.

The strategy proposed to meet these requirements is to organize the collection and integration of annual resolution climate records for specific time periods in the last 1,000 years. The project must also include interpretation, and models of year-to-year and decadal climate change. This must be done using the full range of available natural and human records, from marine and freshwater as well as terrestrial and cryospheric sources. It is important to have the best possible geographical distribution (including low, middle and high latitudes in the Southern as well as Northern hemispheres).

Other relevant programmes and activities. Many agencies and individual scientists are engaged in developing year-to-year and decadal climate records, but there have been few organized attempts to integrate them on a continental or larger scale. Some notable exceptions are i) the European Climate Programme, ii) several separate joint initiatives between bilateral signatories, and iii) programmes or joint projects initiated by national or multinational groups of individual scientists.

Proposed IGBP activities

The goals of a sub-century climate initiative for the IGBP are to characterize climate variability on sub-century time-scales and to identify mechanisms responsible for these changes and to assess global implications through modelling.

The specific objectives should be:

- to establish a global inventory and database of paleoclimate data for the last 1,000 years with at least annual resolution;
- to set up a related global directory of data on possible climate forcing functions (e.g., volcanic, trace gas, solar variations, major oceanic oscillations);
- to develop strategies for comparing various records and integrating them into global reconstructions and annual or seasonal maps;
- to expand the available proxy data by encouraging new collections in regions that are ill-represented or of particular climatic interest;
- to test hypotheses on the possible causes of high-frequency changes identified in the proxy data through climate model experiments, by comparing simulated and observed changes;

- to encourage efforts to understand the mechanisms that control variability in proxy climate records, especially tree-rings (width, density, microanatomy, isotopic composition), coral layers and laminated aquatic sediments.

Priority should be given to:

- establishing global inventories and databases of high-resolution palaeoclimate data and forcing function records;
- expanding the available data to new regions for example, through new tree-ring collections for ring-width, density and other measurements in the high latitudes of the Northern Hemisphere and the heart of Asia, the region surrounding the Tibetan massif;
- developing new annual resolution records in low latitudes, for example in coral layers in the west and east Pacific basins;
- securing a number of "short term" ice cores, including lower latitude cores (1 to 2 kyr with clear annual resolution) from as many geographic regions and with as much local replication as possible;
- improving mechanistic understanding of the processes creating annual resolution environmental records, by experimental and simulation approaches;
- rescuing or protecting endangered records (dying or destroyed coral, mined, felled forests, housing ancient trees;
- linking GCM experiments with paleoclimate data for relatively well-recorded periods for which there is *prima facie* evidence for possible major forcing factors, such as the Maunder Minimum and the 1790-1825 A.D. period.

Paleo-records of ENSO phenomena

The paleo-record of arid region variability can add much to our knowledge of episodic ocean-climate anomalies (e.g., ENSO, monsoons).

Problem statement. Proxy records of climate variability on time scales of seasons to years are needed to define and test both climate models and model vegetational change. Of particular promise are records of past variations in the extent of arid regions and their fringes.

Background. We need to understand the high-frequency record of past variability of episodic climatic anomalies such as monsoons and El Nino/Southern Oscillations (ENSO), which abruptly affect critical seasonal rainfall patterns. This can be done in part by documenting and analysing arid zone responses.

Arid region changes have occurred on a variety of time scales including those of recurrent glaciations; on decadal time scales thought, for example, to link interactions between the North Atlantic Oscillation and drought in North Africa; and on scales of several years such as the El Nino/Southern Oscillation and monsoons.

Models predicting the past and future changes of insolation and monsoons need to be validated for time spans back to 180,000 years B.P. The models suggest smooth transitions with monsoon maxima near 9,000 B.P. What fragmentary information we have suggests that the natural record is punctuated with a complex pattern of higher frequency events. Natural archives provide the key to defining the important recurrence rates of extreme environmental events.

Other relevant programmes and activities. Various national and international programmes are in progress to collect and study proxy archives. Ocean cores, for example, are available along a monsoon transect of the Arabian Sea. These ocean data are limited by relative sedimentation rates and bioturbation. Non-marine paleoenvironment transects have been devised for Europe, North Africa, USA, USSR and northern South America and Australia. Most of these are aimed at a single proxy archive for major late glacial to post glacial transitions. Such programmes can also act as foci for analyses of short term episodic climatic anomalies.

Proposed IGBP activities. A focussed study of lake sediments and other records in regions presently affected by climate changes of the ENSO type can do much toward understanding and predicting this fundamental interaction. We propose the investigation of selected time-window transects across swaths or belts that link arid zones to the oceans. These provide a means of extending and improving the resolution of proxy archives and should focus on quantifiable geosphere-biosphere interactions including vegetation, seasonality, and the hydrological cycle. The *concept of time-window-transects on* the continents implies a close correlation of proxy records with ocean core and polar ice core results.

Reconstruction of time-window transects for temporal variation requires integration of continuous archives such as historical records, tree-rings, lake and bog cores, palaeosoils, ocean cores, ice cores, loess cores and other more punctuated data sets such as lake levels, soils, middens and volcanic residue.

Large scale multi-national transect studies which can define the variability of episodic climate anaomalies include:

- A transect along the monsoon path from the Arabian Sea across India, Tibet, Mongolia to the USSR and back through China to the China Sea. Closed-basin lakes that are found along this path are particularly sensitive to variations in excess moisture and transport. They also document landscape and vegetation changes. A range of other valuable archives is also available along this swath. This transect can also serve as a critical test of paleo-insolation-monsoon models that are now in development. The IGBP can be of most value where transects cross national boundaries.

- Transects to test the Paleo El Nino/Southern *Oscillations variability* across the Pacific margins of the Galapagos to the Andes, or eastern Australia. These need to link long records of coral growth rings with tree-rings, historical records, lake sediments and offshore varves in upwelling zones.

- A north-south Equator-to-Mediterranean transect through Africa to define shifts in vegetation and paleoclimate with a focus on interactions with the Atlantic Ocean. When linked to work in progress on shifts in tropical forest belts associated with warm and cold climatic phases, these form the basis for integrated variability studies.

- A Tasmania-Australia transect to match *southern and northern hemisphere* records. Programmes in progress on late Glacial records can be encouraged to expand their scope to meet this need.

- An Eastern Pacific-to-Colorado Plateau-Gulf of Mexico transect to provide an unparal- leled opportunity, since within this swath are a wealth of proxy environmental re- cords. These cover time scales as long as 100,000 years and are found in coastal and lake laminated sediments, well-dated fluvial events, pack rat middens and the world's largest concentration of well-understood tree-ring chronologies. A number of well-tested reconstructions of climate aspects for the last 400 to 5,000 years already exists; an integrated approach to at least the last 1,500 years seems entirely feasible with annual resolution.

The IGBP should help organize planning groups for each transect to help to coordinate ongoing work, focus on scientific questions for site selection, and initiate complimentary research projects.

Effects of man on climate and environment.

Problem statement. *It has become evident* that the effects of human activities have increased so much as to influence climate and the environment in a significant way on a global scale. The increase of atmospheric CO_2 and of other trace gases are an obvious case in point. The emission of man-made gases is almost certainly the cause for the observed dramatic decrease of stratospheric ozone over Antarctica ("ozone hole"). The surface of the continents has been modified by human activities including agriculture, industry and construction. These land surface modifications have involved the emission of CO_2 and other greenhouse gases such as methane and nitrous oxide, and they have changed the boundary conditions for atmospheric processes (including albedo, surface roughness, and change of evapotranspiration through deforestation, see also Section 5.3).

Background. Reliable direct atmospheric measurements of concentrations of greenhouse gases are available for only the past 20-30 years. For earlier times, the *main sources of information are analyses of* bubbles included in polar ice. They have given evidence for increasing concentration of CO_2, CH_4 and N_2O in the past centuries, obviously as a consequence of human activities. The increase of carbon dioxide has also been identified by means of ^{13}C analyses in tree rings, but the natural variability of this isotope in trees is so large that it is difficult to isolate the atmospheric signal.

Proposed IGBP activities. The CO_2 increase is caused by burning of fossil fuels as well as by deforestation and agricultural use of soils, and there is still much debate on the relative contributions from the two sources. For clarifying this question, which is important as a basis for predictions for the future, several pieces *of research are necessary:*

- the variations of CO_2 (concentration and isotopic composition) in the past must be established with better precision for the industrial era, but also for the whole Holocene, since it is important to know the amplitude and character of the natural variability; *for this the retrieval and analyses of* polar ice cores is the most promising method;

- data on changes of terrestrial biomass must be improved by establishing the areal extent of land surface changes, the affected biomass density (or the carbon density, tons of carbon per hectare) and regrowth processes. These should be obtained for the present by IGBP spaceborne mapping and land use studies; for the past many types of records and natural archives (such as lake cores and associated pollen studies) will need to be used and coordinated;
- the effect of anthropogenic and natural processes on primary productivity and carbon storage in undisturbed ecosystems, by pollution or inadvertent fertilization by CO_2 and nitrogen compounds, is not at all clear and requires intensive effort in the area of process studies;

- existing global carbon cycle models need to be refined for the interpretation of the paleorecords obtained, especially towards higher resolution in the ocean submodels and the modelling of the terrestrial as well as the marine biosphere.

The history of atmospheric CH_4 and N_2O is less well known than that of CO_2, and nothing is known about other trace gases such as CO for the time before about 1960. Again, ice core studies appear to be the major, if not the only, possible source of information. Similarly, such studies may give information on variations in photochemically-active atmospheric components, but little work has been done so far on this except for H_2O_2. Indirect evidence for changes in stratospheric chemistry might perhaps be found by looking for nitrogen compounds in Antarctic ice. Limited studies toward this end have already been attempted, though for other purposes and with equivocal results.

The growing acidification and general pollution of the atmosphere (especially with metals) can be followed in ice core records and in continental deposits (lake sediments). However, a quantitative interpretation requires a better understanding of the processes responsible for atmospheric transport and for deposition of aerosols.

The effects of land surface changes are primarily local, such as on soil erosion or frequency of floods. However, large-scale consequences must be expected as a result of human modification on a continental scale as in Europe, Asia or North America in the past, or as is now occurring in other parts of the world. These changes must influence the surface water balance (runoff, evapotranspiration) and the radiation budget via albedo changes. These cumulative effects seem now to be less important on a global scale than the better documented increase in greenhouse gases, but they certainly cannot be neglected. The extent of these land surface changes through past centuries and millenia is not well known at present. A European research programme is now being initiated by the European Science Foundation to study the effect of human activities on climate in Europe during the past 9,000 years.

Global changes in the Holocene

Problem statement. The last 10,000 years of Earth's history is a time in which the present ecological conditions, including our present life support systems, were developed and in which the human impact on this ecosystem became obvious, first as a result of rapidly expanding agriculture and later through wide spread industrialization and urbanization. It is important to analyse the changes that took place in this time, both to understand the present and to anticipate the future.

Proposed IGBP activities: *Temperature and precipitation.* Our knowledge of the evolution of climate through the Holocene, in terms of surface temperature, precipitation, atmosphere and ocean circulation, and the responses of the environment, is far from complete. Nor can we model it reliably without a better understanding of the global climate system. As today, changes of temperature and precipitation were not globally uniform. In the higher latitudes the changes of temperature were dominant; in the middle latitudes, there were significant changes of both temperature and precipitation; at low latitudes the changes of precipitation were more important. Of special interest is a comparison between conditions in the northern and the southern hemispheres, because we do not yet know whether the processes were synchronous. Nor do we yet understand the various time lags between significant changes in the atmospheric and oceanic circulation between the northern and southern hemispheres.

Arid and semi-arid lands. The arid and semi-arid regions of the Earth describe the most sensitive ecosystems between the humid extratropical and tropical zones. The smallest changes in humidity, even 100 to 200 mm per year, had not only a very strong effect on the hydrological (lake formation, fluvial systems), biological (vegetation cover, wild life migration) and pedological (soil) formation systems, but also on the development of adapted cultures and land use systems. The combination of many of these indirect climatic indicators allow us to reconstruct the circulation patterns in the atmosphere at this time. The systematic advance of the monsoon, as humid tropical air masses move towards and into today's arid zones, pertains to any future scenario of global warming. We need therefore an intensified effort to recover what happened in the arid zones in the past, through the studies of lake sediments, palynology, palaeosoils, groundwater dating, the analysis of geomorphic processes, etc., to understand the changes that occurred in the dimensions of space and time. Of particular relevance is the IGCP Project No. 252 on the "Past and Future Evolution of Deserts".

Studies of loess deposits. Desert and loess usually developed side by side during the Holocene in arid and semi-arid regions. For this reason a marginal shift between the desert and the loess is a sensitive indicator of a change in regional aridity. An appropriate IGBP effort in this area would pay particular attention to the shifts of Holocene desert and loess areas,

particularly at their transition zones, in both the northern and southern hemispheres. Studies should also be focussed on vegetational and landform changes in the desert and loess region since the beginning of agricultural practice in Holocene time.

Middle latitudes. In this zone smaller changes occurred in temperature and humidity with certain impacts on vegetation, soils, water balance, glacier extent, etc. The study of climate and ecosystems in the Holocene will reveal important interactions; it will also give us some indications about possible changes yet to come in climatic conditions in the most important and most intensely used agroecosystems. Changes in precipitation quantity, regional distribution and variability could influence the water balance and the water content in the soils, which would have serious consequences on world agricultural production in the next century.

High latitudes. The climatic changes during the Holocene had pronounced effects on the dynamics of the glacier and the permafrost systems in the high latitudes. During the thermic optimum of the Holocene there was an active retreat of the high latitude and mountain glacial systems. The extent of permafrost responded to thermal changes.

There are practical reasons to study the past dynamics of permafrost zones. Evaluations of surface temperature and of the change of the depth of the seasonal (active) layer in response to global climatic change can influence present economic and other human activity in permafrost regions. Present day investigations of biogeochemistry have noted that systematic melting of the permafrost during the climatic optimum of the Holocene may have provoked an increase in atmospheric methane as a positive climatic feedback factor.

Sea-level changes in the Holocene. The warming that follows an increase in greenhouse gases may lead to the melting of polar and continental ice sheets and expansion of the volume of sea-water, which will lead to submergence of coastal areas. Relationships between climate and sea water volume changes must be obtained more accurately. Paleo-sea levels recorded in coastal landforms are indicators of changes in sea water volume and in isostatic (glacio- and hydro-) and local tectonic movements. For this reason we need to collect sea level data from tectonically stable coasts, take the isostatic adjustments into consideration, and then obtain water volume changes. This knowledge from the past is essential to predict future sea level rise. Present uncertainties in this area are reflected in the range of predictions that are made, ranging from a few meters to several tens of meters. The IGCP-Project No. 61 on "Holocene Sea-Level Changes" and Project 200 on "Sea-Level Correlation and Application" give some past sea level data, but we need more extensive Holocene sea level data of a higher degree of accuracy to predict future sea level rise. Also needed are improvements in isostatic model development.

Biomass. The biomass of the terrestrial ecosystems has shown a clear response to the climatic evolution during the Holocene. The preliminary investigations show that an increase of the present mean global temperature by 1°C corresponds to an increase of the terrestrial biomass of 10 % to 20 % (from data in regions of Eurasia). But more important than the change in quantity of the terrestrial biomass was the accompanying shifts in the boundaries of climatic zones (such as in the tropical and temperate forest zones, and the tundra zone). An IGBP effort in this area should aim at improving the record of biomass changes throughout the Holocene, by the recovery and interpretation of various proxy indicators.

Orbital and cosmic ray effects. Cycles of Milankovich orbital frequencies are clearly observed throughout the oceanic and the continental stratigraphic record in climate sensitive facies. Yet, very little is known as to how this subtle external forcing works.

The Holocene period provides an excellent time segment of the global climate system for detailed multivariate study.

Documented changes in trace gases and the aerosol content of the atmosphere at the close of the Pleistocene and throughout the Holocene can illuminate the role of the factors that apparently amplify Milankovitch forcing of the climate system.

Although many of the climatic parameters have remained within a narrow range of variability during the Holocene, the variations are still measureable, and some have even varied significantly. Attempts should be made to study the more variable parameters throughout the Holocene with as much accuracy as possible, including $CaCO_3$ preservation, ocean circulation, precipitation, aeolian transport and grain size. Of particular significance during the Holocene would be the study of volcanic eruptions in changing the climate.

The last 150,000 years: Global changes through one glacial-interglacial cycle

Problem statement. Recent marine and continental records have now allowed us to characterize large global changes of climate parameters through a complete glacial cycle. These glacial/interglacial changes have had a large impact on land surface characteristics and on the biosphere. Perhaps more important, ice core results have given evidences of concurrent large chemical changes in the atmosphere. In particular, concentration changes in atmospheric CO_2 and CH_4 during a glacial cycle are comparable to the changes now observed in response to human activities. The reconstructed temperature changes through glacial-interglacial cycles are also of the same order as those predicted by modelled effects of human impact on climate in the next 50-100 years.

These paleodata reveal important Earth system processes. Taken together they show the evolution of climate and environment. This permits a critical evaluation of existing models of climate and environment; it should also stimulate new model experiments that deal with complex Earth system interactions. Such an understanding of Earth system evolution requires additional quantitative, high resolution data from ice cores and from marine and continental records.

Background. Over the last few years proxy data of past climates have provided evidence for important changes in the coupled Earth system. These data tell of changes in air and sea temperatures, distribution of ice sheets, glaciers, permafrost, sea level, ocean circulation, land surface characteristics, continental vegetation and biomass, and in the chemical composition of the atmosphere. Long-term climatic and environmental records allow us to characterize various climatic stages, starting with the last interglacial, culminating about 125,000 years ago, and through a long cold climatic period interrupted by stages of slightly warmer conditions. Full glacial to interglacial conditions are characterized by large precipitation and temperature changes (2 to 4°C globally but up to 10°C in polar areas) with large increases of greenhouse gas concentrations (CO_2, + 50%, CH_4, x 2), and changes in continental dust (up to x 30), and in marine and biospheric (dimethyl sulphide-derived) aerosols.

The few longer quarternary cores available from lakes, peat bogs and loess show a first-order correlation with the marine and ice core record. These archives document the timing of vegetation changes in response to regional glaciation and deglaciation processes.

Long-term variations of atmospheric composition and of cosmic-ray produced isotopes. Atmospheric trace gas and cosmogenic nuclide content undergo substantial changes during a full glacial cycle. The changes are recorded in ice cores and tree-rings (^{14}C). Trace gases such as methane and carbon dioxide determine the greenhouse contribution to climatic change. Cosmogenic nuclides such as ^{14}C and ^{10}Be, provide information on possible changes in Earth geomagnetic dipole intensity, on variations in the exchange rate of the Earth carbon reservoirs, and on the changes in the extended magnetic field of the sun.

Because substantial change in carbon reservoir properties took place at the glacial-interglacial transition, the ^{14}C record in tree-rings should be extended, however, possible beyond the 8,500 year interval currently available in the bristlecone pine. This work should preferably be done for at least two independent tree-ring chronologies.

The presence of ^{14}C and ^{10}Be in ice cores provides information on the solar and geomagnetic modulation of the high energy cosmic ray flux. The two isotopes have different geochemical behaviour, e.g., ^{10}Be is removed from the troposphere by precipitation within a few weeks whereas $^{14}CO_2$ continuously cycles between the ocean and the atmosphere. The combined study of the two isotopes makes it possible to distinguish between the history of production rate changes and the influence of the geochemical processes. The ^{10}Be signal in ice cores may also provide stratigraphic markers for dating and intercomparison of ice core samples.

Analysis of deep polar ice cores have clearly demonstrated that the concentration of atmospheric CO_2 has varied in step with climate during the past 150,000 years, within a factor of about 1.5. Model calculations suggest that these variations have contributed significantly to the glacial-interglacial temperature difference. Recent results have shown that the methane concentration at the glacial maximum was about 50% of the Holocene level. It seems certain that changes in oceanic, physical or biological state must have been responsible for the CO_2 variations, but the processes are not yet known. Methane changes are probably linked to terrestrial ecosystems (wetlands), but well-developed models are still lacking. Rather
surprisingly, CH_4 and CO_2 seem to have varied in parallel, although the chemical and biological processes involved are fundamentally different. More detailed records of gas concentrations are needed, particularly to identify cause-effect relationships between air temperature (^{18}O) and gas concentrations. Of special interest are the variations (magnitude and rate) that characterize the Alleröd-Younger Dryas variation. Answers to these questions are needed to understand what controls the natural trace gas levels and what changes might be expected in the future.

The long-term trend in climate over the last 150,000 years is clearly documented in the delta-^{18}O record and in ocean sediments which to first order reflect changes in the continental ice mass. A very similar trend is observed in the ice core from Vostok Station, Antarctica for the hydrogen-deuterium ratio, delta-D, which to first order reflects regional atmospheric temperature.

Another feature observed in the Greenland ice is a series of rapid climatic changes in the period from 70,000 to 30,000 years B.P. All parameters measured in the ice cores show significant changes at these times including delta-^{18}O, major ions, dust, but also CO_2 and from first indications, CH_4. Similar changes, though less resolved, are also observed in the faunal composition of ocean sediments, and pollen distributions in European peat bogs.

Terrestrial ecosystems reacted emphatically to these documented climatic changes. The first attempts to calculate the change of continental phytomass (for the territory in the northern half of Eurasia) had shown that during the optimum of Eemian time (the last interglacial period, when mean global temperature was 2°C higher than at present) the biomass had increased more than 50% above the present amount. In contrast, at times of increased cooling in the intervening ice age the amount of biomass decreased; during the maximum of last glaciation (18-20,000 years B.P.) biomass was 30% of the present value. With changing amounts of biomass the composition of vegetational formations also changed. In the Eemian, an increase in the different forest formations was typical in the tropics as well as in the middle latitude regions. During the cold periods, the amount of steppe and semi-desert areas increased.

The short term climatic changes observed in the Greenland ice cores Rapid climatic oscillations were found in the Greenland ice core in the time interval from 70,000 to 30,000 years B.P., accompanied by CO_2 concentration changes between 200 and 240 ppm. Since CO_2 is globally well mixed, these temperature changes are assumed to be global in extent, and should also appear in the Antarctic ice cores. So far changes of similar nature have yet to be identified in the Byrd core, in spite of a detailed analysis of a possible attenuation due to the lower Antarctic accumulation rate. It remains an open question if rapid CO_2 changes did indeed occur or whether they could be an artifact of melt-layers in the somewhat warmer Greenland ice sheet.

New measurements of CH_4 planned in Arctic and Antarctic ice cores promise to give new insights regarding the existence of rapid (50 year) changes in atmospheric trace concentrations. Tests are planned to determine whether the CH_4 concentrations follow the general trends of CO_2 and delta-^{18}O, and whether high CH_4 concentrations are found in Greenland and Antarctica at the time of a warm interval during the glacial period. A detailed CH_4 study on Greenland and Antarctic ice cores might enable us not only to reconstruct the atmospheric CH_4 history but also to closely match the time scales (detailed chronologies) of the ice cores from the two hemispheres.

Other related programmes and activities. Several existing programmes and activities are directly related to IGBP efforts to examine the glacial-interglacial cycle. The International Geological Correlation Programme (IGCP) of Unesco and IUGS includes several projects related to environmental changes, in particular its subprogramme on Quaternary Geosciences and Human Survival; the International Hydrological Programme (IHP) provides data on water balances; activities of the Inter-governmental Oceanographic Commission and some of the related programmes (COMAR) provide data on sea-level changes and sea evolution. The activities of the International Union for Quaternary Research (INQUA) deal with the study of the quaternary period and the work of some of its Commissions or Comittees (Commission on Paleographical Mapping of the World, Comittee on Global Changes), etc., are directly related to the above subject. Some projects and activities of WMO may contribute to the study of climatic changes of very long term.

Proposed IGBP activities. The combination of various proxy records should allow one to document the physical, chemical and biological states of the Earth over glacial and interglacial stages. Within this very large objective, priority studies should focus on transitions from glacial to interglacial, from interglacial to glacial, and on abrupt climatic changes such as those already found during the last ice age and subsequent deglaciation. It is of particular importance to obtain high resolution records describing the sequence of events of different nature (such as temperature, precipitation, gases and dust) to help identify causal mechanisms.

Of particular interest is also the study of the previous interglacial and the conditions that brought it to a close. The optimum part of the Eemian is characterized by somewhat warmer conditions (+2° to 3°C) and a higher sea level (possibly 5 m) which may represent an useful analogue for future changes in the present interglacial epoch.

Time scales employed in analyzing proxy records are independent and based on a variety of different techniques. It is of primary importance to develop approaches to correlate the various records by using large scale atmospheric events which should be globally simultaneous. Cosmogenic ^{10}Be events, rapid changes in greenhouse gas concentration and volcanic and aerosol events are possible candidates.

There are only limited data to document geographical changes in the biosphere with climatic changes of the past. It would be of great value to collect sufficient data to compile maps of vegetation changes for different climatic stages in order to identify important connections and interactions.

The finding that significant changes in atmospheric chemistry accompany major climatic changes opens up a broad spectrum of questions that are closely related to the objectives of IGBP. Are the atmospheric CO_2 changes accompanied or caused by changes in ocean circulation, affecting the biological pump? What happens to the uptake or release of CO_2 during a climate induced change of ocean circulation? What is the origin of global CH_4 variations? Do they reflect a reduced CH_4 source, or a general change in atmospheric chemistry? Is higher decomposition and increased CH_4 production with rising temperature a significant feedback? Can we detect an effect on cloud cover of a changing aerosol content such as those that are known to characterize major periods of cold? How did past ecosystems respond to changes in the physical climate system as reflected e.g. in the delta-^{18}O profiles determined in lake marl?

For such studies it will be very important to determine the phase relations between the parameters measured in the ice cores (delta-^{18}O, CO_2, CH_4, etc.) and to synchronise northern and southern hemisphere records, if possible within decades, through periods such as the last glacial-postglacial transition.

To improve our knowledge on the Earth system evolution during the last 150,000 years, concerted efforts will be needed to extract information on the changes in the marine and continental records, as has been emphasized in a great number of scientific programmes, e.g., in the IUGS Task Group Report on Global Change. We especially emphasize the development of more intensive ice core studies which includes field programmes, analytical developments and modelling. The presently planned ice drilling projects in Greenland and later in Antarctica deserve highest priority support. In addition to the existing equipment new fast drills should be developed, which provide uncontaminated ice cores of high quality, which are needed for gas analysis. In order to extract the maximum information recorded in ice cores, techniques should be developed for continuous and quasi-continuous high-depth-resolution measurements of a broad spectrum of parameters including ^{18}O, ^2H, ^{18}O (O_2), CO_2, CH_4 (including isotopes), ^{10}Be, H_2O_2, CHOH, and dust. Important new information is expected from ^{14}C and ^{81}Kr.

Most promising analytical techniques include accelerator mass spectrometry, ion chromatography, GC/MS, Fluid injection analysis and resonance ionisation spectrometry.

Needs for ocean and terrestrial data

Problem statement. The manner in which the ocean circulates is important to Earth climate in two ways: (i) large amounts of heat are transported from low to high latitudes by ocean currents; and (ii) the strength of the Earth's biological pump (and hence the CO_2 content of the atmosphere) is influenced by the pattern and rate of ocean mixing. Based on the record of cadmium to calcium and carbon isotope ratios in foraminifera from deep sea sediments, we now know that the pattern of deep ocean ventilation during glacial time was fundamentally different from that of today. One important aspect of this difference is that the strong "conveyor belt" system, which currently dumps enormous amounts of heat into the atmosphere over the northern Atlantic, appears to have been inoperative during glacial time. In addition, the transition from the glacial mode to today's mode of ocean operation occurred abruptly about 13,000 years ago. This was quite likely the event which initiated the demise of the northern hemisphere Laurentine and Scandinavian ice sheets.

Proposed IGBP activities. It is important that we know much more about the mode of ocean circulation which existed during glacial time and also about the extent to which contemporary ocean circulation matches that for the full span of the Holocene. Most important to these reconstructions are measurements of cadmium to calcium, $^{13}C/^{12}C$ and $^{14}C/^{12}C$ ratios in benthic and planktonic foraminifera. The first two provide information regarding the pattern of circulation; the third provides information regarding the rate of circulation. Studies of marine sediments designed to reconstruct sea ice cover, opaline silica rain rate and calcium carbonate dissolution rates are also important. These studies should be carried out on cores drawn from many geographic locations and water depths in the world's oceans.

In addition to the very important studies of ice cores cited in the previous section, it is important to improve our knowledge of marine and continental records. Particularly needed are those which are continuous and subject to quantification. For marine cores a way must be found to separate the contributions of ice volume and temperature in the oxygen isotope record. One promising approach is to carry out $^{18}O/^{16}O$ measurements on coexisting opal and calcite. Also the delta-^{13}C record must be firmly established. This record is important to the understanding of the reason for atmospheric CO_2 change. To do this will require a better knowledge of which planktonic species to use. Finally the record of calcite and aragonite dissolution must be better quantified. Special effort must be made to establish the relative timing of the changes in the above parameters at terminations I and II in the glacial/interglacial cycle.

For the continents, tree records are of particular interest. Long detailed pollen records, such as those now available for Les Echets and Grande Pile in France and Phillipi in Greece, should be obtained at ten to twenty sites around the world. The loess records in China, Europe and Argentina should be studied with the view of establishing the source of the material and the vegetation cover associated with this source. Finally, lake level records for closed basin water bodies in the world's major desert regions need to be obtained. The Great Basin of the US, Patagonia in Argentina, the Saharan region and northwest China are of particular interest.

Another area of special promise is that of paleomagnetic and archaeomagnetic research, with special attention to changes in the strength of the geomagnetic moment and the position of the paleomagnetic poles throughout the Holocene.

Requirements for modelling paleo-data

Problem statement. Global geosphere-biosphere models have various strengths for investigating the dynamics of climate (see Section 6.1). They provide a quantitative and physically consistent treatment of the different components of the climate system. They are an invaluable tool for the testing of theories of climatic changes and for predicting or suggesting phenomena that can subsequently be studied with observations. They will help to identify the most important climate parameters to be measured and the most sensitive sites where samples must be taken. Models can also give some information on the structure of the environment between widely spaced data.

Conversely, records and reconstructions of paleoclimates will continue to allow both calibration and validation of geosphere-biosphere models. The models will, in turn, provide useful information about gaps and "failures" in existing paleoclimate data banks. Needed is a "two-way" interaction between data-generating and modelling communities.

Background. A wide variety of models are now being usefully applied to paleoclimatic problems. Because of the large computational costs that are involved, atmospheric general circulation models (GCMs) have only been used to provide "snapshot" views of the climate in equilibrium, under prescribed boundary conditions. These boundary conditions include the seasonal and latitudinal changes of solar radiation at the top of the atmosphere, variations in sea-surface temperatures, major ice-sheet configurations, and atmospheric composition and turbidity derived from geologic records. Detailed comparisons have been made between the simulated climates and the geological reconstructions of paleoclimates. On the other hand, statistical-dynamical models, which include atmosphere, ocean, sea-ice and land surface processes in an interactive way, have been coupled to an ice-sheet model in order to investigate the transient response of the climate system to orbital forcing. Results of these models

have been compared with time-series of ice volume changes deduced from geologic records. Continued research is now needed to develop models which take into account all the components of the climate system and their interactions in an interactive and time-dependent way. These models could then be used to study the transient response of the climate system to any prescribed "external" forcing. It is also important to continue testing the many computer models with the entire array of paleoclimatic data that is available.

Other relevant programmes and activities. Development of fully-coupled models of the climate system and the comparison of their results with observations are integral parts of the WCRP and of activities of the IUGG. The US NSF Mapping Project (COHMAP) is constructing global maps of paleoclimatic conditions from 18,000 yr B.P. to the present at 3,000 year-intervals by comparing observed paleoclimates with "snapshot" simulations performed by GCMs.

Proposed IGBP activities. Priority must be given to:

- the development of more reliable ocean circulation models (see Section 6.1). We need to be able to include both horizontal and vertical motions in sea surface circulation, divergences and convergences, deep and bottom water formation, water mass advection and distribution, and ocean-sea ice interactions;
- the development of models which simulate the dynamics of ice sheets;
- the development of models of the biosphere and of its interactions with the other component of the climate system;
- the development of 2D (latitude-height) or 3D fully-coupled models which take into account the complex physical and chemical interactions between the atmosphere, hydrosphere, cryosphere, lithosphere and biosphere and which allow us to analyse the internal behaviour of the system and its transient response to external forcings;
- the development of regional scale models, the time-dependent boundary conditions of which are provided by global models. By allowing a more direct comparison of the simulated variables with the recorded proxy-data, regional scale models will help to improve our understanding of the observed local environmental changes;
- the modelling of surface energy, including hydrological processes and vegetation dynamics. Simulation of certain isotopic fractionations and transports is needed to understand past climate gradients;
- the development of methods to facilitate the comparison of data with model results;
- the transformation of basic climatic variables available from models into meaningful terrestrial and oceanographic processes or features.
- the formatting of data sets in spatial as well as temporal arrays, i.e., in map view, to facilitate the comparison between model simulations and paleoclimatic proxy data;
- the development of accelerated integration techniques such as asynchronous coupling of the component models;
- the compilation of a catalogue of paleoclimatic data of interest to modelers, to include input data, as boundary and/or initial conditions (such as sea-ice and ice sheets extent and elevation, sea surface temperature and albedo) or as data potentially useful in the model itself (such as CO_2 or other trace gas contents or dust load of the atmosphere) as well as output data including ground-level temperature, precipitation rate, atmospheric circulation and windspeed changes and relative humidity over the sea-surface; and

- development of the *in situ* cosmogenic isotope method for quantifying geomorphological processes.

6.3.4. Underlying Needs

The process of recovering information from historical and natural records involves four distinct processes. These are briefly described below.

The identification of natural and historical archives

Geomorphological investigations and studies of sediments, ice and organic deposits are well established disciplines, as are studies of tree-rings, and lacustrine and ocean sediments. Equally valuable, though as yet less studied, are other natural diaries found in deep layers of loess, coral deposits, lake-level variations, and mid-latitude glaicers. Least utilized, yet the most powerful for studies of Earth system behaviour, are combined analyses of these records of the past in specific eras of interest or in the study of long-term trends in regional or global changes.

Adequate attention has not been paid to existing historical records of climate and other environmental changes and its impact on ecosystems and on man.

Fieldwork

In principle, the techniques to drill cores in sediments and ice have now been well established. Nevertheless, the taking of cores, for example, through ice sheets is still a major operation, requiring several years and the dedication of highly trained crews. Recent technological advances offer new opportunities. On the one hand new analytical techniques, such as accelerator mass spectrometry, have significantly reduced the size of sample that is needed for the study of a given parameter; the same advances offer the potential of measuring a much larger spectrum of parameters which are needed, in turn, to derive detailed information on the Earth system evolution. This calls for improvements in drilling techniques, for the development of continous or quasi-continuous measuring techniques of a broad spectrum of physical and chemical parameters, and if possible, analytical measurements in the field on newly-drilled cores.

Similar problems and opportunities exist in the acquisition and analysis of other types of natural environmental records.

Field work in terrestrial archives must be *organized in a more integrated and* multidisciplinary manner: studies of geology, pollen, paleosoils and also fluvial, glacial and marine sediments require a team of specialists to collaborate both in the laboratory and in the field.

Laboratory techniques

New analytical techniques, such as accelerator mass spectrometry, ion chromatography, investigations of paleosoils, fluid injection analysis, optical spectral analysis, and combined gas chromatography/mass spectrometry, have contributed much to our ability to secure more complete and higher-resolution pictures of past Earth system events. These methods need to be perfected and adapted to secure rapid analyses of samples of natural records of many kinds. Other emerging analytical techniques offer additional opportunities.

Data interpretation

An initial area of needed emphasis is the coordinated analysis of different natural records to obtain an overall view of interacting components of the natural Earth system. The interpretation of these data is not a simple matter, for it involves a deep understanding of the relevant properties and mechanisms of the natural archives themselves.

A second step in the interpretation of the data concerns modelling of the processes that are involved in the production of variations of the reconstructed parameters, such as models of solar and geomagnetic shielding of cosmic radiations, transport of isotopes and

particles, and attempts to explain the variations of atmospheric gases such as CO_2, CH_4 and N_2O and of decay products of dimethylsulphide.

The third step is the use of these data in evolving interactive Earth system models. These tests may reveal weaknesses of the models; they will also suggest further process studies which will help improve the integrated understanding of the geosphere-biosphere system.

It would also be of value to establish a global inventory and database of the IGBP (see also Section 6.2), to facilitate the exchange of information between field research and modelling efforts and the exchange of data between different disciplines. A readily accessible archive of this nature would go a long ways toward resolving differences of temporal and spatial scales, terminology, methodology and the general needs of information flow in multidisciplinary and interdisciplinary research.

6.3.5 Action plan

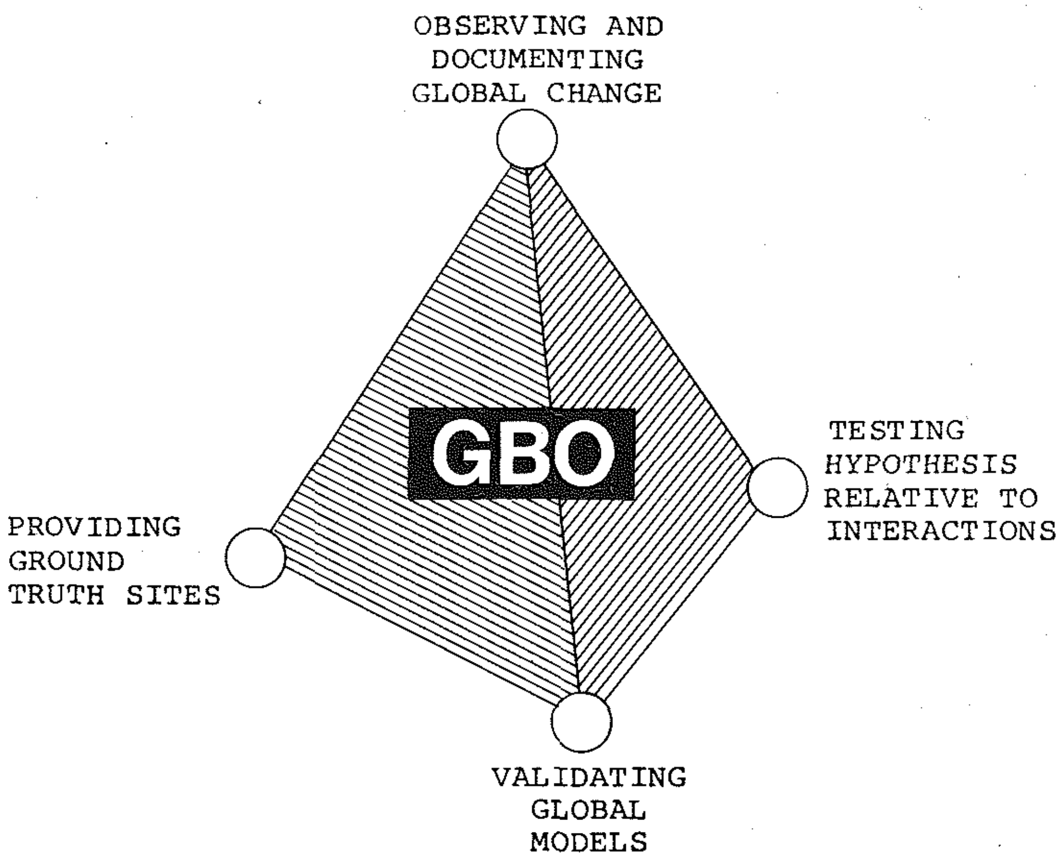
An interdisciplinary programme, coordinated internationally, to recover environmental records of the past that illuminate the study of global change is a high priority need of the IGBP. Toward this end the SC-IGBP should immediately establish a Scientific Steering Committee (SSC) on "Global Changes of the Past". The SSC, of about 10 members, should be comprised of active scientists, who represent the array of techniques listed in Table 6.3.1. It should supplant the "Working Group on Techniques for Extracting Environmental Data from the Past".

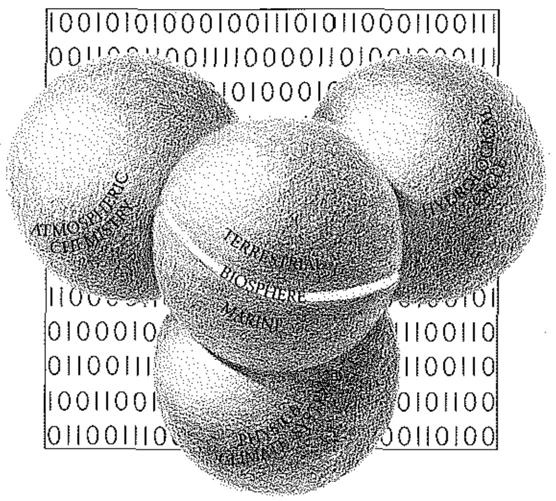
The charge to the SSC should be:

- to assess the possible contributions of planned or existing national and international efforts in this area, as they pertain to the underlying themes of the IGBP and the research goals of the four Coordinating Panels;
- to develop within one year of appointment of the SSC, an initial multi-technique programme of field activities focussed on these specific needs; and
- to initiate pilot segments of this programme within two years of appointment.

The activities of the SSC on "Global Changes of the Past" should be carried out under the auspices of the SC-IGBP and in close contact with the other Coordinating Panels and Working Groups. Close contacts need to be maintained with other relevant international activities e.g., INQUA and IGCP.

Figure 6.4.1.





A coordinated surface-based measurement network to study geosphere-biosphere processes is greatly needed. A network of geo-biosphere observatories across ecosystem-biome types is one possibility for the acquisition of long-term data sets, ecosystem experimentation, validation of models, and ground-truthing for remote sensing. They should also serve as regional research and study centres. A candidate list of parameters to be measured as well as the general principles for observatory siting and duration need to be determined. The establishment of IGBP Research and Training Centres need to occur and links with cooperative Geosphere-Biosphere Observatories need to be established.

6.4. Geosphere-Biosphere Observatories

6.4.1. Introduction

The scientific issues of global change dictate that a long-term coordinated network of marine, and land-based measurements of geosphere-biosphere processes be established. The monitoring should be guided by needed measurements and experiments as part of IGBP projects; the specifications for the quantity and quality of data needed; and the calibration and intercomparison of observations and experimental results. A network of globally distributed marine- and land-based observatories (Geosphere-Biosphere Observatories, GBO) simultaneously measuring various earth system parameters is an essential component of the IGBP. The GBO network will play a major role in observing and documenting global changes, test hypotheses relative to the interactions among earth system components, serve as ground truth locations for remote sensing measurements, and provide inputs and serve as validation sites for regional and global simulation models (Fig. 6.4.1).

The establishment of a GBO network will be conducted in coordination with various international organizations (e.g., WMO, Unesco, UNEP-GEMS). The development of plans for implementation will be guided by the research projects as proposed by IGBP Coordinating Panels and Working Groups. Quality and uniformity of data collection and storage will be assured for all GBOs and this will be guided by the considerations of the Working Group on Data and Information Systems (Section 6.2). Compatibility with data from other networks will be attempted whenever possible.

The establishment of permanent monitoring and observation sites has been an integral component of research programmes in meteorology, oceanography, soil science, geology, ecology, atmospheric studies and space research. The development of an interdisciplinary integrated observatory network is a key step toward the investigation of global change. The development of this concept has been aided by the cooperation fostered between governmental and nongovernmental organizations. An early contribution to the discussion of the GBO concept was initiated by SCOPE and Unesco-MAB.

6.4.2. Objectives

The network of GBOs will be designed to facilitate the achievement of the underlying themes of the IGBP (see Section 3) through the following primary objectives:

- to identify and decipher global change phenomena, as distinct from local or regional signals;
- to encourage transdisciplinary research in the IGBP;
- to promote coordination, cooperation, and communication among the participating disciplines and among nations in an attempt to facilitate global change research;
- to serve as focal points for documenting earth system parameters, process studies, development and validation of models, and ground-truth locations for remote sensing data.

6.4.3. Structure of the Geosphere-Biosphere Observatories network

The development of a GBO network is envisioned as a hierarchical structure (Table 6.4.1) consisting of a small number (5-10) of regional research and training centers, which are multinationally supported, interdisciplinary in operation and multi-purpose in function. In addition, there will be cooperating GBO facilities (no more than 100), which are nationally supported and function as sites for experiments and as key monitoring sites. The next tier in the hierarchy consists of stations in affiliated networks (perhaps numbering as many as 1000), which are primarily monitoring sites (e.g., meteorological stations, soil survey sites, marine monitoring sites). In addition, the last level in the hierarchy is referred to as the "tents and rowboats", which are transient research and monitoring sites, in both time and space, and variable in number at any one time.

The responsibilities and function within the GBO network hierarchy have been delineated relative to the degree of integration the specific tier will provide within the IGBP (Table 6.4.1). The various activities which the GBO network will undertake include:

Training. The Research and Training Centers will provide support for regional educational and training activities relative to ongoing IGBP research with focus on interdisciplinary aspects. Equipment and techniques will be state-of-the-art, but development of simple and reliable techniques for use in collaborative, international projects will also be pursued. The educational and training activities will insure that IGBP research developments are made available to the global community.

Table 6.4.1. Hierarchical structure of Geosphere-Biosphere Observatories

Hierarchical type	Suggested number	Integrative manipulative experiments	Training for IGBP
GBO Research and Training Centres	5 to 10	yes	yes
Cooperating GBOs	100	yes/no	yes/no
Affiliated networks	1000	no	no
"Tents and rowboats"	variable	yes/no	no

Process studies and integration. Process studies and synthesis work will be an important activity at the Research and Training Centers and many of the cooperating GBOs. These will include experiments, detailed process studies, cross-ecosystem and transdiscipline comparisons, global comparisons, and global synthesis as identified by the IGBP research programme.

Monitoring. Key processes, environmental parameters, or earth system components will be routinely monitored or characterized depending on the type of research being conducted. The monitoring will be guided by the contents of the IGBP research projects.

Given the various activities listed above, the Research and Training Centers will function as a centralized data storage facility (see Section 6.2), coordinate process studies and synthesize results be a support facility for surrounding GBO

facilities, and serve as an educational and training center.

The cooperating GBO facilities will function in a similar fashion to the Research and Training Centers, except that at a national, or perhaps a bilateral, level and with less emphasis on training, data archives and global synthesis. Examples of sites which might develop into cooperating GBOs are MAB Biosphere Reserves, Long-Term Ecological Research Sites (US/NSF), agricultural research stations and forest experimental stations.

The affiliated networks will act as high resolution observation or monitoring sites with a broad geographical distribution. Training, experiments, and synthesis studies will not play a major role at these facilities (Table 6.4.1). Examples of these are the meteorological station network, ocean buoys, atmospheric deposition stations and geophysical monitoring stations.

The final level of the network, "tents and rowboats", will function as transitory measurement and experimentation sites. These may be associated directly with an existing facility or may be a temporary study at another location. These will function to capture ephemeral events or study specific processes. Short-term, intensive experiments to study crucial aspects of global change will also be part of this final level in the GBO network.

6.4.4. Data management

Data management issues are intimately related to the structure and nature of the data collecting stations and are discussed also in section 6.2. In a GBO network with a hierarchical structure as described above, the Research and Training Centers will each have a small number (no more than 10) of associated field experiment sites that cover an area of about 20 x 20 km each. These field experiment sites should be ideal for remote sensing experiments, and should have access to satellite receiving capabilities. Multiple fixed ground-truth sites are required within each of the field experiment sites as well as temporary sites in order to calibrate the remote sensing images. *It is important to emphasize* that not all parameters of interest can be determined by remote sensing. Thus, the ground stations play a more fundamental role than just for remote sensing calibrations.

A discussion of the variety of data types, the volume of data, the frequency of data base update required, the level of user support and the mode of access to the data base will all have implications for the design and continued maintenance of the GBO information system.

The GBO information system (see also 6.2) should focus on timely provision of the data, provision of an easily usable data base management system (with good supporting documentation and training), making the system easily accessible through reliable data networks, and supporting the users with a browse facility and a regularly available user support person to answer questions and inquiries at their individual institutions. However, some commonly required "value added services" can be preformed by the GBO information system (e.g., geo-tagging the data, providing calibration data, etc.).

The data holdings for the GBO information system will consist of (i) site-level data (e.g., satellite images, aircraft images and line samples, site meteorological networks, site biophysical, physiognomic and pedological characteristics) and (ii) project-level data acquired over more localized sites.

All data will be catalogued and inventoried for reference on a data base management system but, for the most part, site-level data will be stored on the GBO information system. Project-level data will, for the most part, be held by the individual project leader, but made available on request by other research groups. In cases where the demand for a project data set exceeds the individual project resources to provide it, the set may be declared a site-level data set and transferred to the GBO data base management system.

Users will have access to the GBO information system through commercial digital networks and a menu driven system, which will provide an inventory of the data tables available and their contents.

The Research and Training Centers will need to be staffed to acquire some site-level data, maintain site instrumentation and manage the GBO information system. The staff will consist primarily of scientists, who should also be involved in the ongoing research associated with the site. They will have responsibility for data system upgrades and operations. Upgrades will consist primarily of defining the data base contents, calibration approaches and data formats, but could also consist of some programming tasks. It is also desirable to provide support in acquiring and preprocessing and entering routine site-level data such as plant biophysical measurements, meteorological network data, soils data, topographical data, etc.

An example of such an information system has been established by NASA in conjunction with the First ISLSCP Field Experiment (FIFE) to handle the diverse set of measurements from satellite imagery to soil moisture measurements. The data base management scheme consists of a series of tables accessed through a user-friendly interface. At the most general level, these tables will contain a comprehensive inventory of the total FIFE data. Some of the shorter data sets will be available on-line. A separate geographical information data base will be on-line. Data which cannot be stored on-line due to volume (e.g., imaging data) or form (e.g., photographic images) will be placed in a readily accessible archive along with copies of all other data so users can expect quick retrieval upon request of this material. A system such as this will be needed for the GBO network.

6.4.5. Scientific issues

Temporal and spatial scaling. Data collected in the network will span various temporal and spatial scales. The data will range from broad ground coverage of remote sensing observations from space to point specific measurements of soil or vegetation. Certain observations will be made continuously with 30 to 60 minute averages stored, while slowly changing parameters of the Earth system may be collected every few years to a decade.

Synthesis activities. Compilation and integration of data from the network will be a major activity of the GBO Training and Research Centers and to some extent the cooperating GBO facilities. Information transfer between centralized global data centers and the GBO network will be facilitated through the GBO Training and Research Centers, which will serve as a major information node.

The GBO Training and Research Centers will also be the major facility for global and regional synthesis research and will coordinate synthesis activities within its region. The primary GBO facilities will also play important roles in regional analyses. The tracking of global trends, the development of global process models, and the integration of multidisciplinary studies are examples of the synthesis activities which will be conducted through the Training and Research Centers and some coordinating GBO facilities.

Although the Training and Research Centers and coordinating GBOs will serve the primary role in data storage and synthesis activities, the importance of the scientific input from all levels of the network cannot be neglected. A mechanism to ensure frequent communication between the Training and Research Centers and other levels of the network needs to be established, so that experimenters in the field have access to information in the Training and Research Centers and interact and participate in the synthesis activities. The field scientist inputs into the synthesis research is essential for validating results and interpretation of field observations.

6.4.6 General attributes of the GBO network

The development of this hierarchy of observatories will create a cluster of monitoring and synthesis facilities in various regions of the world. The general attributes of a cluster includes the following features:

- representative ecosystems of at least some minimum viable size;
- control areas for experimental comparison;
- gradients of biospheric and geospheric parameters or driving functions;
- areas for manipulative experimentation;
- areas sensitive or responsive to global change;
- areas with a variety of anthropogenic influences;
- areas where various biogeophysical processes converge.

6.4.7. Issues and operational objectives

In the establishment of the GBO network, a number of issues need to be considered:

Communication and coordinated needs. The GBO network will succeed only if adequate coordination and state-of-the-art communication system are maintained among the participating organizations and scientists. The IGBP is by design multi-national and multidisciplinary, and coordination must occur at various levels of the network, including across disciplines, between and among tiers of the network, between nations, and within a nation. An essential component necessary to carry out the coordination will be a state-of-the-art communication system. Such a system will provide the vehicle of informing all participants of ongoing developments and research findings, request and transmit data between facilities, confirm observations of different phenomena by other facilities, and aid in maintaining of data quality.

Existing networks and research facilities. The GBO network will make the best possible use of existing networks such as the meteorological stations associated with WMO, air quality monitoring stations operated or mandated by existing government agencies, geophysical monitoring stations operated under international agreement, among others. A major part of global monitoring activities will be found outside the field experiment sites associated directly with GBO research and training centers or cooperating GBOs. GEMS of UNEP plays an essential role as a global monitoring system utilizing such networks and this organization should play an important part in the development of appropriate links between the GBOs and existing networks.

Support and benefits. Long-term focus of the IGBP research goals dictate that GBO Research and Training Centres need to be developed within a long-term framework. Long-term commitment at governmental or inter-governmental levels will be needed to ensure that these facilities once established will be able to function for the duration of the IGBP and hopefully beyond. All nations taking part in the IGBP should support the network of Research and Training Centres regardless of their location.

The facilities within the GBO network will not be solely used for global change studies. Important local or regional research with other focusses will also occur, and the GBO facilities will thus be a valuable resource also for other scientists. The educational and training role provided by the Centers is also a valuable attribute of the network. The transfer of new technological advances in experimental research, data management, and simulation modelling are only a few areas where local and regional researchers could benefit from access to the GBO network. It is important to stress that, although the GBO network is designed to address global issues, the network will also play a major role in local and regional efforts and a coordinated programme is desired.

Technological and staffing expertise. It is unrealistic to assume that all data will be centralized in each GBO Research and Training Center. Therefore, it is essential that good communication be established among the various centers. Technology presently available permits distributed data bases, where particular data is stored in different computers in different geographical locations, but is accessible from any point in a data network through a central data directory. On a global level, fast communication between centers is vital, including sending messages to request stored data or to announce the occurrence of important short lived phenomena of general interest. This implies that the main computers at the central stations must be connected together or access the same computer network.

It seems that dedicated data acquisition systems, or data acquisition systems linked to personal computers, are quite adequate for the initial handling and analysis for field data. Consolidation at primary (e.g., 20 x 20 km) field sites requires some kind of mass storage beyond the capability of PCs. This, and the fact that remote sensing images will be handled at this level, indicates that minicomputers (work stations), at least, are required at this level. These are extremely good at manipulating and displaying images and can provide significant mass storage. Mainframes will play an important role as central repositories of data to be exchanged on an international basis. The system should be compatible with other key international data base systems, especially GEMS/GRID and WDC (see Section 6.2). The development of global digital data bases is an essential component and a Working Group under IGU is pursuing this issue. The link of such data bases to global and regional GIS is being developed by UNEP-GRID, and this effort should be supported.

separate or one combined group for "Data and Information Systems" and "Geosphere-Biosphere Observatories". The establishment of a Scientific Steering Committee will be considered.

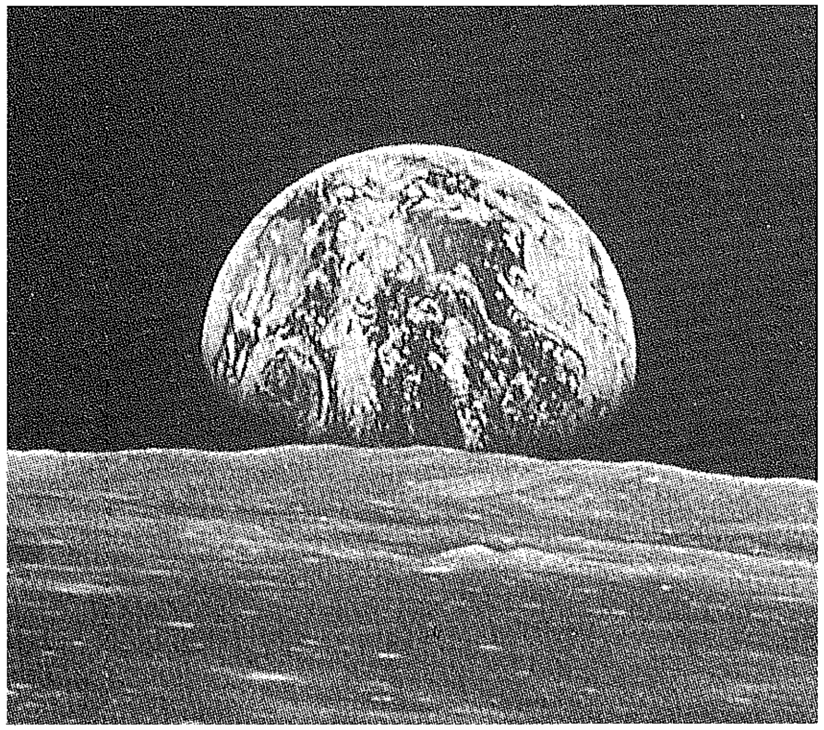
The next IGBP meeting to discuss GBOs will be arranged in Bangkok, Thailand 17 - 21 April, 1989. The main aim of this meeting is to develop a detailed proposal for the establishment of GBO Research and Training Centers based on the report to and discussions during the SAC meeting. A rationale for the selection of locations for GBOs should also be worked out. Special efforts will be made to allow the participation of scientists from developing countries. Invitations will be sent out to other international organizations, especially UNEP, Unesco and WMO, and their possible roles will be another major item for discussion. In addition, representatives from the IGBP Coordinating Panels will be present to ensure that the development of an international GBO network meet the needs of the forthcoming IGBP research projects. Specific attention will also be given to the integration of recommendations from the Working Group on Data and Information Systems (Section 6.2).

A second meeting of the Working Group will be arranged in Poland, September 1989 in collaboration with IIASA. This meeting will be in two parts. The first part will specifically consider the relationships of GBOs to existing national, regional and global monitoring systems. The second part of the meeting, which will consist of Working Group members only, will develop a presentation of the GBO network in the form of a funding proposal, estimate costs for the development of the Research and Training Centers and an action plan for approaching potential donors.

The third meeting during 1989 should specifically discuss the relationships between a GBO network and present and future remote sensing needs for ground truth observations. This should occur in close contacts with appropriate space agencies, perhaps through SASIFY and COSPAR.

7

Toward the IGBP: A Plan for Action



For the purpose of understanding global changes and predicting their practical impacts the IGBP will address the crucial questions that currently limit our understanding of the Earth as an interlinked system. At the heart of this are interactions that link key physical, chemical and biological processes, and how these are influenced by anthropogenic activities. For this reason the programme must be interdisciplinary, and because the problems it addresses are global in nature, the IGBP must be international in scope, and aimed at providing a holistic understanding.

To achieve its goals, the IGBP research must be far more than a collection of planned or ongoing activities that are related to global changes. Efforts are needed that will tie together relevant parts of other ongoing programmes related to global change. Even more, new initiatives are needed to fill crucial gaps in our knowledge, especially those gaps that cannot be filled without an integration of different disciplines. The IGBP research phase should consist of specific core projects with clear objectives, and specified methodologies and criteria, by which progress can be measured and success evaluated in relation to the stated objectives. These projects must have a broad international base and should be initiated for limited periods of time. If some projects need to be continued for long periods, rigorus evaluation of achievements and goals should be made at regular intervals.

Core research projects of the IGBP will be strengthened by other international activities, which are not coordinated by the Special Committee. The mutual benefits of this are obvious. Certain of these activities may be the key to an understanding of the global system within the objectives and the underlying themes of the IGBP. Some of these research programmes are already underway or in the advanced planning phase. They have been coordinated by ICSU scientific members of other international bodies. In the cases where other activities are crucial to achieving the overall objectives of the IGBP, more formal associations will be sought within a framework of mutual needs and common goals. In other cases, where formal associations have no obvious mutual benefits, or where research goals are more peripheral to those of immediate interest to the IGBP, it will be sufficient to establish less formal connections.

Key examples of essential collaboration include the Joint Global Ocean Flux Study (JGOFS of SCOR) and the International Global Atmospheric Chemistry Programme (IGAC of CACGP/IAMAP). The future links between JGOFS, IGAC, and the IGBP should be further discussed and agreements reached regarding possible joint sponsorship in the near future.

A major component of the international effort to understand the functioning of the Earth system is the World Climate Research Programme (WCRP) of WMO/ICSU. In particular, special attention needs to be paid to the possibilities for joint planning between GEWEX and the IGBP. Mechanisms for cooperation between the WCRP and the IGBP need to be strengthened and their complementary nature stressed. Many other important international programmes of relevance to the overall goals of the IGBP are underway. These are listed in Annex 2.

National participation and priorities will be crucial for the development of the IGBP. Research activities will often be national in nature, and most of the funding will come from national sources. As is evident from the many national reports to the SAC-IGBP, planning is already underway for the development of national components of the IGBP. Bilateral efforts that address fundamental elements of global change have also been initiated and are to be encouraged as nuclei for broader involvement. Regional and national priorities vary, and it will be necessary to derive from these national efforts a coherent and focussed international research programme. The priorities formulated by the SC-IGBP will be used as guidelines.

The SC-IGBP envisages a three component structure for the implementation phase of the IGBP:

1. Core IGBP projects, which are the responsibility of the SC-IGBP, sometimes in cooperation with other international bodies.

2. Supporting activities, which are essential to the overall goals of the IGBP effort and

which are officially recognized by, but not directly the responsibility of, the SC-IGBP.

3. Affiliated activities which are clearly related to the overall goals of the global change effort, but which require no formal designation by the SC-IGBP. Efficient communication links between such activities and IGBP core projects need to be established.

The discussions during the Scientific Advisory Council meeting in October will be decisive for the development of the core programme. On the basis of these discussions, the Special Committee will develop detailed plans for 1989. It is hoped that certain pilot projects can already be initiated in late 1989 or early 1990. In order to prepare plans for the implementation of specific research projects, the SC-IGBP will appoint Scientific Steering Committees (SSC). The first to be proposed is an SSC on "Global Changes in the Past", which would replace the Working Group on "Techniques for Extracting Environmental Data of the Past".

Core projects will be selected by the SC-IGBP. The selection will be based on the reports from the existing Coordinating Panels and Working Groups, on the research recommendations of national committees expressed in the reports to and during the discussions at the SAC-IGBP, and research recommendations of relevant scientific members of ICSU. Detailed descriptions of selected core projects will be ready by early 1990. The preparation of detailed project plans will be led by expanded Coordinating Panels and Working Groups under the guidance of the Special Committee.

In order to ensure that the work proceeds efficiently, the SC-IGBP will seek funds to allow one Research Fellow to work for at least one year with each of the Chairmen of the Coordinating Panels, the proposed Scientific Steering Committee for "Global Changes in the Past" and a proposed joint "Data and Information Systems/Geosphere-Biosphere Observatories" Working Group. A collaborative effort towards this end has been proposed between the IGBP and the Wissenschaftskolleg zu Berlin (West Berlin). As part of this agreement, the scientists appointed to the six Chairmen would serve as Fellows of the Wissenschaftskolleg for six months and work with the Chairmen of the IGBP groups for at least another six months. The Fellows will be responsible for the developments of draft plans for IGBP projects under the guidance of the Chairmen and the Coordinating Panels (or SSC). They will also, together with the Chairmen, prepare state-of-the-art reviews of the research areas as a background to the proposed IGBP projects. The final document should be a document with review articles on our present scientific understanding of the key areas selected for priority in the IGBP as well as detailed plans for IGBP core projects. During the stay of the six Research Fellows in Berlin, all Chairmen will spend at least two weeks with them working on the integrative aspects of proposed projects and on how research should be linked to data/information systems as well as the Geosphere-Biosphere Observatories. Toward the end of the stay in Berlin, the Special Committee will meet for one week to discuss the draft plans for the projects. On this basis, the final project descriptions will be circulated widely and presented at the Second Meeting of the IGBP Scientific Advisory Council tentatively planned for the Spring of 1990.

The discussions during the 2nd meeting of the SAC-IGBP should result in the initiation of core projects in 1990. To achieve this, it is expected that most of the IGBP Coordinating Panels and Working Groups will need to meet twice during 1989.

8

The IGBP as Part of International Science Cooperation

ICSU

As outlined in the previous section, an understanding of global-change phenomena cannot rely on the IGBP core projects alone. A number of other international programmes/projects already exist or are being planned. Concern has been expressed by members of the scientific community that (i) the IGBP will compete with and possibly prejudice projects in progress or in preparation; (ii) there is currently insufficient manpower in both the developing and industrialized countries to proceed with the IGBP and the other ongoing international, interdisciplinary programmes; and (iii) current cooperative mechanisms are inadequate to avoid conflicts of interest and to ensure complementarity. Previous experiences (IGY, IBP, WCRP, etc.) clearly demonstrate that with an adequate period of planning it is possible to mobilize the necessary financial and manpower resources to launch major international efforts, such as the IGBP. The present scientific and political climate is also such that the research community has to address global-change issues, and this cannot be done in an adequate way without an IGBP.

The IGBP Scientific Advisory Council meetings are essential components in the development of efficient links between the IGBP and other relevant ICSU programmes and projects. Discussions of the IGBP in relation to other ICSU activities should also be part of other ICSU sponsored meetings, and the Special Committee will ensure that key members of the Special Committee will be available for such discussions whenever possible. It is the view of the Special Committee that the best means of communication is on an ad hoc and personal basis and that there is no need for formal mechanisms other than the SAC-IGBP. The SC-IGBP will ensure that proper links to other relevant programmes are taken into account in the selection of members of the expanded Coordinating Panels and Working Groups as well as the Scientific Steering Committee as discussed above.

The Special Committee has already initiated discussions with representatives of appropriate organizations of the U.N. family (e.g., UNEP, UNESCO, WMO, UNCSTD). On the recommendation of the IGBP Executive Committee, an Interagency Coordinating Committee (ICC-IGBP) has been set up, and UNEP, UNESCO and WMO have been invited to be represented on the committee. The IGBP members will consist of the Executive Committee members, and the ICC-IGBP will meet for one day in connection with each meeting of the EC-IGBP. It is foreseen that the ICC-IGBP will be the major mechanism for permitting discussions with UN bodies in regard to scientific content, implementation strategy and institutional arrangements for the IGBP. The first meeting of the ICC-IGBP is scheduled for January, 1989 in London (UK).

The following list of international programmes of key relevance to the IGBP has been drafted by Dr. F. W. G. Baker (ICSU Executive Secretary) to provide an overview of ongoing and projected studies. The list of projects and activities of other organizations shows the pervasive nature of Global Change problems. It is essential that interactions among these organizations and projects are facilitated to develop a truly international cooperative research programme for the study of global changes. The list of activities is preliminary, and in certain instances there has been no time to receive responses from the organizations and programmes listed. The section should, therefore, be considered as a draft only. Brief descriptions of the activities are found in Annex 2.

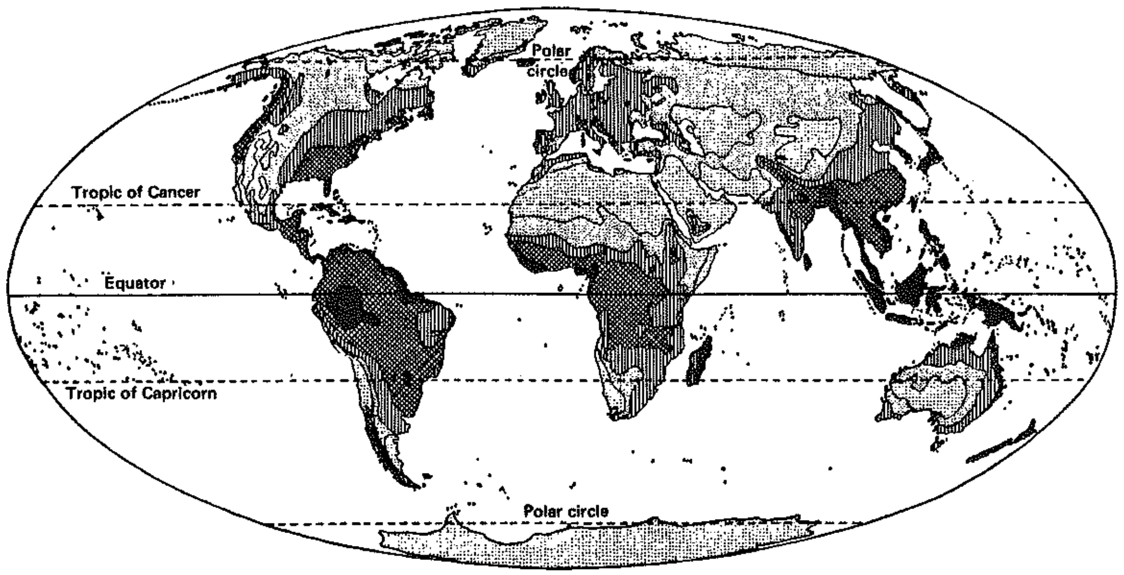
Table 8.1. Activities of ICSU and other international organizations of direct relevance to the IGBP

Programme	Status	Subject	Sponsor
A. Lithosphere			
1. International Lithosphere Programme (ILP)	Ongoing (1981-) Tectonics	Solid-Earth Physics;	ICL; IUGG; IUGS; ICSU
2. Global Geoscience Transects (GGT)	Ongoing (1985-)	Geology; Geophysics	IUGG; IUGS; ICL
3. International Geological Correlation Programme	Ongoing (1973-)	Geology;Solid-Earth Physics; Geochemistry	IUGS; Unesco
B. Biosphere			
1. A Decade of the Tropics	Ongoing (1983-92)	Tropical Biology	IUBS
2. The Biogeochemical Cycles and their Interactions	Ongoing (1974-)	Biology; Meterology Oceanography; Chemistry	SCOPE
3. Bioindicators	Ongoing	Pollution of Environment; Biogeochemical Cycles	IUBS
4. Man and the Biosphere (MAB)	Ongoing	Ecology	Unesco; IUBS INTECOL; SCOPE
5. International Satellite Land Surface Climatology Project (ISLSCP)	Ongoing	Variations in Physical and Biological Land Surface Characteristics	COSPAR; IAMAP; UNEP; JSC of WMO-ICSU
C. Oceans, Atmosphere, Hydrology			
1. World Climate Research Programme (WCRP)	Ongoing	Meteorology; Oceanography	WMO; ICSU
2. Tropical Oceans and Global Atmosphere (TOGA)	Ongoing (1985-94)	Meteorology; Oceanography	WCRP; IOC; SCOR
3. World Ocean Circulation Experiment (WOCE)	1990-95	Oceanography; Meteorology; Circulation; Air-Sea Interaction; Sea Ice	WCRP; CCCO IOC; SCOR
4. International Hydrological Programme (IHP)	Ongoing 1975-	Hydrology	Unesco; WMO; UNEP; IAHS; IUGG
5. Global Energy and Water Cycle Experiment (GEWEX)	Proposed	Transport and Distribution of Water and Energy	WCRP
6. Joint Global Ocean Flux Study (JGOFS)	Proposed	Air-Sea Interaction	SCOR
7. International Satellite Cloud Climatology Project (ISCCP)	Ongoing (1983-)	Cloud Cover; Solar Radiation Fluxes	IAMAP; COSPAR; SCAR; JSC
8. International Global Atmospheric Chemistry Programme (IGAC)	Proposed	Atmospheric Trace Constituents; Atmospheric Photochemistry; Aerosols	IAMAP; IUGG
9. Integrated Management of Coastal Systems (COMAR)	Ongoing	Coastal/Marine Ecological Processes	Unesco; IABO; IUBS
D. Solar-Terrestrial			
1. Middle Atmosphere Programme (MAP)	Ongoing (continuation proposed)	Solar - Terrestrial Physics; Atmospheric Physics	SCOSTEP
2. Polar and Auroral Dynamics (PAD)	1985-90	Auroral Particles; Particle Physics; Physics of Aural Formation	SCOSTEP; SCAR
3. Solar-Terrestrial Energy Programme (STEP)	Proposed	Plasma Physics; Solar Physics	SCOSTEP; URSI IGAG
4. World Ionosphere-Thermosphere Study (WITS)	1987-89	Global Dynamics of Ionosphere-Thermosphere	SCOSTEP
5. Solar Interplanetary Variability (SIV)	1988-90	Transition of Sun and Inter-Planetary Medium	SCOSTEP

Programme		Status	Subject	Sponsor
E.	Monitoring and Data			
1.	Global Environmental Monitoring System (GEMS)	Ongoing	Meteorology; Environmental Sciences; Ecology	UNEP; WMO; IOC; ICES; FAO; SCOPE
2.	World Digital Data-base for Environmental Science (WDDES)	Proposed	Hydrology; Bathymetry; Terrain; Coastline; etc.	ICA; IGU
3.	World Soils and Terrain Database (SOTER)	Proposed	Soils;Terrain	ISSS; UNEP
4.	Multi-Satellite Thematic Mapping Project	Ongoing	Geology; Mineral Resources	CODATA
5.	World Data Centers (WDC)	Ongoing	Solar and Geophysical Information	ICSU
6.	Federation of Astronomical and Geophysical Services (FAGS)	Ongoing	Astronomical and Geophysical Observations	ICSU
7.	Monitoring the Sun Earth Environment (MONSEE)	Ongoing	Solar - Terrestrial Interaction Data	SCOSTEP
8.	World Climate Data Programme (WCDP)	Ongoing	Atmosphere - Ocean - Cryosphere - Terrestrial Earth Science Climate Data	WMO; ICSU; UNEP

9

Role of National IGBP Committees



The national IGBP committees (see Appendix 5 for list of currently established committees) must play a crucial role in the development of the IGBP. These committees will be focal points for linking the national contributions to the core projects of the IGBP as well as with the Special Committee and its subsidiary bodies. The national reports to the first SAC-IGBP will be important inputs to the international planning efforts. These cannot proceed, and specific projects cannot be implemented, without the active participation of national committees and the national scientific communities. The Special Committee is cognizant of important documents describing proposed national contributions to the IGBP. Although organisationally they are not always wholy consistent with the project areas proposed by the SC-IGBP in setting up the Coordinating Panels, this should not be interpreted as a lack of consensus on the key problems to be addressed by an IGBP, but rather as a reflection of different emphases and ways of structuring research related to global change. The views of the National Committees, as well as the outcome of the deliberations during the first meeting of the Scientific Advisory Council for the IGBP, will be important inputs for the further development of a programme, which will serve as guidelines for nations that wish to contribute to this global effort.

It is expected that major parts of national programmes will be formal parts of the core IGBP projects. However, all national activities in relation to global change will not necessarliy be part of the international effort, but will be supporting activities as outlined in Section 7.

The Special Committee will seek to ensure that national committees members will be appointed to the expanded Coordinating Panels and Working Groups, as well as the Scientific Coordinating Committies, although they will not be appointed to represent national committees.

The Special Committee members have been asked to take an active part in promoting the concept of an IGBP in countries where no national committees have yet been formed. It is essential for the success of the programme that the planning and project activities take advantage of existing scientific expertise in as many countries as possible. This process will certainly be facilitated by the existence of national committees. In addition, the Commission of the European Communities (DG XII) plans to arrange a meeting between scientists from those member states prior to the first meeting of the Scientific Advisory Council. It is hoped that this will stimulate the member states, which do not yet have national IGBP committees, to establish such. The possibility of setting up regional committees should also be investigated. During the ICSU General Committee meeting in Rome (1987), a possible Committee for the Balkan countries was discussed. Discussions are under way with the Caribbean Academy of Sciences for a Caribbean Committee, and the IGBP is sponsoring a meeting on climate change in the Southern Hemisphere (Swaziland, December 1988) at which time the issue of promoting a regional committee for southern Africa will be discussed. A regional IGBP meeting for Latin America is tentatively planned for October 1989 in Colombia. The Special Committee welcomes additional initiatives in this field.

All efforts should be made to involve scientists from developing countries in the programme, and the possibility of doing this in cooperation with the Third World Academy of Sciences will be explored.

According to the constitution, national IGBP committees or ICSU national members, who wish to participate in the programme, should pay annual dues (see Section 10).

10

Financing an IGBP

The financing of the IGBP scientific projects will need considerable resources, and it is at present not possible to make even a rough estimate of the totals costs. In order to ascertain that sufficient resources will be committed to the implementation of IGBP during the 1990s it is foreseen that during the next few years special meetings will be held with representatives of nations and national funding agencies that carry responsibilities for resource allocation. It is expected that most of the funding will come from national funding agencies. During the first SAC-IGBP there will be a small meeting between members of the SC-IGBP and representatives of national funding bodies, and this meeting is seen as a first step in developing a strategy for funding the implementation phase of the programme.

It will be particularly important to secure support for the required satellite sensors, which will be needed for the IGBP research by about the middle of the 1990s. The Special Committee notes that an international agreement has been reached to establish a Space Agency Forum on International Space Year (SASIFY). The IGBP should take the initiative to arrange a meeting with SASIFY and COSPAR aimed at exchanging views on the future IGBP programme and preparation for possible collaboration. In order to develop and safeguard scientifically well-conceived and coordinated core projects of the IGBP it is obviously important that national committees also become engaged in such initiatives.

Apart from financing the research projects, there is also a need for funds to cover the costs for planning as well as the coordinating activities of the Special Committee. At present funds are being received from ICSU, the Andrew W. Mellon Foundation, UNESCO and UNEP. The cost for the IGBP Secretariat in Stockholm is to a large extent covered by a grant from the Swedish government. The Commission of the European Communities and CIDA have also been approached. In addition, several national ICSU members/national IGBP committees have pledged voluntary financial contributions to the planning during 1988. According to the Constitution, all national members should pay annual dues from 1989, and the following is the scale of annual contributions:

	USD
1.	500
2.	1,000
3.	5,000
4.	10,000
5.	25,000
6.	50,000
7.	75,000
8.	100,000
9.	150,000

The estimated budget for 1989 is approximately USD 1,200,000. It must be emphasized that the planning of this major scientific undertaking will be expensive. The planning of a research programme to unravel aspects of the functioning of Planet Earth in order to predict global changes and their effects is a complex undertaking. A truly international effort during the first phase of the IGBP effort is a necessity but also a costly enterprise. Almost all of the expenditure in the draft plan for 1989 will defray the costs of meetings with Coordinating Panels and Working Groups as well as Scientific Steering Committees.

During the implementation of the programme, it is expected that each major IGBP project will need a small coordinating unit and that these will not be parts of the Stockholm Secretariat. It is hoped that national committees, for example, will host such coordinating units. This is similar to what is the case for the WCRP projects (TOGA and WOCE) as well as was the case for, e.g., IBP.

11

Societal Aspects of Global Change

One of the criticisms during the discussion of the IGBP that lead to the ICSU General Assembly in Berne was that it is impossible to understand and predict global change without considering them in a societal context. It was decided in Berne, however, that whereas ICSU is in a unique position to launch an IGBP with a strong scientific focus, it must rely on other organizations to develop a social sciences counterpart to the programme. The Special Committee is pleased to note that a number of other organizations are now considering the initiation of a parallel activity in the social sciences. For example, a programme called "Human Response to Global Change" (HRGC) is being planned by IFIAS, ISSC and UNU with participation of IIASA, Unesco and UNEP. The SC-IGBP welcomes this initiative, as well as others. The Chairman of the SC-IGBP, Professor J. J. McCarthy, will give a presentation on the IGBP at the forthcoming HRGC meeting in Tokyo (September 1988), and in May 1988, on behalf of the SC-IGBP, Professor V. A. Troitskaya attended a planning meeting in Warsaw. The SAC-IGBP will receive a plenary presentation of the plans for this programme.

Discussions on how future cooperation between the IGBP and the social sciences should be developed need to be persued.

12

Appendices

Appendix 1

Brief History of the Developments Toward an IGBP

ICSU has a long tradition in international collaborative research programmes, the most important ones being the International Geophysical Year (IGY, 1957-58), the International Biological Programme (IBP, 1964-1974), the Global Atmospheric Research Programme (GARP, 1967-1980) and the World Climate Research Programme (WCRP together with WMO, 1980-). For a more complete list of ICSU projects relevant to the IGBP, see Appendix 2. ICSU is in a unique position to address complex scientific issues in the natural sciences with its 20 unions and 10 scientific committees with members from 71 countries, thus having both a disciplinary and geographic breadth. In launching the IGBP, ICSU can look back at a successful series of accomplishments in initiating international research programmes, which have helped advance science and foster international scientific cooperation. In this it has had and will continue to have a unique role.

In 1982, Professor G. Garland made a presentation to the 19th General Assembly of ICSU in Cambridge (UK) in commemoration of the 25th anniversary of IGY. In this lecture he remarked:

> *"Today we have a reasonably complete understanding of the links between physical processes affecting our planet and the region around it. Many of the mysteries which remain involve the interaction between the physical processes and biological material, including man himself. Indeed, further progress in some of these areas requires the expertise of literally every discipline now represented in ICSU."*

Planning for an International Geosphere-Biosphere Programme: A Study of Global Change was also initiated by the US National Research Council, which arranged a workshop in July 1983 under the chairmanship of Professor Herbert Friedman, Chairman of the Commission on Physical Sciences, Mathematics, and Resources of NAS.

A document proposing a project to consider changes in the habitability of the Earth was submitted to the ICSU Executive Board at its meeting in Stockholm in January 1983. There was general approval of the ideas expressed in the document and the Executive Board decided to organize a colloquium on the subject at the meeting of the ICSU General Committee in Warsaw in August 1983. The objectives of the Colloquium on Global Change was to develop a discussion concerning a scientific strategy for a programme that would be attractive to the international scientific community and simultaneously address pressing current and future human needs. There was general agreement that it would be possible for ICSU to develop a group of interdisciplinary programmes that would help decision-makers to comprehend the changes that are taking place, the actions necessary at a national and an international level and would permit scientists to elucidate the studies that should be continued or developed.

The 17th meeting of the ICSU General Committee decided "... to establish an ad hoc committee to carry out the study of those aspects of global change which are not yet adequately covered, to prepare an inventory of existing programmes and their inter-relations, and to make recommendations to the 20th General Assembly for further planning in fields that are interdisciplinary and require international cooperation." ICSU set up an organizing committee with Professors Thomas F. Malone and Juan G. Roederer as co-conveners to prepare for the discussions of the ICSU 20th General Assembly (Ottawa, 1984). During the General Assembly a symposium on Global Change was arranged and the proceedings were later published (Malone & Roederer, 1985). The ICSU General Assembly decided to explore the possibility of launching a major new research programme on "Global Change" and an ad hoc planning group was set up under the chairmanship of Sir John Kendrew, President of ICSU, later succeeded by Professor Bert Bolin.

The ad hoc group appointed four Working Groups in October 1985 to consider related programmes, to provide inputs that would further define programme emphasis and to suggest priority subjects for initial emphasis. The following groups were set up and prepared reports for the planning committee:

- Terrestrial Ecosystems and Atmospheric Interactions (Chairman F. di Castri)

- Marine Ecosystems and Atmospheric Interactions (Chairman J. J. McCarthy)

- Geological Processes, Past and Present (Chairman R. Price)

- Upper Atmosphere and Near Space Environment (Chairman J. G. Roederer)

In addition, COSPAR appointed a Working Group on Remote Sensing (Chairman S. I. Rasool), and the report from that group was also used as resource material for the report of the planning group, which was presented to the ICSU 21st General Assembly in Berne (Switzerland) in September, 1986.

The General Assembly adopted the following resolution:

> **Noting** the successful symposia on Global Change held at Ottawa in 1984 and at Berne 1986;
>
> **acknowledging** with appreciation the planning activities carried out by the Ad hoc Planning Group on Global Change, the four Working Groups and the COSPAR Working Group on Remote Sensing;
>
> **taking into consideration** the recommendation of the 21st Meeting of the General Committee;
>
> **accepts with enthusiasm** recommendations given in the final report of the Ad Hoc Planning Group;
>
> **resolves** to establish an International Geosphere-Biosphere Programme: A Study of Global Change to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human action;
>
> **authorizes** the establishment of a Special Committee for the Geosphere-Biosphere Programme to provide for the development and coordination of the scientific programme;
>
> **acknowledges** the expressions of interest and support by Unions, scientific and special committees and other members of the ICSU family;
>
> **urges** that provision be made to ensure effective liaison between the SCGB and the relevant scientific Unions and other members of the ICSU family, and appropriate international organizations;
>
> **accepts** with thanks the offer of the Government of Sweden to provide an international secretariat for the Programme;
>
> **endorses** the decision to establish a nominating group charged with recommending the Chairman and Members of the SCGB by January 1987, for appointment by the Executive Board;
>
> **encourages** the development of an appropriate financial plan for the programme including regularly scheduled contributions by participating national members;
>
> **urges** that every effort be made to take full advantage of the strong impetus that now exists to begin the preliminary phases of the programme and to allow the commencement of the operational phases in the early 1990s.

The ICSU Executive Board decided to appoint Professor Thomas Rosswall, Department of Water in Environment and Society, University of Linköping, Sweden and Secretary-General of SCOPE as

Executive Director of the IGBP. It also appointed a Nominating Group under the chairmanship of Professor J. W. M. la Rivière, which was charged with recommending a Chairman and Members of the Special Committee for the IGBP (SCGB). The Nominating Group met in Paris on 3 and 4 December 1986 with the following participants: J. W. M. la Rivière (Chairman), F. Bourlière, T. N. Khoshoo, K. Labitzke, T. F. Malone and T. Rosswall (Secretary). Regrets and recommendations were received from E. Seibold.

The Nominating Group was particularly pleased with the enthusiastic response from ICSU Unions, National Members and individuals to the invitation to propose candidates. Two hundred and ten nominations were received to fill the limited number of appointments to the Special Committee. The Group concluded in its letter with recommendations sent to Sir John Kendrew that "such a wealth of interested competence augurs well for the success of this ICSU activity." In addressing the difficult task of selection of only a few nominees from a large number, the Group was guided by the following considerations:

1) Noting the particularly interdisciplinary character of the new programme that the SCGB was charged to conceive, develop and steer and the charge to the SCGB by the 21st General Assembly to provide for effective liaison with ICSU bodies, the Group directed its attention to outstanding scientists not already burdened with major elected responsibilities within ICSU Unions and Committees.

2) In making its recommendations, the Group took note of invitations from the President to Members of the ICSU family to give special attention to young scientists, women and scientists in developing countries.

The Nominating Group proposed membership to the Special Committee, which was confirmed by the ICSU Executive Board in January 1987 (Appendix 3).

Appendix 2

Activities of ICSU and those carried out jointly with other international bodies related to the International Geosphere-Biosphere Programme

The following preliminary summary has been prepared by Dr. F. W. G. Baker, Executive Secretary of ICSU. It should be considered as a preliminary version and further comments to bo received from the organizations and programmes will be incorporated in a final version.

A. Lithosphere

A.1. International Lithosphere Programme (ILP)

The ILP, which was launched jointly by IUGG, IUGS and ICSU in 1980, has as its principal objective the elucidation of the nature, dynamics, origin, and evolution of the lithosphere, with special attention to the oceans and of parts of the Earth below the lithosphere are also included. The problems to be investigated are interdisciplinary and global in scope, and they require international co-operation involving the coordinated efforts of geophysicists, geodesists, geologists and geochemists. The full scientific potential of the programme can only be attained with the active participation of scientists concerned primarily with the present state of the lithosphere, particularly the continental lithosphere, and with its origin, evolution and dynamics. Special goals of the programme are: strenghtening the interaction between basic research and the applications of geological sciences to the exploration for and development of mineral and energy resources, the mitigation of geological hazards, environmental maintenance, and strengthening the earth sciences in developing countries.

A.2. Global Geosphere Transects (GGT) (part of A.1)

The GGT is an attempt to compile all existing global, geological, geochemical and geophysical information on interpretative cross sections of the Earth's crust down to the Mohole layer and deeper through crucial tectonic structures. The compilation will be carried out with standardized scale, legend and colour code, and will become available in digital format. The intention is not only to assemble the data into a single picture that attempts to show the present state of the crust but also the way in which it evolved to its present state. A preliminary revised map of transects, for which an interest was formulated by regional groups, has been prepared. It comprises transects in Africa, China, U.S.S.R., Australia, Western Europe, Near East, Antartica, South America, India and North America. Close links are being developed to the Studies in East Asian Tectonic and Resources (SEATAR) programme of transects in S.E. Asia, as well as to the programmes of the Circum Pacific Map and of the Atlantic Map. The European Geotraverse Project organized by the European Scientific Foundation (ESF) is cooperating with the GGT.

A.3. International Geological Correlation Programme (IGCP)

The IGCP is a joint enterprise of the International Union of Geological Sciences (IUGS) and Unesco, which was accepted by the 17th General Conference of Unesco and was formally established in 1973. Its aim is to arrive at a better understanding of the geology of the whole earth and, hence at a better knowledge of its mineral resources, through regional, interregional, intercontinental and global correlation of geological formations, phenomena and events. Since it was launched a wide range of scientific contributions have developed from more than sixty IGCP projects. An indication of the extent of the activities can be obtained form "Scientific Achievements 1973-1977" and "IGCP Catalogue 11 1978-82".

B. Biosphere

B.1. Decade of the Tropics

Launched by the International Union of Biological Sciences (IUBS) in 1983 the programme has two principal objectives: 1) to increase our understanding of the biology of tropical species and ecosystems, including man and man-made ecosystems; and 2) to aid in the inventory of the tropical biota, and the preservation of tropical genetic diversity.

Five major areas of tropical biology are being given special attention:

a) Tropical Diversity

The problem of tropical diversity, and the ways that exceptional species richness is maintained and the capacity for simplification of species-rich systems without detriment to their sustainability.

b) Tropical Soil Biology and fertility (TSBF)

The problem of nutrients and tropical soils, and the means by which nutrients are trapped, transferred and stored within systems, which, despite their species richness and large biomass, exist in habitats poor in nutrients. A Manual of Methods for TSBF has been published.

c) Ecosystem Studies

The structure and function of selected ecosystems, including the relation of water, temperature, carbon dioxide, and various elements in tropical terrestrial ecosystems, especially in savannas and dry forest and tropical mountain regions. Two Monographs on "Determinants of Tropical Savannas" and "Savanna Methodology" have been published. Research sites have been established for both types of ecosystem.

d) Agroecosystems

An understanding of the interactions of plants, animals, microorganisms and soils in agroecosystems to provide an increased sustained production.

e) Human Biology

An understanding of human societies as intrinsic components of tropical systems, in the context of human ecology and in collaboration with the social sciences.

The second phase of the Programme was completed in 1987. There will be two further three-year phases, after which there will be a crucial evaluation of the Programme and the results obtained.

B.2. Biogeochemical Cycles and their Interactions

This study of biogeochemical cycles was initiated in 1974 by SCOPE. The study has stimulated scientists throughout the world to cooperate in providing information on the individual cycles, but particularly carbon, nitrogen, phosphorus, sulphur and the heavy metals and their interactions.

Current projects seek to:

a) present a more global picture of element cycling and provide information on interactions and linkages of global cycles;

b) identify and address main gaps in knowledge; and

c) contribute to the understanding of the effects of global change by developing new projects related to changing biogeochemical fluxes. These projects can be defined as follows:

   1) Global Carbon and Nutrient Cycling in Lakes and Estuaries
   2) Sulphur Cycle in Aquatic Ecosystems and its Interaction with Other Biogeochemical Cycles
   3) Acidification in Tropical Countries
   4) Phosphorus Cycles in Terrestrial and Aquatic Ecosystems.

B.3. Bio-Indicators

The Bio-Indicators programme was begun in 1983 by IUBS. Workshops were held in 1986 on Biological Monitoring of the State of the Environment and on Bio-Indicators: Emphasis on Oil and Heavy Metal Pollution.

B.4. Man and the Biosphere (MAB)

The Man and the Biosphere programme was launched by Unesco at a Conference on the Biosphere in 1968 and follows many of the studies initiated during the International Biological Programme (1964-74). The programme began in 1971 and is basically concerned with the interations between Man and his Environment. A series of multinational research projects on the effect of human activities on various ecosystems, including land-use management, energy utilization and resource conservation are being carried out. Unesco cooperates with a number of organizations in the execution of the programme, including UNEP, FAO, WHO, WMO, ICSU and IUCN.

The four main themes of MAB are:

1) the search for sustained production systems in the humid and sub-humid tropics;
2) the scientific basis for the management of grazing and marginal lands;
3) providing a basis for ecosystem conservation;
4) ecological approaches for improving urban planning.

B.5. International Satellite Land Surface Climatology Project (ISLSCP)

ISLSCP was initiated in mid-1983 to generate the activities necessary to produce global data sets of the land surface characteristics needed for climate studies, such as climate modelling, climate diognostic and climate impact assessment. To implement such a project, three research areas were identified as especially urgent:

a demonstration of what measurements from satellites can usefully contribute to the assessment of climate relevant changes which occur at the surface ("retrospective satellite data evaluation");

specification of type, resolution and accuracy of information needed for studies and to improve the algorithms to derive this information from the primarily pixel-radiance measurements; and

development of methods to validate and calibrate by direct surface measurements information inferred from the satellite measurements.

It was clear from the beginning that only if the last two problems can be solved satisfactorily can the expectations be met with respect to the information content and quality of products derived from satellite measurements.

ISLSCP's further purpose is to improve the awareness of the potential of satelite measurements for the assessment of land surface characteristics in connection with climate studies, to disseminate knowledge on how to use this information and to ensure that as many groups as possible contribute to the success of the project. Especially in marginal land use areas further support becomes more and more essential.

C. Oceans, Atmosphere, Hydrology

C.1 World Climate Research Programme (WCRP)

Initiated in 1980, as a follow-up to the Global Atmospheric Research Programme (GARP), the WCRP is a joint programme of WMO and ICSU the major objectives of which are to determine: 1) to what extent climate can be predicted; and 2) the extent of man's influence on climate. The overall work to be carried out in the WCRP has been described in a Preliminary Plan, prepared in January 1981 under the guidance of the WMO/ICSU Joint Scientific Committee. The Preliminary Plan recommended that the strategy to meet the objectives of the WCRP should include: 1) the study of climatologically significant processes; 2) the development of physical-mathematical models of the climate system; and 3) the statistical analysis of observed climate variables. The Joint Scientific Comittee singled out for particular attention: 1) the controlling effect of cloudiness on the radiation energy budget of the climate system; and 2) the effect of the physics and dynamics of the ocean on the global cycles of heat, water and chemicals (especially carbon) in the climate system.

C.2. Tropical Oceans and Global Atmosphere (TOGA) (part of C.1)

The TOGA programme is being conducted within the framework of the World Climate Research Programme. Its overall objectives are:

1) to gain a description of the tropical ocean and the global atmosphere as a time dependent system, in order to determine the extent to which this system is predictable on time scales of months to years, and to understand the mechanism and processes underlying its predictability;

2) to study the feasibility of modelling the coupled ocean-atmosphere system for the purpose of predicting its variations on time scales of months to years;

3) to provide the scientific background for designing an observing and data transmission system for operational prediction if this capability is demonstrated by coupled atmosphere-ocean models.

The TOGA programme will require an internationally coordinated measurement programme to provide a consistent ten year record of the basic geophysical variables describing the variability of the coupled tropical ocean and global atmosphere system. This will constitute the basis for the range of diagnostic and phenomenological studies that are necessary to understand the variability of the coupled system and for research into the key large-scale physical processes, especially in the upper layers of the tropical oceans and at the ocean-atmosphere interface. In turn, appropriate coupled ocean-atmosphere models, adequately representing the large-scale physical processes, will be developed and their verisimilitude in simulating TOGA phenomena assessed. The data collected will also be used for determination of initial states when running the models in prediction mode and for verification of forecast states.

TOGA will include investiagtions to determine the nature of long-period fluctuations of the monsoon and their relationship to the planetary scale circulation, and to grasp the mechanisms and extent of the tropical ocean's role in determining the interannual variability of monsoons and the predictability of their variations.

C.3 World Ocean Circulation Experiment (WOCE) (part of C.1)

The basic objectives of the Experiment, which forms part of stream three of the World Climate Research Programme, are to develop models for predicting climate change and to collect the data necessary to test them; to determine whether specific WOCE data sets are representative of the long-term behaviour of the ocean and to find methods for determining long-term behaviour of the ocean and to find methods for determining long-term changes in the ocean.

In order to develop a practical experimental design for WOCE, three Core Projects have been identified that will require special attention because of the need to overcome logistical difficulties, to obtain special resources and to coordinate the activities of many groups.

1) The Global Perspective. The aim of testing global circulation models will not be achieved unless the WOCE data set is truly global in extent. Satellites provide the systematic global coverage, for the first time. In situ measurements will be designed to fill gaps in the existing coverage and to increase the sampling density in areas of special importance for the understanding of the global circulation.

2) Inter-ocean Fluxes. The global balances of heat and water depends on large-scale fluxes within and between the oceans. Special attention will be paid in this Core Project to the linkage between the Pacific and Indian Oceans affected by the Antartic Circumpolar Current.

3) Gyre Dynamics. The third Core Project is concerned with testing and understanding the dynamical balance of the ocen within a basin. The aim will be to test, using information from the North Atlantic Ocean, current ideas concerning the effects of transient eddies, diabatic processes in and below the seasonal boundary layer, exchange with peripheral basins, etc., and to test their representation in computer models of large scale circulation.

The resources required for WOCE are of two categories: those that already exist in oceanographic institutions which can in principle be obtained through the normal funding mechanisms available to principal investigators; and resources that are not now available and which cannot be obtained by the normal mechanisms. Resources of the second category will be included as specific highlighted items in the WCRP Implementation Plan. They include satellites, a dedicated research ship, floats and drifters, expanding instruments, Voluntary Observing Ships, meteorology and current profilers, data management, a sea level network, and vastly improved computers for modelling.

The WOCE timetable calls for an intensive observation period starting with the launch of the new generation of ocean-observing satellites (TOPEX-POSEIDON, ERS-1, NROSS) in about 1990 and continuing for five years. In situ measurements that have to be made while the satellites are operating will be concentrated into that intensive observation period.

C.4 International Hydrological Programme (IHP)

The IHP began in 1964 as the International Hydrology Decade to try to ensure that the nations of the world can obtain more practical benefits that can be derived from a scientific approach to water problems. At the end of the decade the studies that continued or were initiated became the IHP. The present programme initiates and coordinates research that will contribute to a better knowledge of the hydrological system and serve as a basis for the exploitation and better management of water resources.

C.5 Global Energy and Water Cycle Experiment (GEWEX) (part of C.1)

The Joint Scientific Comittee for the WCRP agreed to begin the planning phase of GEWEX at its meeting in March 1988. The aims of the experiment are:

1) to determine the hydrological cycle and energy fluxes by means of global measurements of observable atmospheric and surface properties;

2) to model the global hydrological cycle and its impact in the atmosphere and the ocean;

3) to develop the ability to predict the variations of global and regional hydrological processes and water resources, and their response to environmental change;

4) to foster the development of observing techniques, data management and assimilation systems suitable for operational application to long-range weather forecasts, hydrology and climate predictions.

It is planned that the framework for GEWEX studies shall be provided by comprehensive models of the global atmospheric flow, upper ocean and land-surface processes. GEWEX will include a strong numerical model development programme, aiming to expand the range of interactive physical and chemical processes taken into account in atmospheric climate simulations, especially regarding exchanges through the air-sea and atmosphere-land interfaces.

Furthermore, climate models or suitably modified numerical weather prediction models must play a central role in the analysis of GEWEX data. The GEWEX programme will require the determination of subtle quantities, such as surface fluxes of heat and moisture, which cannot be measured directly and can only be inferred from measurable atmospheric and land (or ocean) variables, by means of a model.

C.6 Joint Global Ocean Flux Study (JGOFS)

The main goal of JGOFS will be to determine and understand on a global scale the processes controlling the time-varying fluxes of carbon and associates biogenic elements in the ocean, and to evaluate the related exchange with the atmosphere, sea floor, and continental boundaries. A long-term aim of JGOFS will be to establish strategies for observing, on long time scales, changes in ocean biogeochemical cycles in relation to climate change.

The JGOFS programme will have four major elements: global studies, process studies, coastal ocean studies, and modelling. Planning for JGOFS has begun under the auspices of a Scientific Planning Committee established by SCOR. It is expected that initial elements of the programme could be implemented in 1990; and that the programme would interact closely with such related programmes as the World Ocean Circulation Experiment (WOCE), the Tropical Ocean and Global Atmosphere programme (TOGA) and the International Global Atmospheric Chemistry Programme (IGAC). During this planning phase there will be close interaction with the planning efforts of ICSU's Special Committee for the development of the International Geosphere-Biosphere Programme (IGBP) and with the SCOR/IOC Joint Committee on Climatic Changes and the Ocean (CCCO), particularly in regard to plans for WOCE, and with SCOPE in relation to the programme on the Carbon Cycle.

C.7 International Satellite Cloud Climatology Project (ISCCP)

ISCCP began its operational data collecting phase in July 1983. The objectives of ISCCP are to compile a global climatology of cloud cover, cloud top heights or pressures and cloud optical thicknesses.

C.8 International Global Atmospheric Chemistry Programme (IGAC)

The focus of the programme will be to improve our understanding of the atmospheric component of biogeochemical cycles with particular emphasis on chemical and physical processes in the troposphere and material exchange between the troposphere and the earth's surface. The programme organizers strongly urge increased international research efforts devoted to global changes in the ozone layer, the acidification of precipitation, possible climate modification as a result of increasing concentrations of radiatively active trace gases, and concern that important components of the global trospheric nitrogen and sulphur cycles are being altered.

C.9 *Intergrated Management of Coastal Systems* (COMAR)

The initial programme for a study of coastal systems, including coral reefs, mangroves, coastal lagoons, coastal erosion, offshore productivity, etc., was put forward in 1979 by SCOR, IABO and the Unesco Division of Marine Sciences, and was developed in the early 1980s. The programme is mainly concerned with differences in the energetics of coastal and offshore ecosystems and with significant energy and material fluxes between such systems, including the exchange of organic material and plant nutrients.

D. SOLAR-TERRESTRIAL

D.1 Middle Atmosphere Programme (MAP)

The Middle Atmosphere Programme proper ended in December 1985 but it is anticipated that the publications programme will continue beyond the end of MAP through to the end of the Middle Atmosphere Cooperation (MAC) in December 1988. Beyond that time, it is anticipated that the MAP effort may become a part of a new broadly based programme on solar-system energetics (such as STEP) from 1990 onwards.

One additional activity has been proposed for MAP, namely, cooperation with COSPAR in the preparation of a Reference Middle Atmosphere. This is now under consideration by COSPAR.

D.2 Polar and Auroral Dynamics (PAD)

PAD, which was launched by SCOSTEP in 1985, is a study of polar and auroral upper atmospheric and ionospheric dynamics, energy transfer to and dissipation in the upper atmosphere and ionosphere, turbulence in the ionosphere and upper atmosphere and characteristics of the low attitude, high latitude acceleration region.

D.3 Solar-Terrestrial Energy Programme (STEP)

STEP will be dedicated to the investigation of energy production, transfer, storage, and dissipation through the solar-terrestrial environment. It will involve ground-based, aircraft, balloon and rocket experiments; theory, modelling and simulation studies; and dedicated data and information systems. STEP will be built around a core of solar-terrestrial science missions approved by the Inter-Agency Consultative Groups as the next cooperative project of NASA, ESA, ISAS and INTERCOSMOS, and it will also take into account other relevant satellite missions.

D.4 World Ionosphere/Thermosphere Study (WITS)

This study will concentrate on global investigations of ionosphere and thermosphere energetic, dynamics, aeronomy and coupling between the different regions.

D.5 Solar Interplanetary Variability (SIV)

This programme will study the variability of the various processes in the sun and interplanetary medium.

E. MONITORING AND DATA

E.1 Global Environmental Monitoring System (GEMS)

A study on Global Environmental Monitoring carried out by SCOPE was submitted to the U.N. Conference on the Human Environment in Stockholm in 1972. This Conference established Earthwatch of which GEMS is one of the four components; the others are evaluation, research and the exchange of information. UNEP established a Programme Activity Centre for GEMS, which coordinates international monitoring activities of the United Nations and consisting of networks of the nationally operated monitoring systems. GEMS monitoring activities fall into five closely linked categories: health-related monitoring, climate-related monitoring, renewable resources monitoring, ocean monitoring and international disaster monitoring. The GEMS Centre is not operational. GEMS includes the Global Resource Information Database (GRID) located in Geneva which coordinates within a common geographic reference system the numerous environmental data sets that have been collected and continue to be collected by GEMS, other UNEP programmes and U.N. Specialized Agencies, etc., and to provide a capability to assess and analyse the data for environmental and resource assessments. Data are made available in georeferenced form to the global, regional and national environmental resarch communities and to responsible resource management officials.

E.2 World Digitized Database for Environmental Sciences (WDDES)

The feasibility of developing a standard global data set, in modern topologically structured form has been examined by a joint Working Group of the International Geographical Union (IGU) and the International Cartographic Association (ICA). It has been agreed that the scale should be 1:1 million (c. 1 km resolution) where this is possible (smaller scales seem inadequate in resolution). The following elements of the physical geography of the world will be portrayed: coastlines, drainage networks, land relief (contours at c. 300 m interval, spot heights), bathymetry (contours at 1000m interval, depth values), statistical (e.g., provincial) boundaries, built-up areas, and place names of the above. The estimated size of such a database is about 1 gigabyte.

The objective is to produce tapes (and discs) rather than printed maps; and the purpose is to enable correlation analysis and modelling of new and existing data sets for the environmental sciences.

E.3 World Soils and Terrain Digital Data Base (SOTER)

SOTER was launched by the 13th Congress of the International Society of Soil Sciences (ISSS) in 1986 in order to utilize emerging information technology to produce an operational world soils and terrain digital georeferenced and attribute data base at a general scale of 1:1 million, with the capability for larger scale where required. This will be accessible to a broad array of international, regional and national decision-makers and policy-makers responsible for the development, management and conservation of environmental resources, and transferable to developing countries for national data base development in greater detail. The preparation of SOTER will take more than a decade and will include the preparation of a universal legend that can accommodate current soil mapping and classification systems, and of the minimum data set for each soil that must be entered.

E.4 Multi-Satellite Thematic Mapping Project

This project was initiates by CODATA in 1982 to establish a methodology for producing multisatellite thematic maps. The Task Group chose two areas of Tanzania for a pilot project. It used data from the LANDSAT, METEOSAT, NOAA and TIROS N satellites. The initial project focussed on gepmorphological mapping of the test areas, ground-truth work, and the development of multisatellite evaluation techniques, as well as training of African counterparts in the field and in the laboratories.

The second phase of the project has been carried out in the Kibaran Belt within the scope of the Geological Applications of Remote Sensing (GARS) (IUGS-Unesco Programme). The GARS Reaserch Team has proposed more detailed remote sensing studies at larger scales using LANDSAT Thematic Mapper (TM) and SPOT data. The expected results will contribute to an improved interpretation of the geology of the Kibaran Belt in terms of structure, lithology and mineralization.

A third phase in China is mainly concerned with: 1) an inventory of the Chinese mapping projects using satellites in the Northern Provinces of China; and 2) a test of LANDSAT MSS and TM, and SPOT XS applied to Hebei and Shaanxi Provinces.

E.5 World Data Centres (WDC)

The World Data Centre concept developed just prior to the initiation of the International Geophysical Year. There are usually two and often three centres for each data set: WDC A in the U.S.A., WDC B in the U.S.S.R. and WDC C in other countries, such as Japan, Switzerland and the U.K.

The ICSU WDC Panel is in the process of preparing a revised guide to the WDCs. This will take into account recent developments in the handling of data since most countries now have computer facilities and use electronic networks to meet requests, to exchange information and transfer small data sets. Studies are going on at present with regards to the possibilities of making large data sets available on CD-ROM.

E.6 Federation of Astronomical and Geophysical Services (FAGS)

The federation was formed by ICSU in 1956 and includes, at present, 10 Permanent Services, each of which operates under the authority of one or more of the interested Unions: IAU, IUGG and URSI. The tasks of these services are: to collect, as a continuous activity, observations, information and data relating to astronomy, geodesy, geophysics and related sciences; to analyse, synthesize and draw conclusions from them; to distribute data on request; and to publish the results obtained.

E.7 Monitoring the Sun Earth Environment (MONSEE)

MONSEE is a continuing activity of SCOSTEP. It is concerned with the problems of collecting, safekeeping, cataloguing and distributing nearly 100 types of data obtained on regular schedules at more than 400 stations, and of data sets from special sources. This large body of organized data, managed by the ICSU WDC system, constitutes invaluable background or correlative material for all SCOSTEP programmes, for whose specialized data management problems the MONSEE Committee also renders assistance. The Committee is increasingly directing its attention to improve the efficiency of data-handling methods through the increased use of computer-compatible techniques, and encourages data centres to produce data digests (indices, charts) that are more useful to the non-specialist than the raw data.

E.8 World Climate Data Programme (WCDP)

The World Climate Data Programme is a component of the World Climate Programme organized under the auspices of WHO. The plan emphasizes did to individual countries to upgrade the capabilities in climate data management to rescue, digitize, quality control, store, retrieve, and use climate data. The elements constituting climate data from the atmosphere-ocean-cryosphere-solid Earth climate system are upper air, surface climate, ocean surface and sub-surface, cryosphere, radiation budget, atmospheric composition, hydrosphere, land and vegetation, proxy, and sloar data.

Appendix 3

List of Members of the SC-IGBP

Prof. James J. McCarthy, Museum of Comparative Zoology, Harvard University, Cambridge, MA 02138, USA. Tel. (+1-617) 495 23 30. Telefax (+1-617) 495 05 06. Telex (23) 7402058 MCZL UR. Telemail OMNET; J.McCarthy.

Prof. Thomas Rosswall, IGBP Secretariat, Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden. Tel. (+46-8) 15 04 30, dir. 16 64 48. Telefax (+46-8) 16 64 05. Telex 17509 IGBP S. Telemail OMNET; t.rosswall.

Prof. Paul J. Crutzen, Max-Planck-Institute for Chemistry, P.O. Box 3060, D-6500 Mainz, Federal Republic of Germany. Tel. (+49-6131) 30 54 58/9. Telefax (+49-6131) 30 53 88. Telex (41) 4187674 MPCH D.

Prof. William S. Fyfe, Dean of Science, University of Western Ontario, London, Ontario N6A 5B7, Canada. Tel. (+1-519) 661 30 41. Telefax (+1-519) 661 32 92. Telex (21) 0647134 UWO LIB LDN.

Prof. Rafael Herrera, Centre for Ecology and Environmental Sciences, IVIC, Apartado 21827, Caracas 1020A, Venezuela. Tel. (+58-1) 69 19 49, 681 11 88 ext 280; home (+58-2) 961 10 02.
Telex (31) 21657 el. 21338 IVICB VC.

Prof. Vladimir M. Kotlyakov, Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109017, USSR. Tel. 238 86 10. Telex (64) 411478 SGC SU.

Prof. Bert Bolin, Meteorologiska institutionen, Stockholms universitet, S-106 91 Stockholm, Sweden. Tel. (+46-8) 15 77 31 el. vx 16 20 00 ankn 2401; sekr Marianne Lundström ankn 2400. Telefax (+46-8) 15 71 85. Telex 15959 MISU S. Telemail OMNET; MISU.IMI.

Dr. Marie-Lise Chanin, Service d'Aeronomie du CNRS, B.P. 3, F-91371 Verriers le Buisson Cedex, France. Tel. (+33-1) 69 20 07 94 el. 64 47 42 45 ext 275. Telefax (+33-1) 69 20 29 99. Telex (42) 692400 AERONO F.

Prof. El Hadji Salif Diop, Department of Geography, University of Dakar, Dakar, Senegal. Tel. (+221) 21 63 70 el. 22 50 73 ext 136. Telex (906) 262 UNIV DAK SG.

Prof. Siegfried Dyck, Division of Hydrology and Meteorology, Dresden Technical University, Mommsenstrasse 13, 8027 Dresden, German Democratic Republic. Tel. (+37-51) 463 39 31. Telex (69) 2278MZ TEUNI DD.

Dr. John A. Eddy, Office for Interdisciplinary Earth Studies, UCAR, P.O. Box 3000, Boulder, CO 80307, USA. Tel. (+1-303) 497 16 80. Telefax (+1-303) 497 11 37. Telex (230) 989764 NCAR BDR UD. Telemail OMNET; J.Eddy.

Prof. Takahisa Nemoto, Ocean Research Institute, University of Tokyo, 1-15-1 Minamidai, Nakano-ku, Tokyo 164, Japan. Tel. (+81-3) 376 12 51. Telefax (+81-3) 377 33 95. Telex (72) 25607 ORIUT J. Telemail OMNET; ORI.Tokyo.

Prof. Hans Oeschger, Institute of Physics, University of Berne, Sidlerstrasse 5, CH-3012 Bern, Switzerland. Tel. (+41-31) 65 81 11. Telefax (+41-31) 65 44 05. Telex (45) 912643 PIBE CH.

Dr. S. Ichtiaque Rasool, Office of Space Science and Applications, Code E, NASA, Washington, DC 20546, USA. Tel. (+1-202) 453 10 00. Telefax (+1-202) 755 92 34. Telex (23) 4979843 NASA WSH. Telemail OMNET; IRASOOL.

Prof. Jai S. Singh, Department of Botany, Banaras Hindu University, Varanasi 221 005, India. Tel (+91-542) 54291 ext 352. Telex (81) 545208 TECH IN.

Prof. Valeria A. Troitskaya, Institute of Physics of the Earth, USSR Academy of Sciences, Bolshaya Gruzinskaya 20, Moscow 123242, USSR. Telex (64) 411478 SGC SU.

Dr. Brian H. Walker, Division of Wildlife and Ecology, CSIRO, P.O. Box 84, Lyneham, ACT 2602, Australia. Tel. (+61-62) 42 16 00. Telefax (+61-62) 41 33 43. Telex (71) 62284 WLR AA.

Dr. John D. Woods, Natural Environment Research Council, Marine Sciences, Polaris House, North Star Avenue, Swindon, Wiltshire SN3 3EH, UK. Tel. (+44-793) 401 01 ext 420. Telefax (+44-793) 51 11 17. Telex (51) 444293 ENVRE G. Telemail OMNET; J.Woods/Science.

Prof. Duzheng Ye, Academia Sinica, Beijing, People's Republic China. Tel. (+86-1) 86 83 61-843. Telex (850) 22474 ASCHI CN.

Appendix 4.

List of IGBP Meetings and their Participants

Meetings:

SC-IGBP meetings:	Paris 16-19 July, 1987 Cambridge, MA 8-11 February, 1988
EC-IGBP meetings:	Cambridge, MA 4-5 December, 1987 Budapest, 4-5 June, 1988

CP meetings:

CP 1	Snowmass 13-14, 20-21 August, 1988
CP 3	Cambridge 12 February, 1988
CP 3	Potsdam 7-9 June, 1988
CP 4	Canberra 29 February - 2 March, 1988

WG meetings:

WG 2	Moscow 9-13 August, 1988
WG 3	Berne 6-8 July, 1988
WG 4	Caracas 2-4 May, 1988

Participants at CP and WG meetings

ABID, G.	WDC-A for R&S, Code 692, NASA CSFC, Greenbelt, MD 20771, USA	WG 2
ABSTON, C.C.	NOAA/NCDC, E/Gc, 325 Broadway, Boulder, CO 80303 USA	WG 2
ACEVEDO, M.	Escuela de Ingenieria de Sistemas, Universidad de los Andes, Apactado 72 Mérida 5101-A, VENEZUELA	WG 4
AGARDY, T.	Woods Hole Oceanographic Institite, Woods Hole, MA 02543, USA	WG 4

ALLAN, T.D.	Space Department R.16 Bldg, Royal Aircraft Establishment, Farnborough, Hampshire GU14 6TD, UK	WG 2
ALLEN, J.H.	WDC-A for STP / NOAA, E/GC2, Boulder, CO 80303, USA	WG 2
ANDREAE, M. O.	Biogeochemistry Department, Max-Planck Institute for Chemistry, Postfach 3060, D-6500 Mainz, FEDERAL REPUBLIC OF GERMANY	CP1
ANNENKOV, V.V	Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109117, USSR	WG 2
ARNOLD, R.J.	NASA Headquarters, Code EC, Washington, DC 20546, USA	WG 2
ARSHINOV, B.M.	Institute of Hydrometeorology Koroleva ul. 6, Obninsk 249020, USSR	WG 2
AUSTIN, M.	Division of Wildlife and Ecology, Ecology, CSIRO P O Box 84 Lyneham, ACT 2602, AUSTRALIA	CP 4
BADENKOV, Y. P.	Institute of Geography, USSR Academy Sciences, Staronomonetny 29, Moscow 109017, USSR	WG 4
BAKER, F.W.G.	ICSU Secretariat, 51 Boulevard de Montmorency, F-75016 Paris, FRANCE	WG 4
BARRY, R.	World Data Center-A, CIRES, University of Colorado, Campus Box 449, Boulder, CO 80309, USA	WG 2
BASSA, G.	Cartographia II, A'fonya u.l, H-1025 Budapest, HUNGARY	WG 2

BASSO, E.	Technical Co-operation Department, WHO, Case Postale No. 5, CH-1211 Geneva 20, SWITZERLAND	WG 4
BECKER, F.	Universite Louis Pasteur, 7 Rue de l'Universite, F-6700 Strasbourg, FRANCE	WG 2
BELCHANSKY, G.I.	Institute of Evolutionary Morphology and Ecology of Animals, USSR Academy of Science, Leninsky prospect 33, Moscow 117071, USSR	WG 2
BELOUSSOV, V.V.	Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117292, USSR	WG 2
BLANAR, F.	Institute of Atmospheric Physics, Acadademy of Sciences, Bocni 11, 140 00 Praha 4 CZECHOSLOVAKIA	WG 2
BOICHENKO, V.A.	Institute of Problems of Management, Profsojuznaja 65,Moscow, USSR	WG 2
BOLDIREV, V.	World Meterological Organization, Case postale no. 5, CH-1211 Geneva 20, SWITZERLAND	WG 2
BOLIN, B.	Department of Meteorology Arrhenius Laboratory University of Stockholm S-106 91 Stockholm SWEDEN	CP 1
BOLLE, H-J	Freie Universität Berlin, Institut für Meteorologie, Dietrich-Schäfer-Weg 6-8, D-1000 Berlin 41 FEDERAL REPUBLIC OF GERMANY	CP 3 (P) WG 2
BOWMAN, G.	Division of Soils, CSIRO, Private Bag No. 2 Glen Osmond, AUSTRALIA	CP 4

BRETHERTON, F.P.	Space Science and Engineering, University of Wisconsin, 1225 West Dayton, Rm 1007, Madison, WI 53706, USA	CP 4 WG 2
BROECKER, W.S	Lamont-Doherty Geological Observatory and Department of Geological Sciences, Columbia University, Palisades, NY 10964, USA	WG 3
CARVALHO, J.C.M	Museau Nacional, Quinta Boa Vista, Rio de Janeiro, RJ 20940 BRAZIL	WG 4
CAUGHLEY, Graeme	Division of Wildlife and Ecology, CSIRO, P O Box 84, Lyneham, ACT 2602, AUSTRALIA	CP 4
CELECIA, John F.	Division of Ecology, UNESCO, 7 Place de Fontenoy, F-75700 Paris, FRANCE	WG 4
CHANIN, M.L.	Service d'Aeronomie de CNRS, B.P 3, F-913171 Verrieres le Buisson Cedex, FRANCE	WG 2
CHINNERY, M.A.	NOAA/NGDC, E/GC, 325 Broadway, Boulder, CO 80303, USA	WG 2
CHORBADZE, N.B.	Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR	WG 2
CHUCHKALOV, V.S.	Department of World Weather Analysis, Moscow, USSR	WG 2
CHUIKOVA, R.N.	Publishing House "Znaniye", proezd Serova 4, Moscow 101835, USSR	WG 2

CIHIAR, J.	Application Development Division, Canada Centre for Remote Sensing, 2464 Scheffield Road, Ottawa, Ontario, CANADA K1A OY7	WG 2
CREASE, J.	Marine Physics Group, Institute of Oceanographic Sciences, Brook Road, Wormley, Godalming, Surrey GU8 5UB, UK	WG 2
de CUNHA, R.P.	Brazilian Institute of Space Research, P.O. Box 515, Sao Jose Dos Campos, S.P. 12200, BRAZIL	WG 2
DICKINSON, R	National Centre for Atmospheric Research, P O Box 3000, Boulder, CO 80307, USA	CP 3 (C,P) CP 4
DORMAN, L.I.	IZMIRAN, Troitsk, Moscow Region 142092, USSR	WG 2
DROZDOV, A.V.	Institute of Geography USSR Academy of Sciences, Staromonetny per. 29. Moscow 109017, USSR	WG 2
DYCK, S	Division of Hydrology and Meteorology, Dresden Technical University, Mommsenstrasse 13, DDR-8027 Dresden, GERMAN DEMOCRATIC REPUBLIC	CP 3 (B,P) WG 2
DYER, M.I.	Division of Ecology Unesco, 7, place de Fontenoy, F-75700 Paris, FRANCE	WG 4
DZIEWONSKI, A.	Department of Earth and Planetary Sciences Harvard University, Cambridge, MA 02138, USA	WG 4
EDDY, J.A.	UCAR/Office for Inter- disciplinary Earth Studies, Boulder, CO 80307, USA	WG 3 CP 1

EFREMOV, S.A.	Institute of Oceanography, USSR Academy of Sciences, Moscow, USSR	WG 2
EGOROV, V.I.	Laboratory of Monitoring the Environment and Climate, Moscow, USSR	WG 2
ELMAN, R.I.	All-Union Association "Lesproekt", Moscow, USSR	WG 2
ELUTIN, A.V.	Institute of the Earth Physics, B. Gruzinskaya 10, Moscow 123810, USSR	WG 2
EROSHENKO, E.A.	IZIRAN, Troitsk, Moscow region 142092 USSR	WG 2
FARQUHAR, G.	Research School of Biological Sciences, Australian National University, P O Box 4, Canberra, ACT 2601, AUSTRALIA	CP 1
FICHEFET, T.	Institut d'Astronomie et de Géophysique, Université Catholoque de Louvain, 2 Chemin de Cyclotron, B-1348 Louvain-la-Neuve, BELGIUM	WG 3
FONSECA, F.	Evironement Department, Cia Vale do Rio Doce, Av. Presidente Wilson 231-21°, Rio de Janeiro, BRAZIL	WG 4
FUNG, I.	NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025 USA	CP 1
FYFE, W.S.	Dean, Facaulty of Science, University of Western Ontario, London, Ontario, CANADA NGA 5B7	WG 2 WG 4
GAIDUKOV, V.Yu.	Institute of Applied Geophysics, Glebovskaya 20b, Moscow, USSR	WG 2
GIFFORD, R.	Division of Plant Industry, CSIRO, G.P.O. Box 1600, Canberra, ACT 2601, AUSTRALIA	CP 4
GILLE, J.C.	NCAR, P.O. Box 3000, Boulder, CO 80307, USA	WG 2
GIULL, M.	Division of Plant Industry, CSIRO, GPO Box 1600, Canberra, ACT 2601, AUSTRALIA	CP 4
GLADWELL, J.	Division of Water Sciences, Unesco, 7, Place de Fontenoy, F-75700 Paris FRANCE	CP 3 (P)
GOLDSTEIN, G.	Laboratory of Biomedical and Environmental Sciences, University of California Los Angeles, CA 90024, USA	CP 3
GOLITSYN, G.S.	Institute of Atmospheric Physics, USSR Academy of Sciences, Moscow, USSR	WG 2
GOLOVKOV, V.P	IZMIRAN, Troitsk, Moscow Region 142092, USSR	WG 2
GORCHAKOV, E.V.	Research Institute of Nucclear Physics, Moscow University, Moscow 119899, USSR	WG 2
GREEN, J.L.	National Space Science Data Centre, NASA/GSFC, Code 630, Greenbelt, MD 20771, USA	WG 2
GREEN, A.W. JR.	US Geological Survey, Mail Stop 946 DFC,	WG 2

	Denver, CO 80225, USA	
GRUZA, G.V.	Hydrometeocenter, Moscow, USSR	WG 2
GULJAEVA, T.L.	IZMIRAN, Troitsk, Moscow Region 142092, USSR	WG 2
GVISHIANI, A.D.	Institute of the Earth Physics, B. Gruzinskaya 10, Moscow 123810, USSR	WG 2
GWYNNE, A.W.	UNEP/GEMS, PO Box 30552, Nairobi, KENYA	WG 2
HADEEN, K.	NOAA/NCDC, Federal Building, Asheville, NC 28801, USA	WG 2
HALEM, M	Goddard Space Flight Center, NASA Code 630, Greenbelt Road, Greenbelt, MD 20771, USA	WG 2
HALL, F.G.	Goodard Space Flight Center, Greenbelt Road, Greenbelt, MD 20771, USA	WG 4
HART, P.J.	WDC-A Coordination Office, 2101 Constitution Ave, NW, Washington, DC 20418, USA	WG 2
HERRERA, R.	Centro de Ecologia y Ciencias Ambientales, IVIC. Apartado 21827, Caracas 1020A, VENEZUELA	WG 2 WG 4
HSU, K.J.	Geologisches Institut der ETH Zürich, Sonneggstrasse 5, CH-8092 Zürich, SWITZERLAND	WG 3
HU, Z.H.	International Cooperative Bureau, Chinese Academy of Science,	WG 2

	52 San Lihe Rd, Beijing, CHINA	
HUGHES. M.K.	Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ 85721, USA	WG 3
IVANOV, M.V.	Institute of Microbiology USSR Academy of Sciences, propojurnaja 7a, Moscow 117811, USSR	WG 2
JENNE, R.	NCAR, P.O. Box 3000, Boulder, CO 80307, USA	WG 2
JIAN, H.Y	Bureau of Resources and Environment, Chinese Academy of Sciences, 52 San Lihe Road, Beijing, CHINA	WG 2
KAMEI, T.	WDC-C2 for Geomagnetism, Data Analysis Centre for Geomagnetism and Space Magnetism, Hyoto University, Kyoto 606, JAPAN	WG 2
KARASEV, A.B.	Hydrometeocenter, ul. Bolshevistskaya 9-13, Moscow 123376, USSR	WG 2
KAZANTSEV, N.N.	Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109017, USSR	WG 2
KELTS, K.	EAWAG, Überlandstrasse 133, CH-8600 Dübendorf, SWITZERLAND	WG 3
KHARIN, E.P.	Soviet Geophysical Committee, WDC B2, Molodezhnaya 3, Moscow 117296, USSR	WG 2
KIRILLIN, G.B.	Institute of Space Researche,	WG 2

	Profsojuznaya 84/32, Moscow, USSR	
KONDRATJEV, K.Yu.	Institute of Lake Research, USSR Academy of Sciences, ul. Sevasnanova 9, Leningrad 196199, USSR	WG 2
KOROPALOV, V.M.	Institute of Applied, Geophysics, USSR Academy of Sciences, Moscow 107258, USSR	WG 2
KOROTKOV, V.E.	All-Union Institute of Hydrometeoinformation, Obninsk 249020, USSR	WG 2
KOSHKAREV, A.V.	Institute of Geography, USSR Academy of Sciences, Staromonetny per 29, Moscow 109017, USSR	WG 2
KOTLYAKOV, V.M	Institute of Geography, USSR Academy of Sciences, Staronometry per 2a, Moscow 109017, USSR	CP 3 (B)
KOZODEROV, V.V	Department of Computer, Gorky Street 11, Moscow 103009, USSR	WG 2
LAL, D.	Scripps Institute of Oceanography University of California, San Diego, CA 92093, USA	WG 3
LI, W.H	MAB Programme Chinese Academy of Sciences, 52 San Lihe Road, Beijing, CHINA	WG 2
LIU, T	Institute of Geology Academia Sinica, P.O.Box 634, Beijing 100011 CHINA	WG 3

LOIKO, P.F.	Institute of Land Resources Moscow, USSR	WG 2
LORIUS, C.	Laboratoire de Glaciologie et Géophysique de l'Environment, B.P. 96, F-38402 St. Martin-d'Héres Cedex, FRANCE	WG 3
MALAKOVA, R.Yu.	VINITI, Baltijskaya 14, Moscow 125219, USSR	WG 2
MANDYCH, A.F.	Institute of Geography, USSR Academy of Sciences, Staromonetny 29, Moscow 109017, USSR	CP 4
MATSUMOTO, E.	Water Research Institute, Nagoya University, Nagoya 464-01, JAPAN	WG 3
McCARTHY, J.J	Museum of Comparative Zoology, Harvard University, Cambridge, MA 02138, USA	CP 3 (B) CP 1
MEDINA, E.	Centro de Ecologia y Ciencias Ambientales, IVIC, Apartado 21827, Caracas 1020A, VENEZUELA	WG 4
MESSERLI, B.	Institute of Geography, University of Berne, CH-3012 Berne SWITZERLAND	WG 3
MIKHAILOVSKY, G.E.	Institute of Oceanology, ul. Krasikova 23, Moscow 117218, USSR	WG 2
MOLION, L.C.	Instituto de Pesquisas Espaciaias, Caixa Postal 515, 12201 Sao Jose dos Campos, S.P. BRAZIL	WG 3 WG 4
MOONEYHAN, W.	GRID-Geneva, 6 Rue de la Gabelle, CH-1227 Carouge Geneva, SWITZERLAND	WG 2

MOREL, A.	Laboratorie de Physique et Chimie Marines Universite Pierre et Marie Curie, B.P. 8, F-06230 Villefranche-sur-Mer, FRANCE	WG 2
MOSTINSKY, A.Z.	Institute of the Earths Physics, B. Gruzinskaya 10, Moscow 123810, USSR	WG 2
MURPHY, R.E.	NASA Headquarters, Code EEL, Washington, DC 20546, USA	WG 2
MUSIN, M.M.	First Moscow Medical Institute, B. Pirogovskaya 2/6, Moscow 119435, USSR	WG 2
NABOROV, I.V.	First Moscow Medical Institute, B. Pirogovskaya 2/6, Moscow 119435, USSR	WG 2
NECHITAILENKO, V.A.	Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR	WG 2
NEWSOME, A.	Division of Wildlife and Ecology CSIRO, P.O. Box 84 Lyneham, ACT 2602, AUSTRALIA	CP 4
NISBET, E.G.	Department of Geology, University of Saskatchewan, Saskatoon S7N OWO, CANADA	WG 4
NIX, H.	Centre for Research and Environmental Studies Australian National University, P.O. Box 4, Canberra, ACT 2601, AUSTRALIA	CP 4
NJOKU, E.	NASA Headquarters, Code EEC, Washington, DC 20546, USA	CP 4
NOBLE, I.	Research School of Biological Sciences Australian National University,	CP 4

	P.O.Box 4, Canberra, ACT 2601, AUSTRALIA	
OBRIDKO, V.N.	IZMIRAN, Tsoitsk, Moscow Region 142092, USSR	WG 2
OCTAVIO, K.H.	Intevep S.A., Filial de Petróleos de Venezuela S.A., Apartado 76343, Caracas 1070A, VENEZUELA	WG 4
OESCHGER, H.	Physics Institute, University of Berne, Siedlersstrasse 5, CH-3012 Berne, SWITZERLAND	WG 3
OJIMA, D.S.	IGBP Secretariat, Royal Swedish Academy of Sciences Box 50005, S-10405 Stockholm, SWEDEN	CP 3 (B.P) WG 4 CP 1
OSMOND, B.	Botany Department, Duke University, Durham, NC 27706, USA	CP 4
PALTRIDGE, G.	Division of Atmospheric Research CSIRO Private Bag No. 1, Mordialloc, VIC 3195, AUSTRALIA	CP 4
PANNIER, F.	Academia de Ciencias Fisicas Mathematicas y Naturales Apartado 1421, Caracas 1010A, VENEZUELA	WG 4
PAPITASHVILI, N.E.	Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR	WG 2
PAPITASHVILI, V.O.	IZMIRAN, Troitsk, Moscow Region 142092, USSR	WG 2
POSSON, D.	U.S. Geological Survey, 801 National Center, Reston, VA 22092, USA	WG 2

POVSNER, A.D.	Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR	WG 2
PUGACHEVA, G.I.	Institute of Nuclear Physics, Moscow State University, Moscow 119899, USSR	WG 2
PUGH, D.T.	Institute of Oceanographic Sciences, Bidston Observatory, Birkenhead, Merseyside, L43 7R4, UNITED KINGDOM	WG 2
PUZACHENKO, YU.G.	Institute of Evolutionary Morphology and Ecology of Animals USSR Academy of Sciences, Leninsky prosp. 33, Moscow 117312, USSR	WG 2
RAPOPORT, S.I.	All-Union Cardiocentre, ul. Cherepkova 5, Moscow, USSR	WG 2
RAVINA, N.B.	VNIGMI-WDC B1, ul. Lenina 102-27, Obninsk 249020, USSR	WG 2
RASOOL, S.I.	NASA Office of Space Science and Applications, Code E, Washington, DC 20546, USA	CP 3 (C) WG 2
REITENBAKH, R.G	All-Union Research Institute of Hydrometeorological Info., WDC-B1, Obninsk 249020, USSR	WG 2
RHIND, D.H.	Department of Geography, Birkbeck College, 7-15 Gresse Street, London WIP 1PA, UK	WG 2
RISSER, P.G.	University of New Mexico, Albuquerque, N M 87131, USA	WG 4

RODKIN, M.V.	Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR	WG 2
ROEDERER, J.G.	Geophysical Institute, University of Alaska, Fairbanks, AK 99775-0800, USA	WG 2
ROSSWALL, T.	IGBP Secretariat, Royal Swedish Academy of Sciences P.O.Box 50005, S-104 05 Stockholm, SWEDEN	CP 3 (C) CP 4 CP 1 WG 3
ROZANOV, B.G.	Soil Department Moscow State University, Moscow 117234, USSR	WG 2
RUNNING, S.W.	School of Forestry, University of Montana, Missoula, MT 59812, USA	CP 3 (P)
RUTTENBERG, S.	UCAR, P.O. Box 3000, Boulder, CO 80307, USA	WG 2
RYZHYKH, E.P.	All-Union Research Institute of Hydrometeoinformation, ul. Koroleva 6, Obninsk 249020, USSR	WG 2
SANDS, D.	Division of Entomology, CSIRO, Indooroopilly Qld 4068, AUSTRALIA	CP 4
SANHUEZA, E.	IVIC, Apartado 21827, Caracas 1020A, VENEZUELA	WG 4
SCHIFFER, R.A.	NASA Headquarters, Code EET, Washington, DC 20546, USA	WG 2
SCHIMEL, D.S.	Natural Resource Ecology Laboratory Colorado State Colorado State University Fort Colins, CO 80523 USA	CP 1

SCHLÜCHTER, C.	Institut für Grundund Bodenmechanik, ETH Hönggerberg, CH-8093 Zürich, SWITZERLAND	WG 3
SCHUBERT, C.	Centro de Ecologiá y Ciencias Ambientales IVIC, Apartado 21827, Caracas 1020A, VENEZUELA	WG 4
SEMENOVA, T.Yu.	Deptartment of Environtal Protection, VINITI, Moscow 125 219, USSR	WG 2
SERGEEVA, N.A.	Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR	WG 2
SHAPLEY, A.H.	NOAA, 325 Broadway, Boulder, CO 80303, USA	WG 2
SHCHERBAKOV, A.I.	State Research Institute of Land Resources, ul. Novaya 30, Moscow Region 123810, USSR	WG 2
SHEBALIN, P.N.	Institute of Earth Physics, B. Gruzinskaya 10, Moscow 123810, USSR	WG 2
SHUMBERA, A.L.	NOAA/NCDC, Federal Building, Asheville, NC 28801, USA	WG 2
SIBRAVA, V.	Division of Earth Sciences, UNESCO, 7 place de Fontenoy, F-75700 Paris FRANCE	WG 3
SIEGENTHALER, U.	Physics Institute, University of Berne, Siedlerstrasse 5, CH-3012 Berne, SWITZERLAND	WG 3
SIMONETT, D.	Geography Department, University of California at Santa Barbara,	WG 2

	Santa Barbara, CA, USA	
SINGH, G.	Research School of Pacific Studies, Australian National University, P.O.Box 4, Canberra, ACT 2601 AUSTRALIA	CP 4
SINGH, J.S	Department of Botany, Banaras Hindu University, Varanasi 221005, INDIA	CP 4
SLAYTER, R.	Research School of Biological Sciences Australian National University, P.O.Box 4, Canberra, ACT 2601 AUSTRALIA	CP 4
SMIRNOV, B.I.	All-Union Research Institute of Hydrometeoinformation, ul. Koroleva 6, Obninsk 249020, USSR	WG 2
SMITH, T.	Research School of Biological Sciences Australian National University, P.O.Box 4, Canberra, ACT 2601, AUSTRALIA	CP 4
SOLOMON, A.	International Institute for Applied Systems Analysis, A-2361 Laxenburg, AUSTRIA	CP 4 WG 2
SOMBROEK, W.G.	Internatioinal Society of Soil Science P.O. Box 353, NL-6700 AJ Wageningen, THE NETHERLANDS	WG 2
STRASSINOPOULOS, E.	Radiation Physics Office, Mail Code 600, NASA GSFC, Greenbelt, MD 20771, USA	WG 2
STUART, W.F.	Geomagnetism Research Group, Murchinson House, West Mains Road, Edinburgh EH9 3LA, UNITED KINGDOM	WG 2

STUIVER, M.	Quaternary Research Center, University of Washington, Seattle, WA 98195, USA	WG 3
TAMM, C.O.	Department of Ecology and Environmental Sciences Environmental Research, Swedish University of Agricultural Sciences, P.O. Box 7072 S-75007 Uppsala SWEDEN	WG 4
TEMNYI, V.V.	IZMIRAN, Troitsk, Moscow Region 142092, USSR	WG 2
THIERSTEIN, H.R.	Geologisches Institut, ETH Zürich, CH-8092 Zürich SWITZERLAND	WG 3
TILFORD, S.G.	NASA Headquarters, Code EE, Washington, DC 20546, USA	WG 2
TISCHENKO, A.P.	Earth Science Museum, Moscow State University, Moscow 117234, USSR	WG 2
TOMLINSON, R.F.	17 Kippewa Drive, Ottawa, Ontario, CANADA KIS 3C3	WG 2
TROITSKAYA, B.A.	Institute of Earth Physics, USSR Academy of Sciences, B. Gruzinskaya 10, Moscow 123810, USSR	WG 2
TSENDENBAL, Z.	Institute of Evolutionary Morphology and Ecology of Animals USSR Academy of Sciences, ul. Fersmana 13, Moscow 117312, USSR	WG 2
TYUPKIN, Yu.S.	Soviet Geophysical Committee, Molodezhnaya 3 Moscow 117296, USSR	WG 2

VADKOVSKY, V.N.	Ecological Department, Moscow State University, Moscow 117234, USSR	WG 2
VANDYSHEVA, V.M.	All-Union Research Centre, Bolshevistsky per 11, Moscow 101000, USSR	WG 2
VASILIEV, L.N.	Institute of Geography, USSR Academy of Sciences, Staromonetny per 29, Moscow 109117, USSR	WG 2
VELITSCHKO, A.A.	Institute of Geography, USSR Academy of Sciences, Staromonetny per 29, Moscow 109017, USSR	WG 3
VETTE, J.I.	WDC-A for R&S, Code 692, NASA GSC, Greenbelt, MD 20771, USA	WG 2
VINOGRADOV, B.V.	Institute of Evolutionary Morphology and Ecology of Animals, USSR Academy of Sciences, Moscow 117071, USSR	WG 2
VISKOV, V.V.	Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR	WG 2
VON DROSTE, B.	Division of Ecological Sciences, Unesco, 7 Place de Fontenoy, F-75700 Paris, FRANCE	WG 2
VOSTOKOVA, E.A.	Research Centre "Priroda", ul. Verkhnepervomajskaya 4b, Moscow 105264, USSR	WG 2
WALKER, B.H	Division of Wildlife and Ecology Ecology, CSIRO, P.O. Box 84, Lyneham, ACT 2602, AUSTRALIA	CP 4

WALKER, J.	Division of Water Research, CSIRO, GPO Box 1666, Canberra, ACT 2601, AUSTRALIA	CP 4
WALKER, P.	Division of Wildlife and Ecology, CSIRO, P.O. Box 84, Lyneham ACT 2602, AUSTRALIA	CP 4
WASSON, R.	Division of Water Research, CSIRO, GPO Box 1666, Canberra, ACT 2601, AUSTRALIA	CP 4
WEBBER, J.D.	Universities Space Research Assoc., American City Building, Suite 212, Columbia, MD 21044, USA	WG 2
WEBSTER, F.	College of Marine Studies, University of Delaware, Lewes, DE 19958, USA	WG 2
WERNER. P.	Tropical Ecosystems Research Centre, CSIRO, Private Bag 44, Winnellie, NT 5789, AUSTRALIA	CP 4
WESTOBY, M.	School of Biological Sciences, Macquarie University, North Ryde, NSW 2113, AUSTRALIA	CP 4
WILLIAMS, J.	Division of Soils, CSIRO, Private Mail Bag, P.O., Aitkenvale, Qld 4814, AUSTRALIA	CP 4
WITHEE, G.W.	NOAA/NESDIS/NODC, 1825 Connecticut Ave., NW, Washington, DC 20235, USA	WG 2
WÖLFLI, W.	Institut für Mittelenergiephysik, ETH Hönggerberg, CH-8093 Zürich, SWITZERLAND	WG 3

WOODWARD, I.	School of Botany, Cambridge University, Cambridge CB2 1TN, UNITED KINGDOM	CP 4
YE, D.	Academia Sinica, Beijing, CHINA	CP 1
ZALETAEY, V.S.	Institute of Water Problems Sadovo-Chernogriazskaya 13/3, Moscow 103064, USSR	WG 2
ZHDANOV, M.S.	IZMIRAN, Troitsk, Moscow Region 142092, USSR	WG 2
ZHDANOVA, O.N.	Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR	WG 2
ZHIZHIN, M.N.	Institute of Earth Physics, USSR Academy of Sciences, B. Gruzinskaya 10, Moscow 123810, USSR	WG 2
ZIMMERMAN, R.	Department of Plant Physiology, Universität Bayreuth, D-8580 Bayreuth, FEDERAL REPUBLIC OF GERMANY	WG 4
ZONOV, Yu.V.	Glavcentre "Ocean", VNIRO, Moscow 117140, USSR	WG 2

Appendix 5.

List of National Committees for the IGBP

Austria

Chairman (ad hoc Committee): Prof. S. J. Bauer, Institut für Meteorologie und Geophysik, Universität Graz, Halbärthgasse 1, A-8010 Graz.

Australia

Chairman: Prof. K. D. Cole, Department of Physics, La Trobe University, Bundoora, VIC 3083. Tel. (+61-3) 478 31 22.

Mr. R. S. Goleby, Assistant Secretary, Space Projects Branch, Department of Science, P.O. Box 65, Belconnen, ACT 2616.

Dr. R. Jensen, Assistant Secretary, Sectoral Policy & Programs Branch, Department of Science, P.O. Box 65, Belconnen, ACT 2616. Tel. (+61-62) 64 40 54.

Prof. K. Lambeck, Research School of Earth Sciences, The Australian National University, P.O. Box 4, Canberra, ACT 2601. Tel. (+61-62) 49 24 87.

Dr. K. G. McCracken, Director - COSSA, P.O. Box 225, Dickson, ACT 2602. Tel. (+61-62) 70 18 00.

Dr. A. McEwan, Chief, CSIRO, Division of Oceanography, P.O. Box 1538, Hobarth, TAS 7001. Tel. (+61-02) 20 62 12.

Prof. C. B. Osmond, Research School of Biological Sciences, Department of Environmental Biology, The Australian National University, P.O. Box 475, Canberra, ACT 2601. Tel. (+61-62) 49 29 99.

Dr. G. Pearman, CSIRO, Division of Atmospheric Research, Private Bag 1, Mordialloc, VIC 3195. Tel. (+61-3) 580 63 33.

Prof. J. P. Quirk, Director, Waite Agricultural Research Institute, University of Adelaide, Private Bag No. 1, Glen Osmond, SA 5064. Tel. (+61-8) 372 24 44.

Prof. B. G. Thom, Department of Geography, University of Sydney, NSW 2006. Tel. (+61-2) 692 28 86.

Dr. B. H. Walker, Chief, CSIRO, Division of Wildlife and Ecology, P.O. Box 84, Lyneham, ACT 2602. Tel. (+61-62) 41 12 11.

Bangladesh

Prof. M. O. Ghani, President, Bangladesh Academy of Sciences, 3/8 Asad Avenue, Muhammadpur, Dhaka 7. Tel. (+880-2) 31 04 25.

Belgium

Chairman: Prof. A. Cottenie, Rijks Universiteit Gent, Sint Pieters Niew Straat 25, Gent B-900.

Vice-Chairman: Prof. Marcel Nicolet, 30 Avenue Den Doorn, B-1180 Brussels. Tel. (322) 374 29 48. Telex 21563 Espace 6.

Prof. Ph. Bourdeau (Secretary), 26 Avenue des Fleurs, B-1150 Brussels.

Prof. O. Vanderborght (Assistant-Secretary).

Brazil

Chairman: Prof. Aristides Azevedo Pacheco Leao, Academy and the Biophysics Institute of the Federal University of Rio de Janeiro.

Dr. John M. Albuquerque Forman (Secretary), Five For Ltda., Rua Anfilófio de Carvalho 29 - Grupo 607, 20030 Rio de Janeiro. Tel. (+55-21) 240 06 76.

Canada

Chairman: Prof. R. Peltier, Department of Physics, University of Toronto, Toronto, Ontario.

Chile

Convener: Dr. Humberto A. Fuenzalida, Departmento de Geofisica, Universidad de Chile, Casilla 2777, Santiago. Tel. (+56-2) 696 87 90.

Dr. Patricio A. Bernal, Pontificia Universidad Católica de Chile, Sede Regional Talcahuano, Casilla 127, Talcahuano. Tel. (+56-41) 54 25 92.

Dr. Tomás R. Fonseca, Universidad Católica de Valparaiso, Casilla 1020, Valparaiso. Tel. (+56-32) 21 75 41, anexo 2614.

Dr. Eduardo Fuentes, Laboratorio de Ecologia, Pontificia Universidad Católica de Chile, Casilla 114-D, Santiago. Tel. (+56-2) 222 45 16, ext. 2614.

Dr. Alberto Foppiano, Departamento de Fisica, Universidad de Consepción, Casilla 947, Consepción. Tel. (+56-41) 22 86 18.

Dr. Luis Gomberoff, Departamento de Fisica, Facultad de Ciencias, Universidad de Chile, Casilla 653, Santiago. Tel. (+56-2) 271 29 73.

Dr. Ernst. R. Hajek, Laboratorio de Ecologia, Pontificia Universidad Católica de Chile, Casilla 114-D, Santiago. Tel. (+56-2) 222 45 16, ext. 2614.

Dr. Rubén Martinez, Departamento de Geologia, Universidad de Chile, Casilla 2777, Santiago. Tel. (+56-2) 696 27 14.

Dr. Vivian Montecino, Departamento de Ciencias Ecológicas, Facultad de Ciencias, Universidad de Chile, *Casilla 653, Santiago. Tel. (+56-2) 271 29 77.*

Dr. José Rutllant, Departamento de Geofisica, Universidad de Chile, Casilla 2777, Santiago. Tel. (+56-2) 696 65 63.

Dr. José Valencia, Departamento de Ciencias Ecológicas, Facultad de Ciencias, Universidad de Chile, Casilla 653, Santiago. Tel. (+56-2) 271 28 65.

China (Beijing)

Chairman: Prof. Duzheng Ye, Chinese Academy of Scienes, 52 Sanlihe Road, Beijing. Telex 22474 ASCHI CN.

Vice-Chairman: Prof. Shijun Ma, Research Center for Eco-Environmental Scienes, Chinese Academy of Sciences, 7 Zhongguancun Road, Beijing.

Vice-Chairman: Prof. Ren Wang, The National Natural Science Foundation of China, 43 Baojia St., Xicheng District, Beijing.

Secretary General: Prof. Shu Sun, Bureau of Resources and Environmental Sciences, Chinese Academy of Sciences, 52 Sanlihe Road, Beijing. Telex 22474 ASCHI CN.

Deputy Secretary General: Prof. Panqin Chen, Bureau of Resources and Environmental Sciences, Chinese Academy of Scienes, 52, Sanlihe Road, Beijing. Telex 22474 ASCHI CN.

Prof. Jiaqi Chen

Prof. Haitin Cui

Prof. Yihui Ding

Prof. Yidong Dou

Prof. Congbin Fu

Prof. Bingwei Huang

Mr. Xinjin Huo

Prof. Wenhua Li

Prof. Yongqi Li

Mr. Zhenshen Lin

Prof. Dongsheng Liu

Mr. Shouben Lu

Prof. Guanlin Qin

Prof. Hong lie Sun

Prof. Guangzi Tu

Mr. Ruiming Wang

Prof. Shen Zhang

Mr. Wenqen Zhang

Prof. Xinshi Zhang

Prof. Qiguo Zhao

Colombia

Chairman (ad hoc Committee): Dr. L. E. Mora-Osejo, President, Academia Colombiana de Ciencias Exactas Fisicas y Naturales, Apartado 44.763, Bogota 1 D.E. Tel. (+57-1) 241 48 05, 242 41 74.

Czechoslovakia

Chairman: Prof. Václav Bucha, Vice-President, Czechoslovak Academy of Sciences, Director of the Geophysical Institute, Narodni Tr. 3, 111 42 Praha 1.

Vice-Chairman: Prof. L. Weissman, Director of the Institute of the Experimental Biology and Ecology of the Slovak Academy of Sciences, Obrancov mieru 49, 885 38 Bratislava.

Secretaries: Dr. J. Rusek, Director of the Institute of Soil Biology of the Czechoslovak Academy of Sciences.

Dr. J. Lastovicka, Geophysical Institute of the Czechoslovak Academy of Sciences.

F. Pertl, Head of the Foreign Relations Department of the Czechoslovak Academy of Sciences.

Egypt

Chairman: Prof. M. A. G. Ayyad, Botany Department, Faculty of Science, University of Alexandria, Moharran Bay, Alexandria.

France

Chairman: Dr. J.-C. Duplessy, CNRS Centre des Faibles Radioactivité, Avenue de la Terrace, F-91198 Gif sur Yvette. Tel. (+33-1) 48 47 31 95. Telex 214627.

Dr. F. Becker, Université L. Pasteur, 7 rue de l'Université, F-67000 Strasbourg. Tel. (+33) 88 35 51 50.

Dr. F. Blanc, Centre d'Océanologie, Station Marine d'Eudorme, rue Batterie des Lions, F-13007 Marseille. Tel. (+33) 91 52 08 48, 91 41 42 10.

Dr. P. Buat Menard, CFR/CNRS, F-91198 Gif sur Yvette. Tel. (+33-1) 69 07 78 28, ext. 789.

Dr. E. van Campo, USTL, Place E. Bataillon, F-34060 Montpellier Cedex.

Dr. F. di Castri, CNRS/CEPE, Route de Mendes, B. P. 5051, F-34033 Montpellier Cedex. Tel. (+33) 67 61 32 00.

Dr. M.-L. Chanin, Service d'Aéronomie, B. P. 3, F-91371 Verrieres le Buisson. Tel. (+33-1) 69 20 10 60, 69 20 07 94. Telex 692400 AERONO.

Dr. J. F. Denisse, COFUSI, Académie des Sciences, 23 Quai Conti, F-75006 Paris.

Dr. H. Faure, Labo. Géol. Quaternaire, Case 907, Faculté des Sciences de Luminy, F-13288 Marseille Cedex 9.

Dr. J. Fellous, CNES - Laboratoire de Palynologie, 2 Place Maurice Quentin, F-75001 Paris.

Dr. M. Glass, TOAE - CNRS, 15 Quai A. France, F-75007 Paris.

Dr. L. Laubier, IFREMER, 66 Avenue d'Iéna, B. P. 107.16, F-75763 Paris Cedex 16.

Dr. G. Megie, Service d'Aéronomie, B.P. 3, F-91371 Verrieres le Buisson. Tel. (+33-1) 69 20 01 83.

Dr. L. Merlivat, L.O.D.Y.C., Université P. & M. Curie, 4 Place Jussieu, F-75252 Paris. Tel. (+33-1) 46 33 21 31. Telex 206317.

Dr. M. Meybeck, Institut de Biochimie Marine - ENS, 1 rue Maurice Arnoux, F-92100 Montrouge. Tel. 46 57 12 86.

Dr. A. Morel, Lab. Physique et Chimie Marine, Université P. & M. Curie, B. P. 8, F-06230 Villefranche sur Mer. Tel. (+33) 93 01 94 31.

Dr. M. Nahon, Faculté des Sciences de St Jérôme, Laboratoire de Chimie-Aix Marseille III, F-13397 Marseille Cedex 13.

Dr. C. Pedro, Laboratoire des Sols, INRA, Route de St Cyr, F-78000 Versailles. Tel. (+33-1) 30 83 32 52.

Dr. A. Perrier, INRA-INAPG, 16 rue Claude Bernard, F-75016 Paris.

Dr. S. I. Rasool, Ecole Normale Supérieure, Paris (and NASA, Washington, see U.S. National Committee for the IGBP).

Dr. R. Sasourny, Laboratoire de Météorologie Dynamique, Ecole Polytechnique RD 36, F-91128 Palaiseau. Tel. 60 19 41 44.

Dr. Servant, ORSTOM, 70-74 Route d'Aulnay, F-93130 Bondy.

Federal Republic of Germany

Chairman: Prof. H.-J. Bolle, Institut für Meteorologie, WE 07 im Fachbereich Geowissenschaften, Freie Universität Berlin, Dietrich-Schäfer-Weg 6-10, D-1000 Berlin 41.

Prof. P. J. Crutzen, Max-Planck-Institute for Chemistry, Postfach 3060, D-6500 Mainz. Tel. (+49-6131) 30 54 58. Telefax (+49-6131) 30 53 88. Telex 4187674 MPCH D.

Prof. D. Ehhalt, Institut für Atmosphärische Chemie der Kernforschungsanlage, Postfach 1913, D-5170 Jülich.

Prof. K. Fuchs, Geophysikalisches Institut der Universität, Hertzstrasse 16, D-7500 Karlsruhe 21. Tel. (0721) 608-4493. Telex 7825740 GEOK D. Telefax 721 711 73.

Prof. H. Grassl, GKSS-Forschungszentrum Geesthacht, Institut für Physik, Max-Planck-Strasse, D-2054 Geesthacht.

Prof. K.-H. Hartge, Institut für Bodenkunde der Universität, Herrenhäuser Strasse 2, D-3000 Hannover 21.

Prof. R. Herrmann, Lehrstuhl für Hydrologie der Universität, Postfach 10 12 51, D-8580 Bayreuth.

Prof. W. Krauss, Institut für Meereskunde an der Universität, Dusternbrooker Weg 20, D-2300 Kiel.

Prof. K. Labitzke, Institut für Meteorologie der Freien Universität, Dietrich-Schäfer-Weg 6-10, D-1000 Berlin 41.

Prof. O. L. Lange, Institut für Botanik und Pharmazeutische Biologie der Universität, Mittlerer Dallenbergweg 64, D-8700 Würzburg.

Prof. W. Manshard, Institut für Kulturgeographie der Universität, Werderring 4, D-7800 Freiburg.

Prof. E. Plate, Institut für Hydrologie und Wasserwirtschaft der Universität, Kaiserstrasse 12, D-7500 Karlsruhe.

Prof. G. Siedler, Institut für Meereskunde an der Universität, Abteilung Meeresphysik, Dusternbrooker Weg 20, D-2300 Kiel 1.

Dr. A. Szillinsky, Coordinator for Environmental Research, Deutsche Forschungsgemeinschaft, Postfach 20 50 04, Kennedyallee 40, D-5300 Bonn - Bad Godesberg.

Prof. J. Thiede, Geologisch-Paläontologisches Institut der Universität, Olshausenstrasse 40/60, D-2300 Kiel 1.

Prof. H. Ziegler, Lehrstuhl und Institut für Botanik und Mikrobiologie der Technischen Universität, Arcisstrasse 21, D-8000 München 2.

Prof. W. Ziegler, Direktor des Naturmuseums und Forschungsinstituts Senckenberg, Senckenberganlage 25, D-6000 Frankfurt.

German Democrate Republic

Chairman: Prof. S. Dyck, Technical University Dresden, Department for Hydrology and Meteorology, Mommsenstr. 13, DDR-8027 Dresden.

Prof. W. Boehme, Director, Meteorological Survey of the DDR, Albert-Einstein-Str. 42-46, DDR-1500 Potsdam.

Prof. J. Heinzmann, Director, Institute for Geography and Geoecology, Georgi-Dimitroff-Platz 1, DDR-7010 Leipzig.

Prof. H. Kautzleben, Director, Institute for Physics of the Earth, Telegrafenberg, DDR-1500 Potsdam.

Prof. W. Mundt, Director, Heinrich-Hertz-Institute for Atmospheric Research and Geomagnetism, Rudower Chaussee 5, DDR-1199 Berlin.

Prof. M. Ringpfeil, Head, Section of Biosciences of the Academy of Sciences of the DDR, Robert-Roessle-Str. 10, DDR-1115 Berlin.

Prof. J. Taubenheim, Head of Department, Heinrich-Hertz-Institute for Atmospheric Research and Geomagnetism, Rudower Chaussee 5, DDR-1199 Berlin.

Prof. K. Voigt, Director, Institute for Oceanic Research, Seestr. 15, DDR-2530 Rostock-Warnemünde.

Hungary

Chairman: Prof. József Tigyi, Biophysical Institute of the Medical University, POB 99, H-7643 Pécs, Hungary. Tel. (36) 721 40 17. Telex 12311 pote h.

Prof. Attila Borhidi (Secretary), Institute of Ecology and Botany, Hung. Acad. of Sci., H-2163 Vácrátót. Tel (36) 271 09 45. Telex 282201 mtabki h.

Prof. Arpád Berczik, Institute of Ecology and Botany, Hung. Acad. of Sci., H-2163 Vácrátót. Tel. (36) 271 09 45. Telex 282201 mtabki h.

Prof. Tibor Jermy, Münnich F. u. 7. H-1052 Budapest. Tel. 17 27 96.

Prof. Mihály Kecskés, Dept. of Microbiology, Agricultural University, H-2103 Gödöllö. Tel. (36) 281 06 16.

Prof. Miklós Kedves, Dept. of Systematic Botany, József Attila University, Egyetem u. 2, H-6722, Szeged. Tel. (36) 622 11 11.

Dr. László Kordos, Hungarian State Institute of Geology, Népstadion u. 14, H-1143, Budapest. Tel. (36) 183 79 40.

Prof. Attila Meskó, Dept. of Geophysics and Geodesy, Eötvös Lorand University, Kun Béla tér 2, H-1088 Budapest. Tel. (36) 134 39 53.

Prof. Ernö Mészáros, Institute of Atmospheric Chemistry, Péterhalmi ut 1, H-1181 Budapest. Tel. (36) 158 57 11.

Prof. János Salánki, Institute of Limnology, Hungarian Academy of Sci., H-8234 Tihany. Tel. (36) 864 80 06.

Dr. László B. Sztanyik, Institute of Radio-Biology, Pentz K. u. 5, H-1221 Budapest. Tel. (36) 138 59 54.

Prof. György Várallyay, Institute of Soil Science and Agrochemistry, Herman Ottó ut 15, H-1022 Budapest. Tel. (36) 156 46 82.

India

Chairman: Prof. R. R. Daniel, Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400 005.

Prof. P. K. Das, Centre for Atmospheric Sciences, Indian Institute of Technology, Hauz Khas, New Delhi 110 016.

Dr. S. N. Dwivedi, Department of Ocean Development, Mahasagar Bhavan, Block 12, CGO Complex, Lodi Road, New Delhi 110 003.

Prof. V. K. Gaur, Director, National Geophysical Research Institute, Hyderabad 500 007.

Dr. T. A. Hariharan, Space Applications Centre SAC P.O., Jodhpur Tekra, Ahmedabad 380 053.

Dr. T. N. Khoshoo, Tata Energy Research Institute, 7 Jor Bagh, New Delhi 110 003.

Dr. A. P. Mitra, Director General, Council of Scientific & Industrial Research, Rafi Marg, New Delhi 110 001.

Dr. M. Parabrahmam, Director, CP Division, Ministry of Environment and Forests, Paryavaran Bhavan, CGO Complex, Lodi Road, New Delhi 110 003.

Dr. M. N. Qureshi, Adviser, SPG, Ministry of Science & Technology, Technology Bhavan, New Mehrauli Road, New Delhi 110 016.

Prof. J. S. Singh, Department of Botany, Ecosystems Analysis Laboratory, Banaras Hindu University, Varanasi 221 003.

Prof. B. L. K. Somayajulu, Physical Research Laboratory, Navrangpura, Ahmedabad 380 009.

Dr. M. K. Tiwari (Non-member Secretary), ISRO (ADCOS), Cauvery Bhavan, Kempegowda Road, Bangalore 560 009.

Israel

Chairman: Prof. Z. Reiss, Department of Palaeontology, Hebrew University of Jerusalem, Givat Ram, Jerusalem.

Dr. U. Marinov, Government Environmental Protection Agency.

Dr. A. Nissenbaum, Weizmann Institute of Science, Rehovot.

Prof. M. Shilo, Hebrew University.

Prof. E. Tchernov, Hebrew University.

Japan

Chairman: Prof. Yasuyuki Oshima, Department of Basic Human Science, School of Human Sciences, Waseda University, Mikajima 2-579-15, Tokorozawa, Saitama 359. Tel. (+81-3) 203 41 41. Telefax 429-48-4314. Telex WASEDA J 2323280.

Prof. Tomio Asai, Ocean Research Institute, University of Tokyo, Minamidai 1-5-1, Nakano, Tokyo 164. Tel. (+81-3) 364 12 51. Telefax (+81-3) 375 67 14.

Prof. Akihiko Hattori, Research Institute for Information and Knowledge, Kanagawa University, Rokkakubashi 3-27-1, Kanagawa, Yokohama 221. Tel. (+81-45) 481 56 61.

Prof. Keiji Higuchi, Water Research Institute, Nagoya University, Froucho, Chikusa, Nagoya 464. Tel. (+81-52) 781 51 11. Telefax (+81-52) 781 39 98.

Dr. Harushige Koga, Japan Meteorological Agency, Office of Climate Program, Ootemachi 1-3-4, Chiyoda, Tokyo 100. Tel. (+81-3) 212 83 41.

Prof. Jiro Kondo, President, Science Council of Japan, Roppongi 7-22-34, Roppongi, Minato, Tokyo 106. Tel. (+81-3) 403 62 91. Telefax (+81-3) 403 62 24.

Prof. Eiji Matsumoto, Water Research Institute, Nagoya University, Froucho, Chikusa, Nagoya 464. Tel. (+81-52) 781 51 11. Telefax (+81-52) 781 39 98.

Prof. Hiroshi Matsuo, The Institute of Space and Astronautical Science, Komaba 4-6, Meguro, Tokyo 153. Tel. (+81-3) 467 11 11.

Dr. Takumi Mori, Japan Oceanographic Data Center, Hydrographic Department, Maritime Safety Agency, Tsukiji 5-3-1, Chuou, Tokyo 104. Tel. (+81-3) 541 38 11.

Prof. Takahisa Nemoto, Ocean Research Institute, University of Tokyo, 1-5-1 Minamidai, Nakano-ku, Tokyo 164. Tel. (+81-3) 376 12 51. Telefax (+81-3) 377 33 95. Telex 25607 ORIUT J. Electronic mail OMNET, Telemail ORI.Tokyo.

Prof. Osamu Nishikawa, Faculty of Letters, Rissho University, Osaki 4-2-16, Shinagawa, Tokyo 141. Tel. (+81-3) 492 66 16.

Dr. Tamotsu Nozawa, Member of Science Council of Japan, Roppongi 7-22-34, Minato, Tokyo 106. Tel. (+81-3) 403 62 91.

Prof. Toshihiro Ogawa, Geophysics Research Laboratory, Faculty of Science, University of Tokyo, Hongo 7-3-1, Bunkyoo, Tokyo 113. Tel. (+81-3) 812 21 11. Telefax (+81-3) 818 07 45.

Prof. Masae Omori, Faculty of General Education, Azabu University, Fuchinobe 1-1771, Sagamihara, Kanagawa 229. Tel. (+81-427) 54 71 11.

Prof. Nobuo Ono, Institute of Low Temperature Science, Hokkaido University, Nishi 8, Kita 19, Kita, Sapporo 060. Tel. (+81-11) 711 21 11.

Dr. Kazuo Oshima, Geological Survey of Japan, Higashi 1-1-3, Tsukuba, Ibaragi 305. Tel. (+81-298) 54 35 21.

Prof. Hitoshi Sakai, Ocean Research Institute, University of Tokyo, Minamidai 1-5-1, Nakano, Tokyo 164. Tel. (+81-3) 376 12 15. Telefax (+81-3) 375 67 14.

Prof. Ryukichi Sawada, Member of Science Council of Japan, Roppongi 7-22-34, Minato, Tokyo 106. Tel. (+81-3) 403 62 91.

Dr. Hiroshi Seino, National Institute of Agro-Environmental Sciences, Kannondai 3-1-1, Tsukuba, Ibaragi 305. Tel. (+81-2975) 681 48.

Prof. Kiyoshi Tsuchiya, Remote Sensing and Image Research Center, Chiba University, Yayoicho 1-13, Chiba 260. Tel. (+81-472) 51 11 11.

Prof. Shizuo Tsunogai, Department of Chemistry, Faculty of Fisheries, Hokkaido University, Minatomachi 3-1-1, Hakodate 041. Tel. (+81-138) 53 27 98.

Prof. Zenbei Uchijima, Faculty of Science, Ochanomizu University, Ootsuka 2-1-1, Bunkyoo, Tokyo 112. Tel. (+81-3) 943 31 51.

Prof. Itaru Watanabe, Members of Science Council of Japan, Roppongi 7-22-34, Minato, Tokyo 106. Tel (+81-3) 403 62 91.

Prof. Kazutoshi Yabuki, President of University of Osaka Prefecture, Mozuumecho 4-804, Sakai, Osaka 591. Tel. (+81-722) 52 11 61.

Prof. Tomoaki Yoshikawa, Meteorological Research Institute of Japan Meteorological Agency, Nagamine 1-1, Tsukuba, Ibaragi 305. Tel. (+81-298) 51 71 11.

Prof. Masatoshi Yoshino, Institute Geoscience, University of Tsukuba, Tennoudai 1-1-1, Tsukuba, Ibaragi 305. Tel. (+81-298) 53 21 11.

The Netherlands

Chairman: Prof. H. Postma, Schilderend 135, NL-1791 BK Den Haag.

Prof. J. W. M. la Rivière, International Institute for Hydraulic and Environmental Engineering, P.O. Box 3015, Oude Delft 95, NL- 2601 DA Delft. Tel. (+31-15) 78 30 60. Telex 38099 Attention la Rivière IHE.

Dr. H. M. van Emden (Secretary), Koninklijke Nederlandse Akademie van Wetenschappen, Het Trippenhuis, Kloveniersburgwal 29, Postbus 19121, NL-1000 GC Amsterdam. Tel. (+31-20) 22 29 02.

Dr. A. P. M. Baede, K.N.M.I. Postbus 201, NL-3730 AE De Bilt.

Dr. G. P. Hekstra, Ministerie VROM, Postbus 450, NL-2260 MB Leidschendam.

Prof. D. J. van de Kaa, Meyboomlaan 1, NL-2242 PR Wassenaar.

Prof D. J. Kuenen, Blauwe Vogelweg 2a, NL-2333 VK Leiden.

Dr. A. Littel, Rijksplanologische Dienst, Willem Witsenplein 6, NL-2596 BK Den Haag.

Ministerie van Onderwijs en Wetenschappen, Postbus 25000, NL-2700 LZ Zoetermeer.

Prof. G. J. Vervelde, Ritzema Bosweg 56, NL-6703 BB Wageningen.

Dr. G. H. Vonkeman, Amalia van Solmslaan 47, NL-3708 CM Zeist.

New Zealand

Ad hoc Committee for the IGBP, National Committee for Geodesy and Geophysics, The Royal Society of New Zealand, P.O. Box 598, Wellington.

Poland

Chairman (ad hoc Committee): Prof. Zdzislaw Kaczmarek, Polish National Committee for ICSU, c/o Polish Academy of Sciences, Palac Kultury i Nauki, PL-00-901 Warsaw. Tel. (+48-2) 20 33 71, 20 33 45. Telex 813697 PAN PL.

South Africa

Chairman: Prof. P. D. Tyson, Deputy Vice-Chancellor, University of the Witwatersrand, Wits 2050. Tel. (+27-11) 716 35 45. Teletex 4-50937 VCWITS.

Prof. H. J. Deacon, Department of Archaeology, University of Stellenbosh, Stellenbosh 7600.

Prof. J. G. Field, Department of Zoology, University of Cape Town, Private Bag, Rondebosch 7700.

Dr. S. C. J Joubert, Kruger National Park, Private Bag X 402, Skukuza 1350.

Mr. I. A. W. Macdonald, Percy FitzPatrick Institute of African Ornithology, University of Cape Town, Private Bag, Rondebosch 7700.

Dr. O. G. Malan, Optical Sciences, N P R L.

Prof. T. C. Partridge, Department of Geography, University of the Witwatersrand, Wits 2050.

Prof. R. E. Schulze, Department of Agricultural Engineering, University of Natal, P.O. Box 375, Pietermaritzburg 3200.

Dr. L. V. Shannon, Sea Fisheries Research Institute, Private Bag, Sea Point 8060.

Prof. W. R. Siegfried, Percy FitzPatrick Institute of African Ornithology, University of Cape Town, Rondebosch 7700.

Prof. J. E. Steffens, Department of Statistics and Marine Operational Research, UNISA, P.O. Box 392, Pretoria 0001.

Mrs. E. P. du Plessis, South African ICSU Secretariat, Foundation for Research Development (F R D), P.O. Box 395, Pretoria 0001. Tel. (+27-12) 86 92 11. Telefax (+27-12) 86 28 56. Telex 321312 SA.

Mr. B. J. Huntley, Programme Manager, Terrestrial Ecosystems, Foundation for Research Development (F R D), P.O. Box 395, Pretoria 0001. Tel. (+27-12) 86 92 11. Telefax (+27-12) 86 28 56. Telex 321312 SA.

Dr. C. W. Louw, Coordinator, Weather, Climate and Atmosphere, Foundation for Research Development (F R D), P.O. Box 395, Pretoria 0001. Tel. (+27-12) 86 92 11. Telefax (+27-12) 86 28 56. Telex 321312 SA.

Mr. O. A. van der Westhuysen, Programme Manager, Earth and Marine Sciences, Foundation for Research Development (F R D), P.O. Box 395, Pretoria 0001. Tel. (+27-12) 86 92 11. Telefax (+27-12) 86 28 56. Telex 321312 SA.

Sweden

Chairman: Prof. Bert Bolin, Department of Meteorology, University of Stockholm, S-106 91 Stockholm. Tel. (+46-8) 15 77 31.

Prof. Björn Berglund, Department of Quaternary Research, University of Lund, Tornavägen 13, S-223 63 Lund. Tel. (+46-46) 10 78 86.

Dr. Bengt Dahlström, SMHI, S-601 76 Norrköping. Tel. (+46-11) 15 80 00.

Prof. Bo Döös, 2130 P-Street N.W., Apt 616, Washington, DC 20037, U.S.A.

Prof. Gunnar Jacks, Department of Land Improvement and Drainage, Royal Institute of Technology, S-100 44 Stockholm. Tel. (+46-8) 790 73 80.

Prof. Bengt-Owe Jansson, The Askö Laboratory, University of Stockholm, S-106 91 Stockholm. Tel. (+46-8) 15 44 77.

Prof. Sune Linder, Department of Ecology and Environmental Research, Swedish University of Agricultural Sciences, S 750 07 Uppsala. Tel. (+46-18) 17 24 40.

Prof. Nils Malmer, Department of Plant Ecology, University of Lund, Östra Vallgatan 14, S-223 61 Lund. Tel. (+46-46) 10 92 99.

Dr. Ingemar Renberg, Department of Plant Ecology, University of Umeå, S-901 87 Umeå. Tel. (46-90) 16 60 29, 16 57 81.

Prof. Henning Rodhe, Department of Meteorology, University of Stockholm, S-106 91 Stockholm. Tel. (+46-8) 16 36 96.

Prof. Thomas Rosswall, IGBP Secretariat, The Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm. Tel. (+46-8) 15 04 30 (exch.) or 16 64 48 (dir.) Telefax (+46-8) 16 64 05. Telex 17509 IGBP S.

Prof. Anders Stigebrandt, Department of Physical Oceanography, University of Göteborg, Box 4038, S-400 40 Göteborg. Tel. (+46-31) 42 28 00.

Prof. Åke Sundborg, Department of Physical Geography, University of Uppsala, Box 554, S-751 22 Uppsala. Tel. (+46-18) 18 25 13.

Prof. Bengt Torssell, Department of Plant Husbandry, Swedish University of Agricultural Sciences, Box 7043, S-750 07 Uppsala. Tel. (+46-18) 17 14 16.

Prof. Leif Wastenson, Department of Physical Geography, University of Stockholm, S-106 91 Stockholm. Tel. (+46-8) 30 52 23.

Dr. Hans Lundberg (Non-member Secretary), The Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm. Tel. (46-8) 15 04 30.

Switzerland

Chairman: Prof. H. Thierstein, Geologisches Institut, ETH-Zentrum, CH-8092 Zürich. Tel. (+41-1) 256 36 66.

Prof. Peter Eberhardt, Physikalisches Institut, Sidlerstrasse 5, Universität Bern, CH-3012 Bern. Tel. (+41-31) 65 44 02.

Dr. A. Fischlin, Projekt-Zentrum IDA, ETH-Zentrum, CH-8092 Zürich. Tel. (+41-1) 256 42 83.

Dr. H. Gäggeler, Eidg. Institut für Reaktorforschung (EIR), CH-5303 Würenlingen. Tel. (+41-56) 99 24 04.

Prof. Jean-Michel Gobat, Institut de botanique, Chantemerle 22, CH-2000 Neuchatel. Tel. (+41-38) 25 64 34.

Prof. H. Haefner, Geographisches Institut, Universität Zürich-Irchel, Winterthurerstrasse 190, CH-8057 Zürich. Tel. (+41-1) 257 51 30.

Dr. K. Hanselmann, Institut für Pflanzenbiologie, Abt. Mikrobiologie, Universität Zürich, Zollikerstrasse 107, CH-8008 Zürich. Tel. (+41-1) 47 32 74.

Prof. J. Hausser, Institut de zoologie et écologie animale, Bâtiment de biologie, CH-1015 Lausanne. Tel. (+41-21) 46 24 63.

Dr. Kerry Kelts, EAWAG, CH-8600 Dübendorf. Tel. (+41-1) 823 50 26.

Prof. H. Oeschger, Physikalisches Institut, Universität Bern, Sidlerstrasse 5, CH-3012 Bern. Tel. (+41-31) 65 44 62. Telefax (+41-31) 65 44 05. Telex 912643 PIBE CH.

Dr. Chr. Schlüchter, Ingenieurgeologie, ETH-Hönggerberg, CH-8093 Zürich. Tel. (+41-1) 377 25 21/25.

Dr. U. Siegenthaler, Physikalisches Institut, Universität Bern, Sidlerstrasse 5, Universität Bern, CH-3012 Bern. Tel. (+41-31) 65 44 71.

Dr. Jean-Pierre Tripet, NAGRA, Parkstrasse 23, CH-5400 Baden. Tel. (+41-56) 22 29 70.

Prof. A. Waldvogel, Labor. für Atmosphärenforschung, ETH-Hönggerberg, CH-8093 Zürich. Tel. (+41-1) 377 27 60.

Dr. Jürg Zettel, Zoologisches Institut, Baltzerstrasse 3, CH-3012 Bern. Tel. (+41-31) 65 45 11.

Prof. F. Zwahlen, Centre d'hydrogéologie, 11 rue Emile Argand, CH-2007 Neuchatel. Tel. (+41-38) 25 64 34.

United Kingdom

Chairman: Prof. W. G. Chaloner, Department of Botany, Holloway and Bedford New College, Huntersdale, Callow Hill, Virginia Water, Surrey GU25 4LN.

Prof. J. R. L. Allen, Department of Geology, The University, P.O. Box 227, Whiteknights, Reading RG6 2AB.

Dr. B. L. Bayne, Director of the Plymouth Marine Laboratory, Procpect Place, West Hoe, Plymouth PL1 3DH.

Dr. J. C. Bowman, National Environment Research Council (NERC), Polaris House, North Star Avenue, Swindon SN2 1EU.

Prof. A. D. Bradshaw, Department of Botany, The University of Liverpool, P.O. Box 147, Liverpool L69 3BX.

Prof. G. Eglinton, 7 Red House Lane, Bristol BS9 3RY.

Prof. D. O. Hall, Department of Biology, King's College, Campden Hill Road, London W8 7AH.

Prof. J. L. Harper, Cae Groes, Glan-y-Coed Park, Penmaenmawr, Gwynedd LL34 6TL.

Prof. J. E. Lovelock, Coombe Mill, St Giles on the Heath, Launceston, Cornwall PL15 9RY.

Sir John Mason, 64 Christchurch Road, East Sheen, London SW14 7AW.

Prof. D. W. Rhind, Department of Geography, Birkbeck College, 7-15 Gresse Street, London W1P 1PA.

Dr. N. J. Shackleton, Sub-Department of Quaternary Research, The Godwin Laboratory, Free School Lane, Cambridge CB2 3RS.

Prof. J. K. Syers, Department of Soil Science, Faculty of Agriculture, The University, Newcastle upon Tyne NE1 7RU.

Dr. J. D. Woods, Natural Environment Research Council (NERC), Polaris House, North Star Avenue, Swindon SN2 1EU. Tel. (+44-793) 401 01 ext 420. Telefax (+44-793) 51 11 17. Telex 444293 ENVRE G.

United States of America

Chairman: Dr. Harold A. Mooney, Department of Biological Sciences, Stanford University, Stanford, CA 94305. Tel. (+1-415) 723 11 79.

Dr. D. James Baker, Jr., Joint Oceanographic Institutions Inc., 1775 Massachusetts Ave. NW, Suite 800, Washington, DC 20036. Tel. (+1-202) 232 39 00.

Dr. Francis P. Bretherton, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307-3000. Tel. (+1-303) 497 13 62.

Dr. Kevin C. Burke, Director's Office, Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058-4399. Tel. (+1-713) 486 21 80.

Dr. William C. Clark, J. F. Kennedy School of Government, Harvard University, 79 Kennedy Street, Cambridge, MA 02138. Tel. (+1-617) 495 39 81.

Dr. Margaret B. Davis, Department of Ecology and Behavioral Biology, University of Minnesota, 318 Church Street, Minneapolis, MN 55455-0302. Tel. (+1-612) 625 11 02.

Dr. Robert E. Dickinson, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307-3000. Tel (+1-303) 497 13 19.

Dr. John Imbrie, Department of Geological Sciences, Brown University, Providence, RI 02912-1846. Tel. (+1-401) 863 31 96.

Dr. Thomas F. Malone, St. Joseph College, Box 2E, 1678 Asylum Avenue, West Hartford, CT 06117. Tel. (+1-203) 232 19 74.

Dr. Michael B. McElroy, Center for Earth and Planetary Physics, Pierce Hall, Room 100B, Harvard University, 29 Oxford Street, Cambridge, MA 02138. Tel. (+1-617) 495 43 59.

Dr. Berrien Moore III, Institute for the Study of Earth, Oceans and Space, Science Engineering Research Building, University of New Hampshire, Durham, NH 03824. Tel. (+1-602) 862 17 92.

Dr. Ellen S. Mosley-Thompson, Byrd Polar Research Center, 5 Mendenhall Laboratory, Ohio State University, 125 South Oval Mall, Columbus, OH 43210-1308. Tel. (+1-614) 292 65 31.

Dr. Paul G. Risser, Vice-President for Research, Scholes Hall, Room 108, University of New Mexico, Albuquerque, NM 87131. Tel. (+1-505) 277 50 64.

Ex-Officio Members:

Dr. John A. Eddy, University Corporation for Atmospheric Research, P.O. Box 3000. Boulder, CO 80307-3000. Tel. (+1-303) 497 15 63. Telefax (+1-303) 497 11 37. Telex 989764 NCAR BDR UD.

Prof. James J. McCarthy, Museum of Comparative Zoology, Harvard University, 29 Oxford Street, Cambridge, MA 02138. Tel. (+1-617) 495 23 30. Telefax (+1-617) 495 05 06. Telex 258127 MCZL UR.

Dr. S. I. Rasool, NASA Headquarters (Code E), 600 Independence Avenue SW, Washington, DC 20546. Tel. (+1-202) 453 15 10. Telex 4979843 NASA WSH.

Dr. Robert E. Sievers, Department of Chemistry, CIRES, University of Colorado, Campus Box 215, Boulder, CO 80309-0215. Tel. (+1-303) 492 80 83.

Government Agency Liaison Representatives:

Dr. Robert W. Corell, Assistant Director for Geosciences, National Science Foundation, 1800 G Street N.W., Room 510, Washington, DC 20550. Tel (+1-202) 357 97 15.

Dr. Bruce R. Doe, Assistant Director for Research, U.S. Geological Survey, 104 National Center, Reston, VA 22092. Tel. (+1-703) 648 44 50.

Dr. J. Michael Hall, National Oceanic and Atmospheric Administration (WSC-5, Room 817), 6010 Executive Blvd., Rockville, MD 20852. Tel. (+1-301) 443 84 15.

Dr. Eric O. Hartwig, Environmental Sciences Directorate, Office of Naval Research (Code 112), 800 North Quincy Street, Arlington, VA 22217-5000. Tel. (+1-703) 696 43 98.

Mr. Frederick A. Koomanoff, Carbon Dioxide Program, MS-E-201, Department of Energy, Washington, DC 20546. Tel. (+1-202) 453 17 06.

Dr. Ray Watts, U.S. Geological Survey, 104 National Center, Reston, VA 22092. Tel. (+1-703) 648 44 53.

National contributions to the IGBP

The following countries are at present financially contributing to the international planning of the IGBP:

Bangladesh
China (Taipei)
Israel
Jamaica
New Zealand
Portugal
South Africa
Sweden
Switzerland
USA

Appendix 6

Global Change Committees of Other ICSU Scientific Members

IGU/IGBP Committee

H. T. Verstappen (the Netherlands), Chairman
S. A. Evteev (USSR)
S. Gregory (UK)
W. Manshard (FRG)
R. Tomlinson (Canada)

INQUA Commission on Global Change

H. Faure (France), President
E. S. Diop (Senegal), Vice-President
D. Grant (Canada), Secretary

IUGG Committee for the IGBP

J. C. I. Dooge (Ireland), Chairman

IUGS Global Change Task Force

Dr. K. J. Hsu (Chairman IUGS Commission on Marine Geology), Chairman
Dr. R. A. Price (IUGS Advisory Board on Research Development, Past President
Prof. N. W. Rutter (President INQUA)
Dr. P. Teleki (Chairman IUGS Advisory Board on Remote Sensing)
Dr. I. Thornton (International Association of Geochemistry and Cosmochemistry - IAGC)
Dr. F. Zwahlen (Swiss National Committee for the IGBP)

URSI Committee on Global Change

Dr. W. E. Gordon (USA), Chairman

Appendix 7.

Bibliography

The following list of references is a limited bibliography of key references of relevance to Sections 5 and 6.

General

IGBP. 1986. The International Geosphere-Biosphere Programme: A Study of Global Change. Final Report of the Ad Hoc Planning Group, ICSU General Assembly, Berne, Switzerland 14-19 September, 1986. IGBP Report No. 1. 21 pp.

IGBP. 1987. A Document Prepared by the First Meeting of the Special Committee, ICSU, Paris 16-19 July, 1987. IGBP Report No. 2. 22 pp.

IGBP. 1988a. A Report from the Second Meeting of the Special Committee, Harvard University, Cambridge, MA, USA, 8-11 February, 1988. IGBP Report No. 3. 42 pp.

IGBP. 1988b. The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP). A Plan for Action. IGBP Report No. 4.

IGBP. 1988c. Effects of Climate Change on Terrestrial Ecosystems. IGBP Report No. 5 (in press)

IGBP. 1988d. Techniques for Extracting Environmental Data from the Past. IGBP Report No. 6 (in press). Malone, T. F. and Roederer, J. G. 1985. Global Change. Cambridge: Cambridge University Press and ICSU Press. 512 pp.

NASA. 1988. Earth System Science. A Program for Global Change. A Closer View. Boulder: Office for Interdisciplinary Earth Studies. 208 pp.

NRC. 1983. Toward an International Geosphere-Biosphere Program. A Study of Global Change. Washington, D.C.: National Academy Press. 81 pp.

NRC. 1986. Global Change in the Geosphere-Biosphere. Initial Priorities for an IGBP. Washington, D.C.: National Academy Press.

Vernadsky, V. I. 1986. The Biosphere. An Abridged Version Based on the French Edition of 1929. London: Synergetic Press.

5.1. Coordinating Panel on Terrestrial Biosphere-Atmospheric Chemistry Interactions

Bolin, B. and Cook, R. B. (eds) 1983. The Major Biogeochemical Cycles and their Interactions. SCOPE 21. Chichester: John Wiley & Sons, Ltd.

Bolin, B., Döös, B. R., Jäger, J. and Warrick, R. A. (eds) 1986. The Greenhouse Effect - Climatic Change and Ecosystems. SCOPE 29. Chichester: John Wiley & Sons, Ltd.

Clark, W. C. (ed.) 1982). Carbon Dioxide Review 1982. Oxford: Clarendon Press.

Crutzen, P. J. 1988. Variability in atmospheric-chemical systems. In: Rosswall, T., Woodmansee, R. G. and Risser, P. G. (eds) Scales and Global Change. SCOPE 35:81-108. Chichester: John Wiley and Sons, Ltd.

Crutzen, P. J., Delany, A. C., Greenberg, J., Haagenson, P., Heidt, L., Lueb, R., Pollock, W., Weiler, W., Wartburg, A. and Zimmerman, P. 1985. Tropospheric chemical composition measurements in Brazil during the dry season. J. Atmos. Chem. 2:233-256.

Dickinson, R. E. (ed.) 1987. The Geophysiology of Amazonia. Vegetation and Climate Interactions. Chichester: John Wiley & Sons, Ltd.

Harriss, R. C. et al. 1988. The Amazon boundary layer experiment (ABLE 2A): Dry season 1985. J. Geophys. Res. 93(D2):1351-1624.

Keller, M., Kaplan, W. A. and Wofsy, S. C. 1986. Emissions of N_2O, CH_4, and CO_2 from tropical forest soils. J. Geophys. Res. 91:11,791-11,802.

Mooney, H. A., Vitousek, P. M. and Matson, P. A. 1987. Exchange of materials between terrestrial ecosystems and the atmosphere. Science 238:926-932.

National Research Council. 1984. Global Tropospheric Chemistry. A Plan for Action. Washington, D.C.: National Academy Press. 194 pp.

Ramanathan, V., Cicerone, R. J., Singh, H. B. and Kiehl, J. T. 1985. Trace gas trends and their potential role in climate change. J. Geophys. Res. 90(D3):5547-5566.

World Meteorological Organization. 1985. Global Ozone Research and Monitoring Project Report No. 16. Geneva: WMO.

5.2. Marine Biosphere-Atmosphere Interactions

Brewer, P. G., Bruland, K. W., Eppley, R. W. and McCarthy, J. J. (eds) 1986. The Global Ocean Flux Study (GOFS): Status of the U.S. GOFS Program. Eos 67:827-832.

Oeschger, H. 1988. The ocean system - Ocean/climate and ocean/CO_2 interactions. In: Rosswall, T., Woodmansee, R. G. and Risser, P. G. (eds) Scales and Global Change. SCOPE 35:319-352.

Walsh, J. J. and Dieterle, D. A. 1988. Use of satellite ocean colour observations to refine understanding of global geochemical cycles. In: Rosswall, T., Woodmansee, R. G. and Risser, P. G. (eds) Scales and Global Change. SCOPE 35:287-318. Chichester: John Wiley and Sons, Ltd.

5.3. Biospheric Effects of the Hydrological Cycle

Becker, F., Bolle, H.-J. and Rowntree, P. R. 1988. The International Satellite Land-Surface Climatology Project. ISLSCP Report No. 10, 100 pp. Berlin:Free University of Berlin, ISLSCP Secretariat.

Bolin, B. 1988. Linking terrestrial ecosystem process models to climate models. In: Rosswall, T., Woodmansee, R. G. and Risser, P. G. (eds) Scales and Global Change. SCOPE 35:109-124. Chichester: John Wiley and Sons, Ltd.

Rosenzweig, C. and Dickinson, R. (eds) 1986. Climate-Vegetation Interactions. Report OIES-2. Boulder, CO: Office for Interdisciplinary Earth Studies.

WCRP. 1987. Report of the Workshop on Space Systems Possibilities for a Global Water Cycle Experiment. WCP-137, WMO/TD No. 180.

WCRP. 1988. Concept of the Global Energy and Water Cycle Experiment. WCRP-55, WMO/TD No. 215.

5.4. Effect of Climate Change on Terrestrial Ecosystems

Corbett, J. R. 1969. The Living Soil. West Como: Martindale Press.

Jarvis, P. G. and McNaughton, K. G. 1986. Stomatal control of transpiration: Scaling up from leaf to region. Adv. Ecol. Res. 15:1-49.

Noble, I. R. and Slatyer, R. O. 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. Vegetatio 43:5-21.

Rosswall, T., Woodmansee, R. G. and Risser, P. G. 1988. Scales and Global Change. Spatial and Temporal Variability in Biospheric and Geospheric Processes. SCOPE 35, 355 pp. Chichester: John Wiley and Sons, Ltd.

Shugart, H. H. 1984. A Theory of Forest Dynamics: An Investigation of the Ecological Implications of Several Computer Models of Forest Succession. New York: Springer-Verlag.

Sutherst, R. W. and Maywald, G. F. 1985. Computerized system for matching climates in ecology. Agr. Ecos. Env. 13:281-299.

Woodward, F. I. 1987. Climate and Plant Distribution. Cambridge: Cambridge University Press. 174 pp.

6.1 Global Geosphere-Biosphere Modelling

Bolin, B. 1986. How much CO_2 will remain in the atmosphere? In: Bolin, B., Döös, B., Jäger, J. and Warrick, R. (eds) The Greenhouse Effect, Climatic Change and Ecosystems. SCOPE 29:93-155. Chichester: John Wiley and Sons, Ltd.

Fung, I. Y., Tucker, C. J. and Prentice, K. C. 1987. Application of advanced very high resolution vegetation index to study atmosphere-biosphere exchange of CO_2. J. Geophys. Res. 92(D3):2999-3015.

Maier-Reimer, E. and Hasselmann, K. 1987. Transport and storage of CO_2 in the ocean - an inorganic ocean-circulation carbon cycle model. Climatic Dynamics 2:63-90.

McElroy, M. B. 1983. Marine biological controls on atmospheric CO_2 and climate. Nature 302:328-330.

Parton, W. J., Stewart, J. W. B. and Cole, C. V. 1988. Dynamics of C, N, P, and S in grassland soils. A model. Biogeochem. 5:109-131.

Sarmiento, J., Toggweiler, R. and Najjar, R. 1988. Ocean carbon cycle principles and atmospheric pCO_2. Proc. Roy. Soc. (London)(in press).

Shugart, H. H., Michaels, P. J., Smith, T. M. Weinstein, D. A. and Rastetter, E. B. 1988. Simulation models of forest succession. In: Rosswall, T., Woodmansee, R. G. and Risser, P. G. (eds) Scales and Global Change. 35:125-151. Chichester: John Wiley and Sons.

Siegenthaler, U. and Oeschger, H. 1987. Biosphere CO_2 emissions during the past 200 years reconstructed by deconvolution of ice core data. Tellus 39B:140-154.

6.2. Data and Information Systems

Anonymous. 1986. Report on Current International Scientific Activities in Improvement and Harmonisation of Techniques and Practices of Environmental Measurement. Report by Economic Summit Environment Experts. Neuherberg:GSF-PFU.

Baumgardner, M. F. and Oldeman, L. R. (eds) Proceedings of an International Workshop on the Structure of a Digital International Soil Resources Map Annex Data Base. Wageningen: ISSS Secretariat. 138 pp.

CODATA. 1986. Directions for Internationally Compatible Environmental Data. A CODATA Workshop. Paris: CODATA. 242 pp.

ICSU. 1987. Guide to the World Data Center System. General Principles, Locations and Services. 91 pp. IGU/ICA. 1987. Report on World Digital Database for Environmental Science - An IGU/ICA Project. 90 pp.

NASA. 1988. Earth System Science. A Program for Global Change. A Closer View. 208 pp.

Rasool, S. I. (ed.) 1987. Potential of Remote Sensing for the Study of Global Change. Advances in Space Research vol. 7. 97 pp.

6.3. Techniques for Extracting Environmental Data of the Past

Barnola, J. M., Raynaud, D., Korotkevitch, Y. S. and Lorius, C. 1987. Vostok ice core provides 160,000-year record of atmospheric CO_2. Nature 329:408-414.

Broccoli, A. J. and Manabe, S. 1987. The influence of continental ice, atmospheric CO_2, and land albedo on the climate of the last glacial maximum. Climate Dynamics 2:87-99.

Genthon, C., Barnola, J. M., Raynaud, D., Lorius, C., Jouzel, J., Barkov, N. I., Korotkevich, Y. S. and Kotlyakov, V. M. 1987. Vostok ice core: climatic response to CO_2 and orbital forcing changes over the last climatic cycle. Nature 329:414-418.

Berglund, B. E. (ed.) 1986. Handbook of Holocene Palaeoecology and Palaeohydrology. Chichester: John Wiley and Sons, Ltd.

Hansen, J. E. and Takahashi, T. (eds) 1984. Climate Processes and Climate Sensitivity. Geophys. Monogr. 29. American Geophysical Union.

Kutzbach, J. E. and Guetter, P. J. 1986. The influence of changing orbital parameters and surface boundary conditions on climate simulations for the past 18,000 years. J. Atmos. Sci. 43:1726-1759.

Langway, C. C., Oeschger, H. & Dansgaard, W. (eds) 1985. Greenland Ice Core: Geophysics, Geochemistry and the Environment. Geophys. Monogr. 33. American Geophysical Union.

Schweingruber, F. H. 1988. Climatic information for the past hundred years in width and density of conifer growth rings. In: Wanner, H. and Siegenthaler, U. (eds) Long and Short Term Variability of Climate, pp. 18-34. Berlin: Springer-Verlag.

Sundquist, E. T. and Broecker, W. S. (eds) 1985. The Carbon Cycle and Atmospheric CO_2: Natural Variations - Archaean to Present. Geophys. Monogr. 32. American Geophysical Union.

6.4. Geosphere-Biosphere Observatories

Brenneman, J. and Blinn, T. 1987. Long-Term Ecological Research in the United States. A Network of Research Sites. 4th revised ed. Corvallis: Forest Science Department, Oregon State University. 39 pp.

Dyer, M. I., di Castri, F. and Hansen, A. J. (eds) Geosphere-Biosphere Observatories. Their Definition and Design for Studying Global Change. Biology International Special Issue 16, 40 pp.

Strayer, D. et al. 1986. Long-Term Ecological Studies: An Illustrated Account of their Design, Operation, and Importance to Ecology. Occasional Publication of the Institute of Ecosystem Studies No. 2. Millbrook: The New York Botanical Garden, Mary Flagler Cary Arboretum. 38 pp.

Appendix 8.

List of Acronyms and Abbreviations

AVHRR	Advanced Very High Resolution Radiometer
BAPMON	Background Air Pollution Monitoring (WMO/UNEP)
CACGP	Commission on Atmospheric Chemistry and Global Pollution
CCCO	Joint Committee on Climatic Changes and the Ocean
CEC	Cation Exchange Capacity
CFC	Chlorofluorocarbon
CIDA	Canadian International Development Agency
CODATA	Committee on Data for Science and Technology
COMAR	Coastal Marine Project (Unesco)
COSPAR	Committee on Space Research
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australi)a
DMS	Dimethylsulphide
EC-IGBP	Executive Committee IGBP
ENSO	El Nino - Southern Oscillation
EOS	Earth Observing System (USA)
ESF	European Science Foundation
ET	Evapotranspiration
FAGS	Ferderation of Astronomical and Geophysical Services
FAO	Food and Agriculture Organization
FIFE	First ISLSCP Field Experiment
GARP	Global Atmospheric Research Programme
GBM	Geosphere - Biosphere Models
GBO	Geo-Biosphere Observatories (IGBP)
GC	Gas Chromatograph
GCM	General Circulation Model
GEMS	Global Environment Monitoring System
GEWEX	Global Energy and Water Cycle Experiment (WCRP)
GIS	Geographic Information System
GMCC	Global Monitoring for Climate Change (USA)
GRID	Global Resource Information Database (UNEP)
HRGC	Human Response to Global Change (IFIAS/ISSC/UNU)
IABO	International Association for Biological Oceanography
IAGA	International Association of Geomagnetism and Aeronomy
IAHS	International Association of Hydrological Sciences
IAMAP	International Association of Meteorology and Atmospheric Physics
IBP	International Biological Programme (ICSU)
ICA	International Cartographic Association
ICC	Interagency Coordinating Committee (IGBP)
ICL	Inter-Union Commission on the Lithosphere
ICSU	International Council of Scientific Unions
IFIAS	International Federation of Institutes of Advanced Studies
IGAC	Internaitonal Global Atmospheric Programme (CACGP/IAMAP)
IGBP	International Geosphere-Biosphere Programme: A Study of Global Change
IGCP	International Geological Correlation Programme (Unesco)
IGU	International Geographical Union
IGY	International Geophysical Year (ICSU)
IHP	International Hydrological Programme (UNESCO)
IIASA	International Institute of Applied Systems Analysis
ILP	International Lithosphere Programme
INQUA	International Union for Quaternay Research
INTECOL	International Association for Ecology
IOC	Intergovernmental Oceanographic Commission (Unesco)
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land Surface Climatology Project (COSPAR/IAMAP)
ISRIC	International Soil Reference and Information Centre

ISSC	International Social Science Council
ISSS	International Society of Soil Science
ISY	International Space Year
IUBS	International Union of Biological Sciences
IUCN	International Union for the Conservation of Nature and Natural Resources
IUGG	International Union of Geodesy and Geophysics
IUGS	International Union of Geological Sciences
IUPAB	International Union of Pure and Applied Biophysics
JGOFS	Joint Global Ocean Flux Study (SCOR)
JSC	Joint Scientific Committee for WCRP
LAI	Leaf-Area Index
LANDSAT	Land Remote-Sensing Satellite (USA)
LAVIP	Land-Surface-Atmosphere-Vegetation Interaction Programme (IAMAP/IAHS)
MAB	Man and the Biosphere Programme (Unesco)
MS	Mass Spectrometer
NAS	National Academy of Science (USA)
NASA	National Aeronautics and Space Administration (USA)
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmosphere Administration (USA)
NSF	National Science Foundation (USA)
OCM	Ocean Circulation Model
PAM	Plant Available Moisture
PBL	Planetary Boundary Layer
PFT	Plant Functional Type
PLSPC	Research Programme on Land-Surface Processes and Climate (WCRP)
QBO	Quasi-Biennial-Oscillation
SASIFY	Space Agency Forum on International Space Year
SAC	Scientific Advisory Council of the IGBP
SCAR	Scientific Committee on Antarctic Research
SC-IGBP	Special Committee for the IGBP
SCOPE	Scientific Committee on Problems of the Environment
SCOR	Scientific Committee on Ocean Research
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
SOTER	World Soils and Terrain Data Base
SPOT	Système pour l'Observation de la Terre
SSC	IGBP Scientific Steering Committee
STEP	Solar Terrestrial Energy Programme (SCOSTEP)
TM	Thematic Mapper
TOGA	Tropical Oceans and Global Atmosphere Programme (WCRP)
UN	United Nations
UNCSTD	UN Center for Science and Technology for Development
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNU	United Nations University
URSI	Union Radio Scientifique Internationale
WCDP	World Climate Data Programme
WCIP	World Climate Impact Programme
WCP	World Climate Programme
WCRP	World Climate Research Programme
WDC	Panel on World Data Centres (Geophysical and Solar)
WDDES	World Digital Database for Environmental Science
WMO	World Meterological Organization
WOCE	World Ocean Circulation Experiment

Appendix 9.

CONSTITUTION OF

THE SPECIAL COMMITTEE FOR THE INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME: A STUDY OF GLOBAL CHANGE (IGBP)

I. THE PROGRAMME

1. The objectives of the International Geosphere-Biosphere Programme: A Study of Global Change (IGBP) of ICSU, hereinafter referred to as <u>the Programme</u>, are to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the changes that are occurring in this system, and the manner in which they are influenced by human actions.

Priority in the Programme will fall on those areas of each of the fields involved that deal with key interactions and significant change on time scales of decade to centuries, that most affect the biosphere, that are most susceptive to human perturbation, and that will most likely lead to practical , predictive capability. In concentrating on interactive biological, chemical, and physical processes the Programme will of necessity put less emphasis on studies that, though they have great strengths and momentum of their own, are already being addressed in existing initiatives, or that will less clearly contribute to our understanding of the changing nature of the environment of life on timescales of decades to centuries.

II. THE SPECIAL COMMITTEE

2. The responsibilities of the Special Committee for the Programme, hereinafter referred to as <u>the Special Committee</u>, are to define and plan the Programme, to guide its implementation and to publicise its results. The Committee, together with ICSU, should also seek to ensure that adequate use is made of its results.

3. The Special Committee will promote the coordination of the national, regional and international activities that constitute the Programme.

4. The Special Committee will ensure liaison, and facilitate cooperation, with related programmes of members of the ICSU family and of other international organizations, both governmental and non-governmental.

5. The members of the Special Committee shall be appointed by the ICSU Executive Board for three year terms *. Each member shall normally not be eligible for re-appointment more than once.

6. The Executive Director (see paragraph 19), on behalf of the Executive Committee (see paragraph 11), shall invite the adhering bodies (see paragraph 25) to put forward names of those scientists that they wish to put forward as candidates for appointment to membership of the Special Committee at least four months before the meeting at which membership is being considered. Each submission should be accompanied by biographical data.

7. The Special Committee will, based on the recommendations received, propose new members to the ICSU Executive Board.

8. The Chairman, the Vice-Chairman and the Treasurer of the Special Committee are elected by the Special Committee from among its members, while the Executive Director is appointed by the ICSU Executive Board. These four persons constitute the Officers of the Special Committee.

9. The Special Committee shall meet at least once a year with the frequency determined by the Chairman in consultation with the Executive Committee (see Section III). The date and place of the meeting and the agenda will be communicated to members by the Executive Director at least four months in advance.

---

*) In each of the second and third year of existence, terms for one third of the membership will be extended to provide for staggered rotation.

10. The Chairman may invite observers to attend meetings of the Special Committee.

III. THE EXECUTIVE COMMITTEE

11. The Executive Committee is responsible for conducting the affairs of the Special Committee between meetings.

12. The Executive Committee shall consist of the Officers, and two ordinary members elected by the Special Committee.

13. The term of the elected members of the Executive Committee shall be for three years *. Each member shall normally not be eligible for re-election more than once. The term of the Executive Director, appointed by the Executive Board of ICSU, is three years, renewable.

14. The Chairman, in consultation with the Executive Committee, may make appointments to fill vacancies in the Executive Committee, such appointment to extend to the time of the next meeting of the Special Committee.

15. In the event of a vacancy of the Chairmanship, the Vice-Chairman shall succeed to this office until the next meeting of the Special Committee.

16. The Executive Committee shall normally meet twice a year. The date and place of the meeting and the agenda will be communicated to the members by the Executive Director at least two months in advance.

17. The Chairman shall be responsible for the implementation of the policy of the Special Committee, assisted by the Executive Director.

18. The Treasurer shall submit annual budgets and financial reports for approval by the Special Committee.

---

*) See note to paragraph 5.

19. Under the general direction of the Chairman, the Executive Director will be responsible for the expeditious and orderly conduct of the activities of the Special Committee. The Executive Director shall prepare an annual report on the activities of the Special Committee, and shall prepare for the meetings of the Special Committee, the Executive Committee and the Scientific Advisory Council (see Section IV).

IV. THE SCIENTIFIC ADVISORY COUNCIL

20. The Scientific Advisory Council (SAC) shall advise on the scientific contents of the Programme, assess its results and make recommendations for the general policies of the Special Committee.

21. It shall have, in particular, the following functions:

a. to give advice on the scientific content of the Programme and to review the scientific activities of the Executive and Special Committees since its previous meeting;

b. to provide a forum and a mechanism for cooperation between the participating Adhering Bodies;

c. to review recommendations of the Special Committee on the range of annual dues to be paid by the National Adhering Bodies (see paragraph 26a).

22. The Scientific Advisory Council shall be composed of scientists nominated by members of ICSU in all categories of membership. In addition, observers from other organizations will be invited to attend SAC meetings, on the authority of the SC-IGBP Chairman.

23. The SAC shall normally meet every two years under the chairmanship of the ICSU President, or his representative. Extraordinary meetings may be called by the Special Committee or by at least one third of the National Adhering Bodies; in either case at least four months notice shall be given.

24. The dates and place of an ordinary meeting of the SAC shall be communicated at least six months in advance. Items proposed for inclusion in the Agenda must be received by the Executive Director at least four months before the ordinary meeting of the SAC. The agenda shall be communicated at least three months before the meeting.

V. ADHERING BODIES

25. The adhering bodies to the Special Committee shall consist of members of ICSU in all categories of membership, i.e.:

a. National* Adherents,

b. Scientific** Adherents wishing to participate in the Programme.

VI. FINANCE

26. The finances of the Special Committee shall be conducted in accordance with ICSU's Rules for Scientific and Special Committees.

27. The funds of the Special Committee are obtained from dues of its National Adherents, subventions, donations, contracts or revenues from sales or investments.

28. The National Adherents shall pay annual dues within a scale determined by the Special Committee.

29. All Adherents will provide for the expenses of their representatives to meetings of the Scientific Advisory Council.

30. In the event of the dissolution of the Special Committee, its assets shall be ceded to ICSU.

---

*) ICSU Statutes, Articles 8, 12 and 13.

**) As given by ICSU Statutes, Articles 7, 14, 15 and 41.

VII. AMENDMENTS TO CONSTITUTION

31. Amendments of the Constitution shall be submitted by the Special Committee after approval by two-thirds of all members, and after consultation with the SAC, to the Executive Board of ICSU for ratification.

This constitution was approved by the ICSU Executive Board in May, 1988.