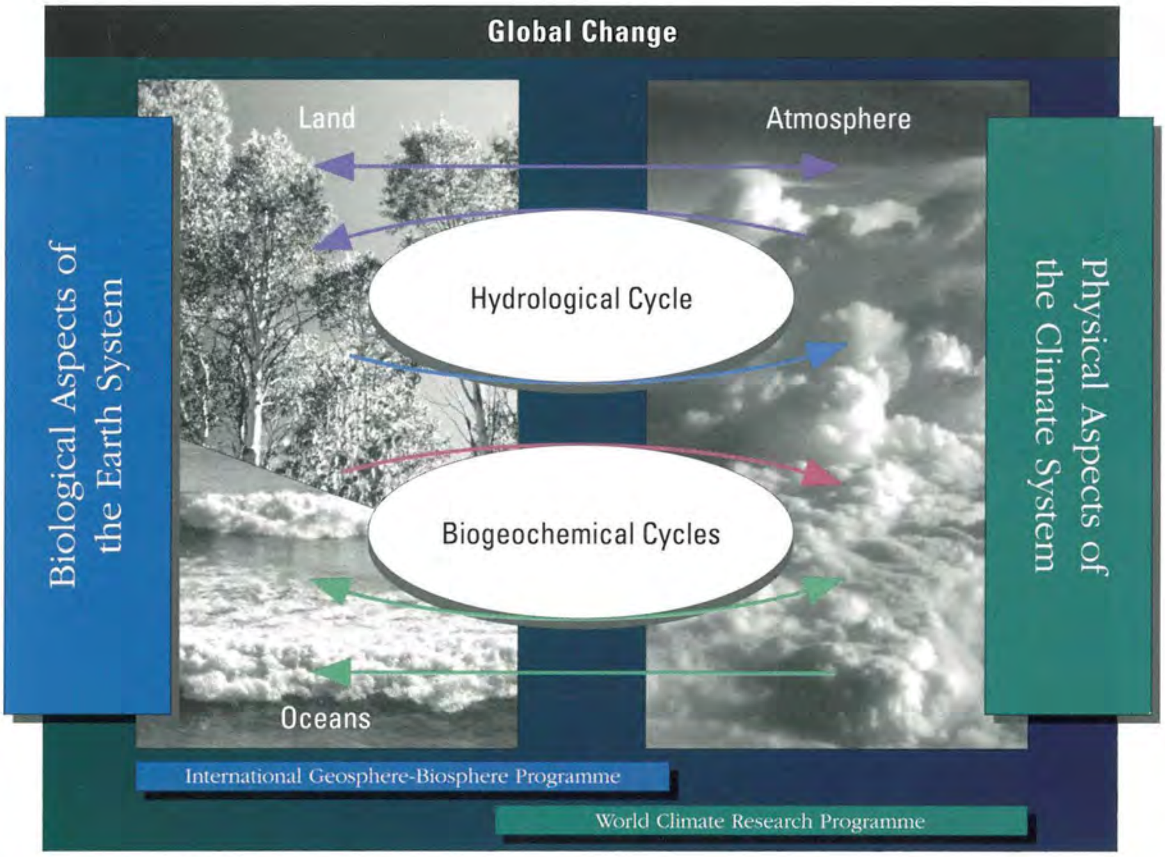
GLOBAL CHANGE

IGBP

REPORT No. 12 1990



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

The Initial Core Projects

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP) of the International Council of Scientific Unions (ICSU)

GLOBAL IGBP CHANGE

REPORT No. 12 1990

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

The Initial Core Projects

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP) of the International Council of Scientific Unions (ICSU)

The planning phase of the IGBP has been supported by ICSU, the governments of Sweden (especially in support of the Secretariat) and other nations (particularly those with established IGBP National Committees), UNEP, Unesco, the Commission of the European Communities, the Organization of American States, the African Biosciences Network, the Commonwealth Science Council, and the Third World Academy of Sciences, the Andrew W. Mellon Foundation, Wissenschaftskolleg zu Berlin, Shell Netherlands and IBM Sweden.

Photo credits:

We thank the following authors and organisations for the use of figures and pictures that appear in this report:

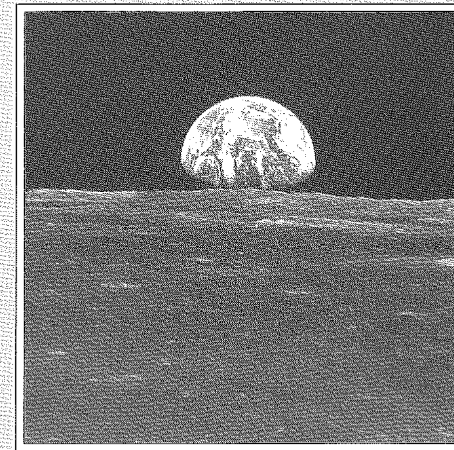
Chapter 1. *Cover and Box A, National Aeronautics and Space Administration, Washington D.C., USA.*
Chapter 2. 1. *Fig. 1, Mooney, Vitousek & Matson (1987), Science 238: 926–932; Box B, Earth System Science Overview, NASA, USA.*
Chapter 2. 2. *Figs. Table 1, Figs. 2–3, Dahback et al. (1989) Photochemistry and Photobiology 49:621; Box A, Ambio, vol. 16, 1, 1987.*
Chapter 4. 1. *Fig. 2, Milliman, J. H. and Meade R. H. (1983) J. Grol, 91:16; Box A, Ambio, vol 6, no. 3, 1988; Box B, Coastal Resources Management Guidelines, Box C, Ambio, vol. 16, no. 1, 1987.*
Chapter 5. 1. *Fig. 1, Ambio, vol. 16, no. 2–3, 1987; Box 1A, Hall F. et al. (1989) Adv. in Geophysics; Fig. 2, NASA: Figure 3, H. H. Shugart.*
Chapter 6. 1. *Box A, Pielke, R. A. and Kittle, T. B. F. (1988). Monitoring Climate for the Effects of Increasing Greenhouse Bas Concentrations, CIRA, Colorado State University, (p. 181); Box B, Davies, M. B. (ed) (1986), "Towards Understanding of Global Change", National Research Council, USA.*
Chapter 7. *Cover, Thompson, L., Byrd Polar Research Center, Columbus OH, USA.*
Chapter 8. 1. *Fig. 1, Earth System Science Uverview, NASA.*
Chapter 9. *Cover, Office for Interdisciplinary Earth Studies, UCAR, Boulder, Co., USA.*
Chapter 12. *Engraving by Hieronymus Bosch, Kupferstich Kabinett, Berlin.*

We also thank all the authors of this report who so generously supplied their own figures for the individual chapters under their responsibility.

Layout, type setting and graphics: Idéoluck AB, Stockholm, Sweden.
Printer: Graphic Systems AB, Stockholm, Sweden, 1990.

The International Geosphere-Biosphere Programme: A Study of Global Change
The Initial Core Projects
IGBP Report 12 (June 1990)

Contents



Overview

"Today the scale of our interventions in nature is increasing and the physical effects of our decisions spill across national frontiers. The growth in economic interaction between nations amplifies the wider consequences of national decisions. Economics and ecology bind us in evertightening networks. Today many regions face risks of irreversible damage to the human environment that threaten the basis for human progress."

Our Common Future
The World Commission on Environment and Development 1987

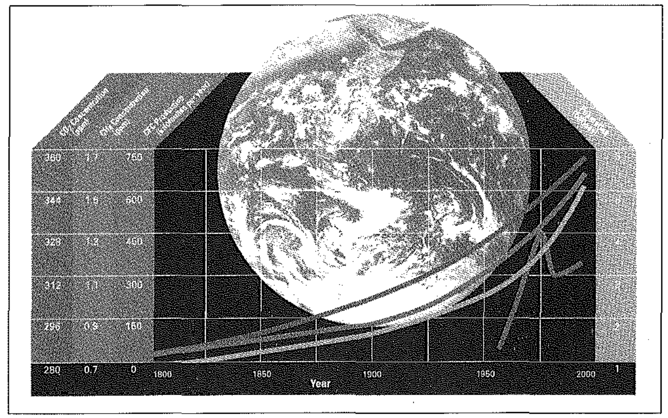
Contents

1. *Overview*

Introduction

Mankind today is in an unprecedented position. In the span of a single human generation, the Earth's life sustaining environment is expected to change more rapidly than it has over any comparable period of human history. Much of this change will be of our own making. Worldwide economic and technological activities are contributing to rapid and potentially stressful changes in our global environment in ways that we are only now beginning to understand. The effects of these changes may profoundly impact generations to come.

Natural forces have influenced and shaped the environment of our planet over the course of its lifetime. The uniqueness and challenge posed by the changes facing us today lie not only in the magnitude and rate at which these changes are occurring, but also in mankind's ability to inadvertently affect such changes. Increasing atmospheric concentrations of greenhouse gases, due in part to the burning of fossil fuels, may significantly alter our climate. Agriculture, forestry, and other land-use practices, industrial activities, waste disposal, and transportation have altered terrestrial and coastal ocean ecosystems; thus affecting, for example, biological productivity, water resources, and the chemistry of the global atmosphere. These fundamental changes, evident also in the decline of stratospheric ozone and in acid precipitation, transcend the traditional boundaries of scientific disciplines and have potential impacts that reach beyond the domains of individual nations.



World population growth and increase in greenhouse gases.

The IGBP is an interdisciplinary research endeavour, carried out within the framework of the International Council of Scientific Unions (ICSU), that is focused on a set of key research questions. Along with the World Climate Research Programme (WCRP) and other international research efforts it addresses critical unknowns related to global environmental change. The extent of intergovernmental endorsement of the programme is reflected in the UN General Assembly resolution of 17 December 1989 (A/C.2/44/L.40/Rev.1), which "Recommends that Governments, with due consideration of the need for increased scientific knowledge of the sources, causes and impact of climate change and of global, regional and local climates, continue and, wherever possible, increase their activities in support of the World Climate Research Programme and International Geosphere-Biosphere Programme, including the monitoring of atmospheric composition and climate conditions, and further recommends that the international community supports efforts by developing countries to participate in these scientific activities". In addition, the Intergovernmental Panel on Climate Change (IPCC) has identified IGBP and WCRP as the two major research programmes devoted to decreasing our uncertainty in relation to global climate change.

The IGBP and WCRP are complementary programmes of research, under the aegis of ICSU (and for WCRP, the WMO), that together address the scientific issues of global environmental change. The research focus of the IGBP is on the biogeochemical aspects of global change phenomena, on Earth system modelling and the recovery and interpretation of data dealing with global changes of the past; the WCRP addresses the physical aspects of the climate system. A schematic depiction of the areas of concern to the IGBP, including the connections addressed in some of the key research questions and the relation of the programme to companion activities of the WCRP, is shown in Figure 1.

Three developments make the IGBP and WCRP possible:

(1) Progress in the individual disciplines that are involved has evolved to the stage that truly interdisciplinary studies of global problems are now tractable.
(2) Modern tools of research are now available that are capable of global-scale observations, theoretical constructs and predictive models. Remote-sensing spacecraft allow global measurements of key parameters of Earth system behavior, including the detection of global environmental change. Modern computers allow, for the first time, the collection and rapid dissemination of global data sets and permit the construction and operation of global models of coupled systems.
(3) National and international infrastructure and communications capabilities make possible the planning and effective administration of research programmes that are interdisciplinary in nature and global in scale.

The concerns that drive the IGBP are international in character, with causes and effects that transcend national boundaries. The global measurements, observations and synthesis that are required necessitates international cooperation; the human and material resources needed to mount the programme cannot be met without involvement of most countries. All nations have a stake in the consequences of global change; any hope of concerted response strategies requires their involvement in the design and execution of research that must be the basis for recommended policy actions.

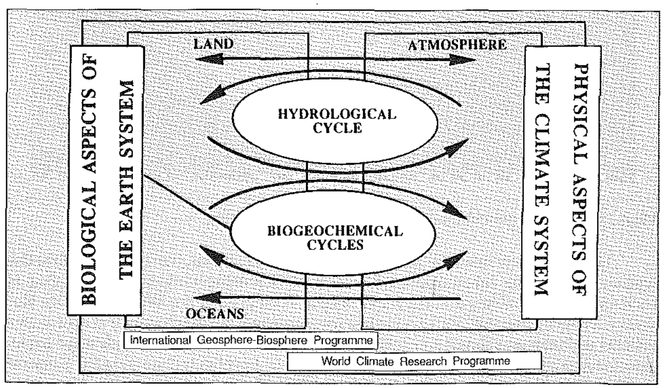


Figure 1. Linkages among biological, chemical and physical processes critical to our understanding of global change on a decade-to-century time scale. Arrows refer to the seven first research priority questions as described in this report.

The Challenge

Within the decade of the 1990s, the IGBP will launch a world-wide research effort, unprecedented in its comprehensive interdisciplinary scope, to address the functioning of the Earth system and to understand how this system is changing. The body of information generated by the IGBP will form the scientific underpinning for predictions relating to future causes and effects of global changes. Through its observational network and process studies, and the effective communication of the resulting data to scientists in all nations committed to this endeavor, the IGBP will help provide the world's decision makers with input necessary to wisely manage the global environment.

The IGBP will design and implement research projects to produce global data sets on properties and processes central to global change. These will include observations and studies at the Earth's surface as well as from an array of Earth-sensing satellites. This research will make use of a network of Regional Research Centres in forging a new understanding of the interactions among biogeochemical cycles and physical processes of the Earth system. The IGBP will also interpret critical records of global changes of the past - particularly the records of the last 2,000 years, which when compared to the most recent glacial cycle will help us to understand the roles of human and natural forces in global change. The unification of global biogeochemical and physical approaches in the study of global change, combined with an understanding of the record of the past, will be used to develop models for predicting future change.

In the course of this endeavour, the IGBP will promote an interdisciplinary approach to studies of the Earth system. This is essential to educate the next generation of scientists, so that they will more fully understand the complexities of this system. This knowledge will be the key to success in the wise use of the Earth's resources for generations to come.

Objective

- *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 activities.*

The IGBP is concerned with the significant interactions of biological, chemical, and physical processes that govern changes in the Earth system and that are most susceptible to human perturbation. The primary goal of the IGBP is to develop a predictive understanding of the Earth system, especially in relation to changes that effect the biosphere. To make this goal achievable, emphasis is placed on a time scale of decades to centuries.

As an evolving programme the IGBP selects from the broad array of subjects that comprise the science of the Earth system, those issues that are deemed to be of greatest importance in contributing to our understanding of the changing nature of the global environment on timescales of decades to centuries, that most affect the biosphere, and that are most susceptible to human perturbations and that will most likely lead to practical, predictive capability.

Structure of the Research Programme

While the objective of the IGBP is to understand the interactive processes that regulate the total Earth system, for practical reasons, a suite of Core Projects on the distinct sub-components of the system must be designed. In this context, the IGBP has defined a number of research priority questions, within which core research projects are being developed. Each of these priorities focusses on process linkages where the current state of understanding is insufficient to predict future changes. In addition, consideration of how natural and human forces contribute to global change is included.

The Core Projects focus on the important sub-components of the global Earth system. Each project must be intellectually challenging and scientifically sound, administered with minimal bureaucracy, and designed with provision for review and with flexibility to adapt to changing needs. The success of each of them will depend on the active involvement, in planning and execution, of the best scientists in each of the fields involved. In view of the global focus, a true international approach is necessary with the involvement of scientists throughout the world. Success of the overall effort will require strong national support and international coordination.

The research priority questions and the projects that make up the programme are expected to evolve with new insights and understanding, but the initial operational phase of the programme focuses on seven key questions:

1. How is the chemistry of the global atmosphere regulated and what is the role of biological processes in producing and consuming trace gases?
2. How do ocean biogeochemical processes influence and respond to climate change?
3. How changes in land use affect the resources of the coastal zone, and how changes in sea level and climate alter coastal ecosystems?
4. How does vegetation interact with physical processes of the hydrological cycle?
5. How will global changes affect terrestrial ecosystems?
6. What significant climatic and environmental changes have occurred in the past, and what were their causes?
7. How can our knowledge of components of the Earth system be integrated and synthesized in a numerical framework that provides predictive capability?

These questions will be addressed through activities of observation, process studies and modelling in the context of a limited set of Core Projects. Based on the above seven questions, the Core Projects described in the following chapters have been developed during many planning meetings held by the IGBP over the past two years where scientists from many nations of the world participated actively. These Core Projects have been designated by the ICSU Special Committee for the IGBP as established, proposed, or potential, reflecting the current status of endorsement by the world scientific community and the state of readiness for implementing them.

Following two key activities relate to the needs of all Core Projects and for this reason are managed separately:

1. The development of a global Data and Information System that will provide immediate and open access to all researchers, that will provide information needed for Earth system models, and that will define and sustain the long-term observations needed to detect significant global changes.
2. The establishment of a set of Regional Research Centers in developing countries where strong synthesis and modelling projects of relevance to overall IGBP objectives and regional priorities will be developed, in close cooperation with existing research networks. Training and exchange programmes will be one of the mechanisms to involve the scientists from the region in Core Project activities.

Descriptions of the specific objectives of the Core Projects; the IGBP Data and Information System, Regional Research Centres, and the relationships between the Core Projects are given below.

Question 1: How is the chemistry of the global atmosphere regulated and what is the role of biological processes in producing and consuming trace gases?

The International Global Atmospheric Chemistry Project (IGAC) - An Established Core Project

- *To develop a fundamental understanding of the processes that determine the chemical composition of the atmosphere.*
- *To understand the interactions between atmospheric chemical composition and biospheric and climatic processes.*
- *To predict the impact of natural and anthropogenic forcing on the chemical composition of the atmosphere.*

Stratosphere-Troposphere Interactions and the Biosphere (STIB) - A Proposed Core Project

- *To determine the consequences of changes in stratospheric O_3 on penetration of potentially harmful UV radiation.*
- *To quantify important stratosphere-troposphere exchange processes.*
- *To evaluate the natural variability of the stratosphere and the impact of anthropogenic activities.*
- *To quantify the influence of stratospheric aerosols on climate.*
- *To assess the impact of stratospheric changes on climate.*

Question 2: How do ocean biogeochemical processes influence and respond to climate change?

Joint Global Ocean Flux Study (JGOFS) - An Established Core Project

- *To determine and understand on a global scale the processes controlling the time-varying fluxes of carbon and associated biogenic elements in the ocean, and to evaluate the related exchanges with the atmosphere, sea floor, and continental boundaries.*
- *To develop a capability to predict on a global scale the response of oceanic biogeochemical processes to anthropogenic perturbations, in particular, those related to climate change.*

Global Ocean Euphotic Zone Study (GOEZS) - A Potential Core Project

- *To develop a predictive understanding of the basic relationships among the physical, chemical, and biological properties of the oceanic euphotic zone.*

Question 3: How changes in land use affect the resources of the coastal zone, and will changes in sea level and climate alter coastal ecosystems?

Land-Ocean Interactions in the Coastal Zone (LOICZ) - A Proposed Core Project

- *To develop predictive understanding of the effects of changes in climate change, land use and sea level on the global functioning and sustainability of coastal ecosystems, with emphasis on the interactions between changing conditions on land and sea, and on possible feedback effects physical environment.*

Question 4: How does vegetation interact with physical processes of the hydrological cycle?

Biospheric Aspects of the Hydrological Cycle (BAHC) - An Established Core Project

- *To determine the biospheric controls of the hydrologic cycle through field measurements for the purpose of developing models of the energy and water fluxes in the soil-vegetation-atmosphere system at temporal and spatial scales ranging from vegetation patches to GCM grid cells.*
- *To develop appropriate data bases that can be used to describe the interactions between the biosphere and the physical Earth system and to test/validate model simulations of such interactions.*

Question 5: How will global changes affect terrestrial ecosystems?

Global Change and Terrestrial Ecosystems (GCTE) - An Established Core Project

- *To develop the capability to predict the effects of changes in climate, atmospheric CO2 and land use on terrestrial ecosystems, and how these effects can lead to feedbacks to the physical climate system.*

Question 6: What significant climatic and environmental changes have occurred in the past, and what were their causes?

Past Global Changes (PAGES) - An Established Core Project

- *To reconstruct the detailed history of climatic and environmental change for the entire globe for the period since 2,000 B.P., with temporal resolution that is at least decadal and, ideally, annual or seasonal.*
- *To reconstruct a history of climatic and environmental change through a full glacial cycle, in order to improve our understanding of the natural processes that invoke global climatic changes.*

Question 7: How can our knowledge of components of the Earth system be integrated and synthesized in a numerical framework that provides predictive capacity?

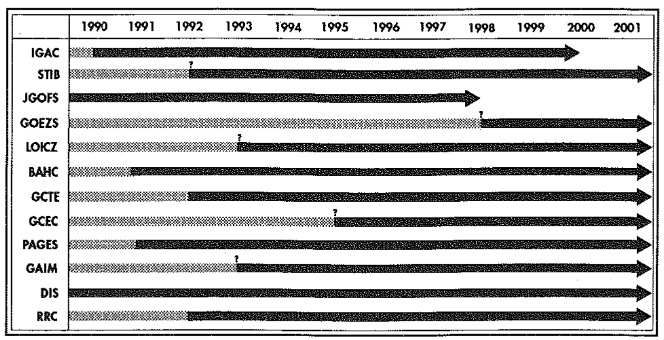
Global Analysis, Interpretation and Modelling (GAIM) - A Proposed Core Project

- *With the aid of models, synthesize a fundamental quantitative understanding of the global physical, chemical and biological interactions in the Earth system during the last 100,000 years and assess possible effects of future changes.*

The science components of the above Core Projects are described in this report. For the established core projects (IGAC, JGOFS, BAHC, GCTE and PAGES), reasonably detailed science plans have been formulated. Implementation of the JGOFS and IGAC Core Projects has already begun. Implementation plans for BAHC, GCTE and PAGES are yet to be developed.

For the proposed Core Projects (STIB, LOICZ and GAIM) science plans have not yet been developed and it is expected that the Scientific Committee for the IGBP (SC-IGBP) will consider their possible establishment within the next year.

The SC-IGBP will consider at a later stage if a science plan should be developed for the potential Core Project (GOEZS and GCEC) following full discussions and consideration by the international science community.



Tentative timelines for IGBP Core Projects and complementary activities.

Data and Information Systems

Efficient data and information systems must be developed and supported in order to accommodate the voluminous amounts of data necessary to address the objectives of the IGBP. Provision must be made for the accessibility and worldwide exchange of information and data. Directories of available data must be compiled and disseminated throughout the research community. Data sets for many properties and processes of the Earth system need to be indexed on comparable time and space scales. The IGBP, in collaboration with the World Data Centres, is undertaking a study to determine the needs of a data and information system for the study of global change, and to develop a strategy for implementation. These and other studies will give particular attention to problems relating to the interpretation and distribution of the vast quantities of data that will be generated by satellite-borne observing systems.

Regional Research Centers

A network of about ten regional research centres for global change studies (RRCs) is being proposed for establishment in developing countries. They will facilitate regional collaboration and research on global change issues, with special emphasis on aspects of processes that manifest distinctly in that region. These centres will assimilate, synthesize, and interpret regional data sets for integration into global-scale synthesis and modelling efforts. They will also extract the relevant regional component from global model output. In this way, these centres will provide to resource managers and decision makers information of particular importance to the region. These centres will also ensure that scientists from less developed countries have an equal opportunity to contribute to the research activities of the IGBP. Long-term core funding for the RRCs must be secured from a broad spectrum of sources and should be administered through a central source to guarantee stable and continuous support during the lifetime of the IGBP.

Relationships between Core Projects

The science components of the Core Projects described in this report clearly have many common links. Particular care has been taken to ensure that the individual descriptions of any Core Project contain explicit references to links with other Core Projects. The broader linkages between the Core Projects are briefly described below.

Production and consumption of important greenhouse gases occur in the terrestrial ecosystem, oceans and the atmosphere. Production and consumption of trace gases other than CO2 are in principle covered in IGAC (Chapter 2.1), while the role of oceans in regulating the atmospheric CO2 concentration is covered by JGOFS (Chapter 3.1) and the comparison studies of the role of the terrestrial ecosystems is described in GCTE (Chapter 6.1).

Water availability is a crucial regulating factor for primary production in most terrestrial ecosystems, and any climate change affecting water availability will have a profound effect on these terrestrial ecosystems. The effects of such changes may influence ecosystem distribution, and in view of the importance of vegetation for the hydrological cycle (BAHC Chapter 5.1), feedback on water availability. The development of Soil-Vegetation Atmosphere Transfer (SVAT) models is an essential component of both BAHC and GCTE.

The studies of processes on land (BAHC, GCTE) and in the oceans (JGOFS) are linked through a proposed Core Project on land-ocean interactions in the coastal zone (LOICZ, Chapter 4.1). Shelf-break processes studies need to be developed further in a dialogue between JGOFS and LOICZ.

The PAGES project addressing past global changes will have close links with the projects assessing the present functioning of the Earth system and in the science plans, several of the latter outline the needs to understand past and present changes in order to predict the future.

In order to distill the information from the core projects dealing with subcomponents of the Earth system and to obtain a comprehensive and predictive understanding of the Earth system, a separate Core Project (GAIM, Chapter 8.1) addresses the integrative aspects of Earth system analysis, interpretation and modelling.

The Requirements

In view of the involvement of many scientific disciplines, the IGBP constitutes the most ambitious scientific programme ever initiated at the international level. Execution of this programme will require unprecedented coordination of field experiments and laboratory studies, powerful computer capability for modelling and data synthesis, Earth-based observations, and multinational ventures in building and operating a comprehensive suite of Earth-observing satellites.

IGBP research will be initiated in the 1990s and will require a decade or more of intensive effort.

The success of the IGBP will depend of the commitment of scientists who are adept at putting disciplinary research into a wider interdisciplinary framework. The IGBP will require the involvement of scientists and national support from all areas of the world in activities such as:

- long-term monitoring and documentation of the Earth system;
- process studies to understand the linkages among the component parts of the Earth system,
- studies to analyze and to synthesize global data sets; and
- development of comprehensive quantitative Earth system models.

Such a bold, urgent, and complex undertaking as that of the IGBP demands that an international infrastructure for planning, coordination, and synthesis be continually and sufficient supported by nations as well as international governmental bodies. There is also an important need for the private sector to participate in this endeavor and to help insure adequate support for all aspects of the IGBP. The scientific progress of the IGBP will depend on high priority being given to a sustained, long-term commitment of financial resources for manpower and facilities in individual nations, as national research programmes will provide the foundation for implementing the research activities of the IGBP. A firm investment now will help to ensure that the abundant gifts of the Earth will be preserved and passed on to future generations.

The Organization

The ICSU initiated detailed planning for the IGBP in late 1986 and appointed a Special Committee to guide the planning and implementation of the programme. Detailed development of the initial research priorities into core projects has been conducted by a number of planning groups that draw upon the expertise of the international science community. Many other ICSU bodies are participating in this process.

Collectively, it is the national IGBP programmes that will have the resources required to implement the core projects. Thus, a close partnership between the national and international planning efforts is essential. To facilitate this, a Scientific Advisory Council for the IGBP has been established. This body consists of representatives from national IGBP committees and ICSU's scientific members with interest in global change research. The council advises on the development of the research programme.

In order to provide for joint planning and coordination with bodies of the United Nations, an Interagency Coordinating Committee has been formed with the participation of the United Nations Environment Programme (UNEP), the United Nations Educational, Scientific, and Cultural Organization (Unesco), and the World Meteorological Organization (WMO).

Other groups are laying the groundwork for a social science based counterpart to the IGBP. The SC-IGBP will strive to ensure the complementarity of these two dimensions of the study of global change.

A Secretariat for the IGBP has been established at the Royal Swedish Academy of Sciences to support the planning and implementation process and to provide a focal point for communication and coordination. The Secretariat publishes the findings of planning group deliberations in a series of IGBP reports, as well as the Global Change NewsLetter.

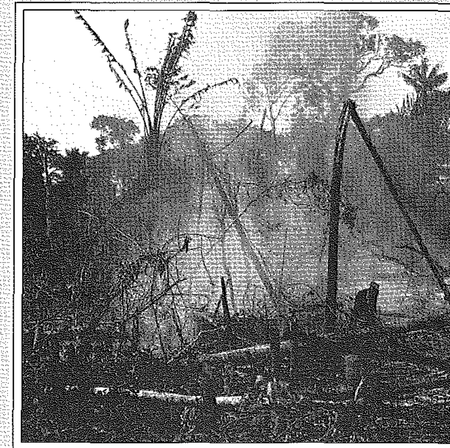
The planning phase of the IGBP has been guided by Special Committee (see Appendix 1). Since its first meeting in July 1987, 50 planning meetings have been organized with the participation of close to 500 scientists (Appendix 6). The dedicated work of all these scientists have been instrumental in the development of the initial IGBP Core Projects.

Through the generous cooperation with Wissenschaftkolleg zu Berlin (West Berlin) it has been possible to appoint IGBP Senior Research Fellows (see Appendix 2). This agreement has been instrumental for the development of the IGBP Core Projects. In addition, a number of IGBP Postdoctoral Fellows (Appendix 2) have also been an important component of the IGBP planning effort.

Acknowledgements

The planning phase of the IGBP has been supported by ICSU, the governments of Sweden (especially in support of the Secretariat) and other nations (particularly those with established IGBP National Committees), UNEP, Unesco, the Commission of the European Communities, the Organization of American States, the African Biosciences Network, the Commonwealth Science Council, and the Third World Academy of Sciences, the Andrew W. Mellon Foundation, Wissenschaftskolleg zu Berlin, Shell Netherlands and IBM Sweden.

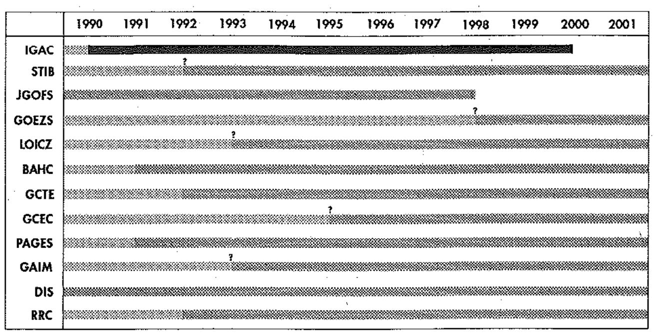
GLOBAL IGBP CHANGE



How Is the Chemistry of the Global Atmosphere Regulated and What Is the Role of Biological Processes in Producing and Consuming Trace Gases?

Atmospheric concentrations of several trace gases are increasing rapidly, mainly due to human activities. Increases in so-called greenhouse and other trace gases result in changes in the composition of the atmosphere thus affecting physical aspects of the climate system. These gases interact in the stratosphere resulting in alteration in the chemical composition, radiation, and dynamics in the stratosphere and potentially affect the lower troposphere and even the biotic system via modulations of the solar UV-B radiation received at the Earth's surface. Many of these gases are produced biologically or affect biological processes. The sources and sinks of important chemical components of the atmosphere and their interactions with living organisms need to be identified and quantified. An understanding of the key processes regulating the composition of the atmosphere and feedback mechanisms that affect the behaviour of the system is necessary.

Contents

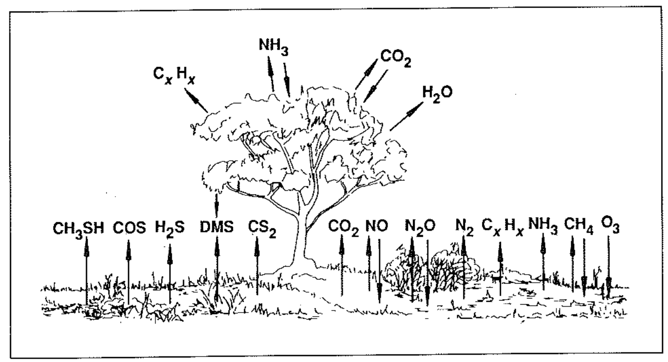


2.1 *The International Global Atmospheric Chemistry Project (IGAC)*

An Established Core Project

Introduction

The chemical composition of the atmosphere is to a large degree determined by the uptake and release of a large variety of trace gases by the biosphere. In turn, the Earth's climate and the deposition of chemical compounds, containing essential nutrient elements (such as C, N, P, S), are of critical importance for the sustainability of the biosphere. Climate, biospheric conditions and atmospheric chemical composition together thus form a strongly interactive system. The biospheric production of relatively small amounts of trace gases such as CO_2, CH_4 and N_2O are of special interest, as these greenhouse gases trap terrestrial infrared radiation, thus warming the Earth's surface. In addition, CH_4, N_2O and a large variety of other biogenic trace gases, such as CO, NO_x and a range of Volatile Organic Compounds (VOC), play a key role in atmospheric chemistry by affecting tropospheric and stratospheric concentrations of ozone, the penetration of photochemically and biologically active solar ultraviolet radiation to the Earth's surface, and the production of hydroxyl (OH) radicals. These are responsible for the removal of almost all trace gases that are emitted by biological or anthropogenic processes into the atmosphere.

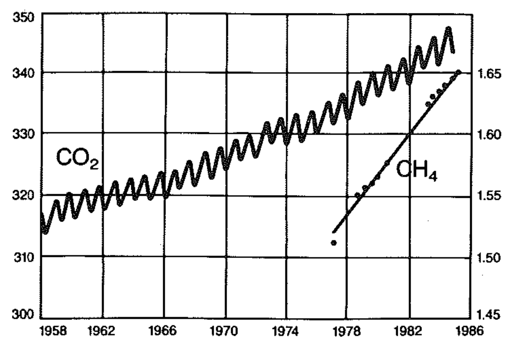


Exchange of gases between ecosystem components and the atmosphere. (Mooney et al. 1987).

Information obtained from the analysis of air bubbles trapped in glacier ice strongly suggests that at least during the present geological period the chemical composition of the atmosphere has tended towards equilibrium conditions that were characteristic of the glacial and interglacial periods. Changes in the atmospheric concentrations of CO_2 and CH_4, with lower values during the glacial periods, together with lower water vapour concentrations, have been shown to be significant amplifiers of the climate forcing that were driven by variations in the orbital characteristics of the Earth's motion around the sun.

The chemical composition of the atmosphere has for the past few centuries been changing, initially under the influence of agricultural, more recently by industrial activities. As a consequence, the atmospheric volume mixing ratio of CO_2 has increased from 280 to 350 ppm and for CH_4 from 0.7 ppm to 1.7 ppm over the past two centuries. Currently, the measured annual increases of these gases are equal to 0.4 - 0.5% and 0.7 - 1.1% respectively. In addition the atmospheric concentrations of several other trace gases are increasing. The most important among these are the industrially produced chlorofluorocarbon gases $CFCl_3$ and CF_2Cl_2, but also N_2O with annual atmospheric growth rates of about 4%, 0.2 - 0.3%, respectively. All these gases have long atmospheric residence times, ranging between about 10 years for CH_4 and about 200 years for N_2O. All these compounds are important greenhouse gases. Although CO_2 is the single most important among them, the combined greenhouse forcing of CH_4, $CFCl_3$, CF_2Cl_2, N_2O, and a few additional gases together is about equal to that of CO_2. In addition, and in contrast to CO_2, which is chemically very stable, CH_4, N_2O, $CFCl_3$, and CF_2Cl_2 are of critical importance for stratospheric and tropospheric chemistry. The observed increases in the above mentioned gases have caused great concern for a rapid climate warming by several degrees in the next century, especially because of the rapid growth of $CFCl_3$ and CF_2Cl_2, major depletions in stratospheric ozone have already occurred.

OBSERVED INCREASES IN ATMOSPHERIC CARBON DIOXIDE AND METHANE, RESULTING IN PART FROM HUMAN ACTIVITIES



In the troposphere, the observed increase in CH_4 concentrations is of great significance for the oxidative power of the atmosphere which is largely determined by the great reactivity of hydroxol (OH) radicals which are formed by the action of solar ultraviolet radiation on ozone and water vapour. In most of the troposphere, OH radicals react mainly with CH_4 and CO. The atmospheric concentration of CO is increasing, at least in the Northern Hemisphere, by 0.7 - 1% per year. With both CO and CH_4 increasing, the result could thus be an overall decrease in global average OH concentrations, leading to further accumulation of most trace gases in the atmosphere, including CH_4 and CO themselves, thus opening the possibility of a strong positive feedback mechanism. This development may to some degree be counteracted, however, at the cost of the buildup of tropospheric ozone during the photochemical oxidation of CO, CH_4 and VOC in the presence of anthropogenically produced NO, which serve as catalysts to produce ozone, especially in the middle latitude regions of the northern hemisphere. The latter development has indeed been observed and may imply an increase stress on the mid-latitude biosphere. Presently the input of NO into the troposphere is dominated by anthropogenic activities; fossil fuel burning in the industrialized and biomass burning in tropical developing countries. It is thus important to obtain information on the atmospheric and biospheric sources and sinks of the aforementioned trace gases. This will be one of the main goals of IGAC.

In addition, studies of the sources, sinks and atmospheric chemical transformation reaction of volatile sulphur compounds, especially dimethyl sulphide (DMS) and sulphur dioxide (SO_2) are of eminent importance, as their oxidation leads to the formation of sulphuric acid aerosol. This is the main source for cloud condensation nuclei (CCN) for much of the atmosphere. This has a large influence on cloud formation processes, and thus on the hydrological cycle and the radiative properties of the Earth's atmosphere through effects on cloud albedo. The main source of SO_2 is the combustion of sulphur-containing fossil fuels; most DMS is produced by marine phytoplankton. It is of importance to find out whether and how the cloud climatology of the mid-latitude regions of the northern hemisphere may have been affected by the large industrial SO_2 emissions. Regarding the DMS emissions, measurements of its oxidation product methane sulphonic acid in polar ice cores show the presence of higher concentrations during glacial than interglacial periods, indicating higher sulphate aerosol concentrations during glacial periods and thus suggesting another positive feedback mechanism between the biosphere and climate in addition to those observed for CO_2, CH_4, and N_2O.

Especially in the tropics the rapid rate of land-use changes that accompany human population growth is contributing to the perturbation of biosphere-atmosphere interactions. For example, the emissions of hydrocarbons, carbon monoxide and nitrogen oxides from biomass burning during the dry season result in the photochemical production of large amounts of ozone. Increased rice production most likely contributes significantly to increasing CH_4 concentrations. Enhanced N_2O releases may well result from increased application of N-fertilizers and tropical deforestation activities.

These and other anthropogenic emissions affect the atmosphere over a range of spatial scales. Hydrocarbon and NO emissions from automobiles produce their greatest impact in the form of photochemical smog in the environs of major urban centers, although some other products, such as CO and O_3, may spill over into the background troposphere. Carbon dioxide, emitted from the burning of fossil fuels and deforestation activities, has a global impact on climate, while sulfuric and nitric acid deposition, originating from the sulphur dioxide and nitrogen oxides from the same combustion, has impacts on regional or sub-continental scales due to the shorter atmospheric lifetimes of these gases.

Many of the atmospheric chemical aspects of the issues indicated above still need to be clarified by research efforts, several of them requiring close international participation. In addition, despite the indisputable importance of atmosphere/biosphere exchange, the magnitude of the fluxes of all of the aforementioned important gases with biological sources, the processes that control these fluxes, and possible future changes in flux strengths remain poorly known. This is due to the complexity of processes occurring in the atmosphere and in the biosphere, as well as at their interface. To address especially the atmospheric chemistry part of these important issues the Commission on Atmospheric Chemistry and Global Pollution (CACGP) of the International Association of Meteorology and Atmospheric Physics (IAMAP/IUGG) has developed an International Global Atmospheric Chemistry Project (IGAC), as described in Galbally (1989), with the following objectives:

Objectives

- *To develop a fundamental understanding of the processes that determine the chemical composition of the atmosphere.*
- *To understand the interactions between atmospheric chemical composition and biospheric and climatic processes.*
- *To predict the impact of natural and anthropogenic forcing on the chemical composition of the atmosphere.*

Although IGAC project planners addressed some of the biosphere-atmosphere interaction issues, the need for stronger interdisciplinary approaches to these problems was recognized, requiring collaboration between specialists such as plant physiologists, marine chemists, microbiologists, ecologists, soil scientists, cloud physicists, meteorologists, oceanographers and atmospheric chemists. While there was thus a strong perception that biological interactions would have to be an essential component of the research activities, the biological and ecological community was not well enough represented to formulate the essential biological component of the initial IGAC research programme. The IGBP, therefore, encouraged the development of strong linkages to biological research related to production and consumption of trace gases.

To establish this linkage, two workshops on issues concerned with trace-gas emissions with participation from both research communities were conducted. The first of these (Andreae and Schimel 1990) identified a large number of fundamental gaps in the understanding of the exchange of trace gases between the atmosphere and terrestrial ecosystems. This realization led to a SCOPE/ IGBP workshop on Trace Gas Exchange in a Global Perspective, which developed a research plan for the biological aspects of the interactions between terrestrial ecosystems and atmospheric chemistry. This plan (Matson and Ojima 1990) emphasizes especially the necessity for understanding the controls and interactions in the plant-soil-water system, which regulate trace gas exchange.

This biologically oriented component has been incorporated into the present updated IGAC science plan. Several of the activities described in the original IGAC report have been enlarged to strengthen their biological aspects. Several new activities have thus been added to the previously identified research foci of IGAC, (Galbally 1989) as well as an entirely new Focus on Trace Gas Fluxes in Mid-latitude Ecosystems.

In addition, the development of research plans for marine biosphere-atmosphere chemistry interactions are ongoing in cooperation with JGOFS. A meeting was held between IGAC and JGOFS scientists on Biogeochemical Exchanges Between the Atmosphere and Oceans, in December 1989. Initial collaborative plans have been made for the North Atlantic regional study. Further developments will be discussed between the IGAC and JGOFS with IGAC taking the primary responsibility for further development of Core Activities.

From the extensive list of Core Activities, it is clear that not all the Activities in the science plan will begin at the same time. Some Activities are ready to begin almost immediately or have already begun. Others are feasible but require further planning and are expected to commence within two to three years. Still others are in conceptual stages. For each of them a planning committee and convener have been appointed, whose task it will be to develop implementation plans for the Activities. The overall IGAC Core Project is overseen by a Scientific Steering Committee whose task is to ensure the progress of IGAC and set priorities.

Finally, because of the existence of strong interactions between stratospheric and tropospheric processes, it is fully recognized that IGAC has strong links with STIB (Chapter 2.2).

Science Components

Focus 1 — *Natural Variability and Anthropogenic Perturbations of the Marine Atmosphere*

The oceans are both major source and sink regions for various atmospheric C, N, S, and halogen containing compounds that influence climate, cloud microphysical properties and atmospheric ozone. The chemistry of the marine atmosphere can be strongly affected by natural and anthropogenic substances carried through the atmosphere from continental sources. In fact, the marine atmosphere constitutes a suitable environment to study the atmospheric chemical processes in "background air", isolated from the large and patchy features of the continental chemical inputs. Furthermore, the marine environment can be substantially altered when substances of continental origin are deposited on the ocean surface. The Core Activities proposed under Focus 1 will concentrate on these issues. Some of them will be carried out in collaboration with JGOFS (Chapter 3.1).

Activity 1 — *North Atlantic Regional Study*

The North Atlantic is rimmed by continental industrial regions, which are major sources of compounds that influence the concentration of tropospheric ozone, as well as hydroxyl radicals, and thus the oxidizing efficiency of the atmosphere. In the marine atmosphere, these compounds are being processed chemically and, together with the resulting products, deposited on the ocean surface by wet and dry deposition. These processes have not been studied in any large-scale experiments. They are, therefore, proposed to be carried out in this Activity which will develop from a number of existing ground-based projects (AEROCE, WATOX, GAGE, and TOR) at measurement sites on Barbados, Tenerife, Bermuda and Ireland. The Activity will be expanded step-wise to include other sites in Europe, N. America, and possibly Latin America and Africa. In the later stages of the Activity intensive aircraft and ship-based observations will be added to the field campaigns.

Objectives

- *To understand the transport, transformation and deposition of continental emissions, especially hydrocarbons, CO, NO_x, SO_2 and resulting reaction products, such as O_3, H_2O_2, HNO_3, and sulphate aerosol in the marine troposphere.*
- *To study the delivery of these compounds to the ocean and their impact on surface seawater chemistry and marine biological productivity.*

Task 1. Inventory of chemical climatology and meteorology.

A preliminary inventory will be made of the chemical climatology and meteorology obtained by existing programmes in preparation for the choice of locations, seasons and meteorological situations for upcoming field experiments.

Task 2. Marine atmosphere chemical data base.

Preliminary investigations will be made of the important chemical mechanisms that operate in the marine atmosphere. This phase will thus involve intensive surface measurements of O_3, CO, H_2O_2, NO_x, PAN, HNO_3, NO_y, SO_2, DMS, particulate nitrate and sulphate, VOC, and CFCs. Vertical soundings of O_3 and H_2O_2 will be made at some locations. The measured chemical composition at the sites will be interpreted with chemical transport models.

Task 3. Regional integration.

A comprehensive chemical data set of the North Atlantic region will be developed along with the key mechanisms involved in the processing of chemicals contained in air masses of continental origin. Ground-based, ship-based and aircraft studies will be conducted. Chemical transport modelling will form an integral part of the study (i.e., both in the planning of the experiments and the interpretation of its results).

Activity 2 — *Marine Aerosol and Gas Exchange: Interaction with Atmospheric Chemistry and Climate*

The oceans are important sources of DMS, NH_3, olefinic hydrocarbons, and halogenated organics of biological origin. These trace gases influence the acid-base characteristics of marine aerosols and precipitation in the ocean regions and may play a role in atmospheric oxidant formation. Emissions of DMS and their conversion to sulphate aerosol probably control the formation of cloud condensation nuclei in much of the marine environment and thereby may affect climate by altering the microphysical and radiative properties (especially albedo) of clouds. This Activity will furthermore measure the deposition of nutrients to the ocean and study their influences on biological productivity.

Understanding the exchange between the atmosphere and oceans requires studies of both emissions from the ocean surface and of deposition to it from the atmosphere. Currently such studies are limited by a lack of methods for direct determination of the most important fluxes.

Objectives

- *To understand the chemical, biological, and physical mechanisms that control the exchange of trace gases and particulate materials between the atmosphere and the ocean surface.*
- *To develop formulations of ocean exchange processes for inclusion in global-scale climate and air chemistry models.*
- *To extend the experimental knowledge of air-sea exchange to conditions with strong winds, rough seas, and spray.*

Task 1. Development of novel measurement techniques.

Improvements in the understanding of marine aerosol properties and gas exchange processes can only by achieved through the development of new measurement technologies. High priority goes to fast-response DMS instrumentation for direct flux measurements. Significant improvements are required in speed and accuracy for airborne aerosol and sulphur gas measurements. Likewise, the development of adequate marine platforms for unimpeded micrometeorological measurements (e.g., buoys and towers) is urgently needed. Measurement methods facilitating studies of the fate of emitted gases will be developed, such as the use of aircraft to repeatedly make measurements in the same air masses, which may be traced by the use of balloons or chemical tracer release. At every possible opportunity, intercomparisons will be made with complementary techniques.

Task 2. Methodology intercomparison tests.

Three field campaigns are planned in which new techniques will be tested against traditional methods. The first, to be conducted on the Equatorial Pacific JGOFS cruises, is to take place in November of 1991. The second will be conducted in the Eastern Atlantic in association with ASTEX, a FIRE-2 experiment planned for June, 1992. The third campaign, which is presently planned in collaboration with Focus 8 in 1993, may involve release of a sulphur gas in the Southern Hemisphere, where its deposition, conversion to aerosols, and impact on cloud properties can be studied simultaneously.

Activity 3

East Asian/North Pacific Regional Study

The region of East Asia is characterized by high and rapidly growing anthropogenic emissions of NO_x, SO_2, hydrocarbons and other air pollutants due to its high and growing population density and, in some regions intensive, industrial development. Evidence has already accumulated that concentrations of background ozone during high pressure episodes are substantially elevated compared to those characteristics of the central Pacific. Long-range transport of continental aerosols from the northwestern Pacific regions to Hawaii has also been reported. No systematic study of atmospheric chemistry in East Asia and the Pacific mid-latitudes has been conducted. Quantifying the emissions and the fate of atmospheric constituents in the East Asian troposphere requires international cooperation among scientists from this part of the world, as well as from other interested nations. Although the scientific objectives are rather similar, a major distinction compared to Focus 1, Activity 1 will be the substantially different meteorological conditions and emission patterns between the study areas. The proposed study will be centred on the oceanic region bounded by the coasts of China and Japan.

Objectives

- *To assess transport and chemical transformations of air pollutants over the East-Asian continent and the North-Western Pacific Ocean.*
- *To determine the depositions of primary and secondary pollutants (sulphate, nitrate, organics) in the East Asian region.*

Task 1. Develop an emission inventory and air chemistry data base for the study region.

Of special importance are emissions and/or wet and dry depositions of NO_x, HNO_3, CO, CH_4, VOC, and SO_2. Furthermore, a compilation of existing measurements on these compounds and ozone should be developed.

Task 2. Surface measurements of important trace gases.

It is important to conduct surface-based measurements of O_3, NO_x, SO_2, VOC, PAN, as well as of the chemical composition of aerosol and precipitation at various sites in the study area (to be determined). These measurements will be interpreted with chemical transport models.

Task 3. The intensive field programme.

Emissions inventory and meteorological data will be incorporated into a numerical model, which includes transport and chemical processes. Aircraft and shipboard measurements will be conducted to verify model predictions. The NASA Pacific Exploratory Mission-West will be the starting point of this task.

Natural Variability and Anthropogenic Perturbations of Tropical Atmospheric Chemistry

Focus 2

Anthropogenic disturbances of the chemistry of the tropical atmosphere are especially important, as the removal of many atmospheric trace gases is to a large degree determined by the high concentrations of hydroxyl radicals in the tropics caused by the maximum penetration of solar ultraviolet through the relatively thin stratospheric ozone shield. Large natural emissions of biogenic trace gases occur from tropical forests and savannas, which play a large role in the regional photochemistry of the atmosphere of these ecosystems. These emissions can be rapidly transported to the free troposphere by convective cloud systems and subsequently carried to other regions of the world, thus influencing extratropical global chemistry as well.

Tropical regions are experiencing rapid changes in land use due to expanding agricultural activities and, in certain areas, accelerated industrialization. Land use conversions due to expanding agricultural activities are often associated with the burning of large quantities of biomass, leading to the emission, of large amounts of aerosol particles and many important atmospheric trace gases, such as CO, CH_4, NO_x, and hydrocarbons, some of which influence the chemistry of the atmosphere even outside the tropics. Continued change, especially due to population growth will produce changes in the biogeochemical cycles of the affected tropical ecosystems with repercussions for the emissions of trace gases, such as NO, N_2O, CH_4 and other VOC. As a consequence, global atmospheric chemistry and associated potential impact on climate cannot be fully addressed without much improved understanding of the chemical state of the tropical ecosystem/atmospheric system.

During the past decade some national and bilateral experimental campaigns have been conducted to study the chemistry of the tropical atmosphere. These campaigns, e.g., the NCAR 1979 and 1980 and the ABLE II experiments of 1985 and 1987 in Brazil, and the DECAFE programme in 1988 in Western Africa have proven highly informative. Additional experiments of this kind, including DECAFE II and TRACE, are planned for the next three years. These campaigns involve ground-based and aircraft measurements to assess the respective roles in atmospheric and precipitation chemistry of processes and human activities in equatorial forest and savanna areas, including those caused by biomass burning. Because of the complexity of the biological/atmospheric system, it is essential to develop coordinated activities, pooling the resources of more nations and the expertise of the atmospheric, chemical, and biological disciplines. Coordination will thus also be required with other IGBP Core Projects including BAHC (Chapter 5.1) and GCTE (Chapter 6.1) and the documentation of tropical land-cover changes addressed in IGBP-DIS (Chapter 9).

Activity 1

Biosphere-Atmosphere Trace-Gas Exchange in the Tropics: Trace-Gas Emissions in the Tropics, and the Impacts of Land-Use Change

Tropical soils and vegetation represent globally significant sources of a broad range of atmospheric gases, including CO_2, CO, N_2O, NO, CH_4, and other VOC. Conversion of tropical forests to agricultural and pasture lands is presently occurring at very rapid rates, but the impact of these land use changes on biogeochemical cycling, trace gas emissions, and atmospheric photochemical and transport processes are not well understood. The intent of this Activity is to examine the impact of tropical land use conversions on the exchange of trace gases between tropical, terrestrial systems and the atmosphere.

Objectives

- *To determine chemical exchanges between tropical ecosystems and the atmosphere.*
- *To examine the impact of tropical land conversion on trace-gas fluxes and regional atmospheric composition and chemistry.*
- *To determine the biological factors that regulate trace-gas fluxes, as well as changes thereof resulting from tropical land conversion.*
- *To extrapolate the effect of current and future land uses and those resulting from climatic changes on trace-gas emissions from local to regional and from regional to global scales.*

This Activity will involve short- and long-term studies of ecosystem and atmospheric processes to be carried out in areas of active land use change in both savanna and humid forest regions. In the savanna areas, studies will examine the effects of conversions from natural to managed savanna (via burning) and intensive agriculture; in humid forest, conversions to pasture and agricultural land uses will be emphasized.

Changes in soil emissions of N_2O, NO, CH_4, CO, CO_2 and their controlling factors will be studied in managed sites, in control forest, and in fallow systems. Enclosure methods will be used to measure soil emissions; for the more reactive gases, box measurements will be coupled to tower-based micrometeorological flux determinations for CO_2, CH_4, NO, and hydrocarbons. Intensive short-term aircraft studies of atmospheric chemical transformations and regional fluxes will utilize measurement of atmospheric stability, depths of the mixed layer and build-up of concentrations in the mixed layer (at night). In addition to the flux measurements and process studies, the development of various modelling components on soil and ecosystem dynamics, canopy exchange processes, and atmospheric chemistry and transport will be necessary. Moreover, besides these detailed mechanistic models, more highly parameterized models will be developed which will be driven with variables available from remote sensing and ground-based data bases.

Activity 2

Deposition of Biogeochemically Important Trace Species

The deposition of chemical species is a source not only of essential plant nutrients, but also toxic substances to the biosphere. At the same time it is a sink for atmospheric trace species that influence atmospheric chemistry. Current knowledge of processes and rates of dry and wet deposition for many compounds must be expanded if the impacts of future environmental change are to be properly assessed.

Objectives

- *To determine the atmospheric removal rates by dry and wet deposition of biogeochemically important chemical species.*
- *To identify the factors that regulate these deposition fluxes.*

Experiments will be conducted on wet and dry deposition of particles and gases containing N, S, P, and C, major sea-salt components, as well as species of special interest such as organic acids, organic N compounds, O_3 and H_2O_2.

Task 1. Composition and acidity of S.E. Asian precipitation.

The composition and acidity of South-East Asian precipitation will be determined on a precipitation chemistry network to be set up in the SE Asian region, from India to China, south to Australia and on several Pacific islands as the first task of this Activity. Its goal is to quantify the wet deposition component of the atmospheric cycles of nutrient-containing and reactive species and to assess the current state of rainwater chemical composition across the region.

Task 2. Extension of activities to other regions

Possible future expansions include studies in other tropical regions and consideration of measurements of additional precipitation and gas phase compounds at each operating site. The long-term goal of assessing the importance of dry as well as wet deposition for atmospheric chemistry in all the tropical regions will require substantial extension of the observational network. Emphasis will be placed on cooperation with existing facilities in many countries, in particular those that are already or will become part of the World Meteorological Organization BAPMoN network.

Activity 3

Impact of Biomass Burning on Atmospheric Chemistry and Biogeochemical Cycles

The products of biomass burning represent a large perturbation to global atmospheric chemistry. Satellite observations have revealed vast areas of the tropics over which O_3 and CO concentrations are strongly elevated. This is due to biomass burning, which represents a major global source for a number of important gases, including CO_2, NO, CO, and CH_4, as well as particulate matter. The gaseous emissions affect regional ozone concentrations and the oxidative characteristics of the tropical atmosphere. The particulates affect regional, and possibly global, radiation budgets by their potential influence on tropical cloud microphysical processes. This Activity will seek to quantify the extent of the temporal and spatial distribution, dynamics, species emissions, and atmospheric consequences of biomass burning.

Fire also has both short- and long-term effects on trace-gas emissions from affected ecosystems which, for instance for CO_2 and N_2O, may be more significant than their immediate release during the fire. Fire also alters the long-term dynamics of the cycling and storage of elements within terrestrial ecosystems, thereby altering their significance as sources or sinks of various trace gases. Finally, deposition of compounds produced by biomass burning on pristine tropical ecosystems may affect their composition and dynamics.

Objectives

- *To characterize the production of chemically and radiatively important gases and aerosol species from biomass burning to the global atmosphere.*
- *To assess the consequences of biomass burning on regional and global atmospheric chemistry and climate.*
- *To determine the short- and long term effects of fire on post-fire exchanges of trace gases between terrestrial ecosystems and the atmosphere.*
- *To understand the biogeochemical consequences of atmospheric deposition of products of biomass burning.*

Task 1. Global inventories of biomass burning.

An initial survey will be made to construct worldwide regional inventories of biomass burning, both current and past. The amount of biomass in important ecosystems subject to biomass burning will be quantified. Remote sensing supported by ground-based evaluations provide the most promising tool for compiling geographical information on the extent of fires and on the distribution of biomass. At a few selected sites, the emissions of a wide range of gases and particulate matter will be measured.

Task 2. Quantification of gas and aerosol emissions from biomass burning.

Process models describing fire dynamics as a function of biomass type and environmental variables will be developed as well as integrated models coupling fire dynamics and combustion chemistry. The models will be tested with field experiments especially in savanna regions. The chemical reactivity of biomass burning plumes will be documented and modelled.

Task 3. Chemical transformation in fire affected air masses.

The chemical transformations in fire plumes and fire affected air masses, as well as their transport into other regions of the atmosphere will be studied through repeated aircraft-based sampling programmes. Satellite observations providing a global survey of the effect of burning on tropospheric chemistry will become available by the middle to late 1990s and will be an important contribution to this task.

Task 4. Post-fire fluxes of trace gases.

Long-term post-fire sampling of trace gas fluxes in well characterized sites that differ in fire history will be based on the pattern of nutrient dynamics at particular times post-fire. Field experiments and models will be used to determine, integrate, and extend knowledge of post-fire trace-gas exchanges. In the longer term, a set of experimentally burned plots will be established in tropical savanna and cleared forest regions, and the long-term effects of fire on the dynamics of C, N, and other nutrient elements, as well as vegetation composition and flammability will be studied in collaboration with the studies conducted within GCTE (Chapter 6.1).

Task 5. Oxidant effects

Information from measurements of plume dispersion and regional deposition will be used to establish studies of the effects of burning-derived oxidants on pristine tropical ecosystems and agricultural yields.

Activity 4

Chemical Transformations in Tropical Atmosphere and Their Interaction with the Biosphere

Land use changes and industrial developments strongly influence the emissions of several trace gases in tropical regions, thereby substantially affecting the photochemistry of the tropical and global troposphere. Depletion of the tropical forests will reduce VOC emissions, but increase the transport of NO to the free troposphere, possibly leading to much enhanced regional ozone formation. The latter trend is strongly enhanced during the dry season, as biomass burning produces large quantities of fire effluents, especially CO, NO and VOC, which interact photochemically, together with water vapour and high intensities of ultraviolet radiation, to produce O_3. As the air moves from the savanna regions to the convective inter-tropical convergence zone, the fire effluents and their photochemical products are transported at high levels into other regions of the atmosphere. Substantial changes in the overall photochemistry, not only of the continental tropics but also globally, may result.

Many important facets of the atmospheric chemical effects of rapid developments in human activities in the tropics are being and will be more intensively studied regionally by interdisciplinary research groups in Latin America, Africa and South-East Asia, mostly by national and bilateral arrangements. These activities must, however, from time to time, be enhanced by some large-scale experiments to be conducted within IGAC.

Objective

- *To understand the photochemistry of the tropical atmosphere and its effect on the global atmosphere, including how these are influenced by industrial and agricultural developments and resulting changes in trace-gas emissions.*

In order to obtain better information on tropical atmospheric chemistry and its interactions with the biosphere, it will be necessary to conduct a few large-scale field expeditions, involving intensive ground-based and airborne observations, and requiring strong international participation of a multidisciplinary team of researchers. Over succeeding years, such field campaigns, typically lasting for 1-2 months, are planned to be carried out in Latin America, Africa, and S.E. Asia during the wet and the dry season.

Atmospheric chemical constituents to be measured will be primarily O_3, H_2O, CH_4, CO_2, CO, VOC, NO_x, HNO_3, organic acids, and H_2O_2. In addition, the intensity of photochemically active solar radiation and concentrations of gaseous sulphur species, as well as the physical, optical and chemical characteristics of airborne particulate matter will be determined.

The comprehensive field experiments require careful planning and design and probably should consist of an intermediate phase of experiments carried out through an extension of the on-going efforts with aircraft surveys.

Activity 5

Rice Cultivation and Release of CH_4 and N_2O.

The anaerobic decomposition of organic matter in the soil of rice fields is one of the most important sources of atmospheric methane. Because of strongly expanding human populations in the tropics, future production of rice and emission of CH_4 will grow. Under some managing practices enhanced emissions of N_2O are also possible. It is therefore critical that the processes that regulate CH_4 and N_2O production and emission in rice cultivation be understood and that management practices to limit emissions will be developed.

Objectives

- *To determine the contribution of rice cultivation to global CH_4 and N_2O emissions.*
- *To understand the causes of variability in CH_4 emissions from rice cultivation from region to region and over time.*
- *To identify management practices for rice cultivation that will reduce future emissions of methane without causing strongly enhanced emissions of N_2O.*

Measurements of CH_4 and N_2O emissions from rice paddy fields should be carried out in Asian areas, as these account for 90% of global rice production. These measurements will incorporate the variability in climate, soils, and cropping practices; they will use a standardized protocol for the measurements, and at some sites micrometeorological measurements to determine large area integrated fluxes. The field studies will be supported by process studies on the regulation of methane production, its oxidation in the sediments and water body, and its emission to the atmosphere. The importance of plant properties in controlling gas transport will be determined, and possible differences among cultivars assessed. The impacts of management techniques, including fertilization applications, on N_2O and CH_4 emissions, will likewise be studied. The measurement and experimental programmes will be developed together with integrative process level models. Global data bases will be assembled to allow extrapolations for global budget analyses. It is planned that much of this Activity will be carried out at agricultural research stations. Close collaboration with the research efforts on rice productivity conducted by the International Rice Research Institute (IRRI) will be established.

Focus 3

The Role of Polar Regions in Changing Atmospheric Composition

The Arctic and Antarctic are regions of major importance in the global climate system through their influence on global albedo and uptake of carbon dioxide by subsiding polar ocean waters. Increasing intrusion of human activities, particularly in the Arctic, are making major impacts on this environment. Additionally, long-range transport of industrial atmospheric effluents, especially from Europe and Asia, are affecting the radiative and chemical properties of the Arctic atmosphere especially during winter and spring, a phenomenon known as "Arctic Haze". Much of the underlying processes and the effects of human activity on these sensitive regions are still largely unknown. In addition, trapped air in the glaciers of both Greenland and Antarctica offer priceless clues to atmospheric composition dating back tens of thousands of years and showing that the atmospheric concentrations of such climatically and photochemically important trace gases as CO_2, CH_4, and N_2O have varied consistently with lower values during glacial than interglacial periods. These important analyses must be extended to other trace gases and substances contained in the glacial ice (Chapter 7.1).

Two Activities are being developed within this Focus; one leading to a better understanding of the atmospheric chemical processes in the polar regions and their roles in global atmospheric chemistry and climate; the other aimed at developing an improved understanding of the relationship between the composition of air and that of snow and ice.

Activity 1

Polar Atmospheric Chemistry

The current spatial and seasonal distributions, the chemical-meteorological origin and the atmospheric chemical transformations of key atmospheric constituents and precipitation in the polar troposphere will be studied in order to assess the impact of anthropogenic activities on polar habitats and climate.

There are many chemical changes that take place in the atmosphere at polar sunrise, most likely via reactions on ice and snow, the study of which will reveal insight into atmospheric chemistry relevant to global change, including processes that may be related to stratospheric ozone hole generation (see STIB, Chapter 2.2). Also, as airmasses are transported into the Arctic region from mid-latitudes, they undergo chemical reactions that alter their gas and particle composition. The influx of particulate matter into the Arctic during winter and early spring influences the radiation budget of this region with potential climatic consequences.

Objectives

- *To understand local sources of chemical compounds in the polar regions particularly from ice-free ocean surfaces.*
- *To quantify regional industrial sources and the transport of chemical compounds from mid-latitudes into the Arctic.*
- *To understand the transformations that determine the chemical composition of the Arctic troposphere.*
- *To determine the influence of atmospheric chemical composition on the radiative properties of the Arctic atmosphere.*

Task 1. Arctic sunrise experiment.

An intensive study of atmospheric chemistry at polar sunrise is planned in the Arctic, utilizing the unique shift from total darkness to total light in a few weeks, without any marked change in large-scale meteorological conditions. It has been noted that under such circumstances ground-level ozone concentrations may be reduced to very low values, concomitant with high concentrations of gaseous and particulate bromine, indicating a possible relationship. Measurements of these phenomena were started in Spring 1988 at Alert, Canada, coordinated by the Canadian Institute for Research in Atmospheric Chemistry (CIRAC) and this work will be expanded in coming years by participation of scientist from other nations (e.g., US, Scandinavia, and Germany) to conduct larger-scale experiments and to extend the measurement network.

Task 2. Long-range transport of air pollution into the Arctic.

The fourth international Arctic Gas and Aerosol Sampling Programme (AGASP IV), with participation from several nations bordering the Arctic, will be undertaken in 1991 using aircraft and ground-based observational platforms, involving both measurements of inert tracers to follow air parcels over long distances while simultaneously studying chemical composition changes during transport. Emphasis will also be placed on the optical and chemical characterization of the Arctic haze aerosol particles.

Activity 2

Polar Air-Snow Experiment

This Activity is aimed at improving quantitative knowledge of the relationship between atmospheric composition and the chemical composition of ice in the central polar areas. It will study in detail the incorporation of constituents into polar snowfalls and the exchange of gases and particles between the atmosphere and snowpack to the point of ice formation. The possible production and destruction of compounds by reactions on snow and in ice will be investigated. Key constituents to be studied include the greenhouse gases, H_2O_2, H_2SO_4, HNO_3, HCl, black carbon, and pesticides (see also PAGES, Chapter 7.1).

Objective

- *To establish the relationship between atmospheric chemical composition and that of glacier ice in the central polar areas.*

Task 1. Model development.

Development of a model of the major physical and chemical processes occurring at very low temperatures, using data that have been obtained in past experiments.

Task 2. Chemical analysis of current snow, trace gas and aerosol composition in the Central Antarctic plateau.

An initial one-year experiment on the central Antarctic plateau is planned which will include measurement of atmospheric trace gases and aerosols and the composition of falling snow, firm snow, ice and air in the ice pores. This Activity will be coordinated with PAGES (Chapter 7.1). The central Antarctic plateau is chosen because major ice-core chemistry records have been retrieved there, so that the process studies will have the greatest relevance to these records. The Amundsen Scott base is selected as the first site to be studied, as it is a good ice core region possessing a long-term baseline air chemistry station and year-round facilities. Other sites will be added in future.

Focus 4

The Role of Boreal Regions in Biosphere-Atmosphere Interactions

The boreal ecosystems of forests, lakes and wetlands, covering vast areas of North America, Scandinavia and the Soviet Union, have significant influences on global climate and atmospheric composition. Climate change modelling scenarios agree that warming will intensify towards the poles providing the potential for strongly enhanced CO_2 and CH_4 emissions from northern wetlands and permafrost regions. These regions may also make substantial contributions to the emissions of other chemically active compounds and act as significant deposits for trace-gas species transported from mid-latitudes. Emissions may increase considerably in response to changes in soil temperature, water table and organic matter storage.

Activity 1

High Latitude Ecosystems as Sources and Sinks of Trace-Gases and their Sensitivity to Environmental Disturbances

This Activity will examine the relations and potential feedbacks between climate change, biogeochemical cycling and trace gas production, especially CO_2, CH_4, and N_2O in northern wetlands, building up from past and ongoing studies in Alaska and in the Hudson Bay Lowland/Labrador region of Canada.

Objectives

- *To estimate trace-gas emissions and uptake in high latitude ecosystems.*
- *To determine the principal ecological and environmental characteristics that control ecosystem trace-gas production, consumption, and transport.*
- *To estimate the sensitivity of northern ecosystems (in terms of trace-gas emissions) to environmental change.*

Task 1. Development of budgets for trace-gas fluxes in northern wetlands.

Standardized ecosystem classifications, based on vegetation, soil types, hydrology and nutrient status, will be developed and data bases established of the northern wetland ecosystems. Existing data bases will be evaluated and new data sets will be obtained, where necessary, for use in modelling studies.

Year-round field measurements of fluxes of CH_4, CO_2, N_2O, NO, COS, H_2S, and VOC will be made using chamber, tower and aircraft techniques covering temporal and spatial variability. Methane and CO_2 flux measurement systems are relatively advanced (including both box and fast-response eddy correlation methods), but appropriate techniques for several of the other gases will have to be developed. The study of the atmospheric chemistry (particularly surface exchange) of the Hudson Bay Lowland and Labrador regions of northern Canada, conducted by CIRAC in collaboration with NASA (ABLE-3B) in 1990, will initiate these kind of experiments. Similar measurements are planned to be made in other major boreal regions in Western Siberia, Scandinavia, and Alaska.

Models will be developed for process studies and extrapolation purposes to larger scales to be tested by comparison with aircraft-based large regional flux and concentration distribution surveys. Isotopic analyses of emissions and CH_4 isotope (13C, 14C, 2H) concentration distributions in the atmosphere will add significant information.

Task 2. Controlling factors and processes of trace-gas exchange in northern wetlands.

On an ecosystem and regional basis, trace-gas exchange will be examined for a range of different physical and environmental conditions. These studies must include the below-surface processes responsible for both production and the partial oxidation of CH_4 prior to release into the atmosphere as well as processes related to trace gas release to the atmosphere, e.g., by vascular transport in plants. Such studies are being initiated in the 1990 CIRAC/ABLE-3B study, but will be extended and also carried out at other sites around the world for extended measurement periods. Models will be developed to relate these process studies to the flux measurements.

Task 3. Sensitivity of high latitude trace-gas sources and sinks to climate change.

This task includes the establishment of long-term atmospheric observatories to measure trace-gas emissions at a range of research sites accompanied by regular aircraft transect surveys. An important part of this task will also be long-term studies of ecological processes and changes affected by anthropogenic factors, including climate changes.

These studies of trace-gas emissions will take place at sites along primary and secondary successional sequences to examine the control of vegetation, soil, and micro climate on fluxes. Ecosystem manipulations are planned in order to examine the influences of changing environmental factors on trace-gas fluxes.

Predictive ecosystem process models will be developed that incorporate relationships between forcing variables and trace-gas exchanges. Landscape models will be constructed to improve estimates of trace-gas fluxes for present and potential future climatic conditions.

Global Distributions, Transformations, Trends and Modelling

Focus 5

In order to understand the chemistry of the atmosphere and its role in the Earth's overall biogeochemical system, much more needs to be learned about how both short- and long-term variations in the chemical composition of the atmosphere reflect the interaction of the major processes to which atmospheric constituents are subjected: emission, transport, transformation and removal. This Focus is aimed at determining the global distribution and temporal variations of important trace gases that are subject to chemical transformation and long-range transport and to quantify their emissions. This will require the establishment of monitoring networks, large-scale aircraft surveys, remote sensing, from satellites and global, regional model developments, and development of emission inventories.

Global Tropospheric Ozone Network

Activity 1

Since ozone plays a central role in most of the key chemical processes in the troposphere, far too little knowledge of its global temporal and spatial distribution and long-term trends is available. There is, therefore, an urgent need to enlarge the data base.

Objective

- *To improve the climatology and trend estimates of ozone in the troposphere.*

Task

The existing ozone sonde network together with available ozone lidar stations will be optimized for accurate measurements of tropospheric ozone profiles by appropriate intercalibrations, intercomparisons and agreements on protocols, frequency and timing of measurements.

Doubling the current number of ozone measurement stations would result in a network that will greatly improve our knowledge of the global distribution of tropospheric ozone in space and time and provide the capability to detect regional and global trends of tropospheric ozone with an accuracy of about 1% per year or better. Uniform procedures for data processing, analysis, archival, distribution and publication are necessary. New stations should be established where the scientific need is greatest.

A close interaction between modelling and the development of measurement strategy is essential. The network will be coordinated with the existing Dobson and Brewer total-column network, which is run by individual nations under the auspices of the Ozone Commission of IAMAP, the newly established UNEP-WMO network for the detection of stratospheric change, the European TOR/Eurotrac project, the WMO BAPMoN Network, and existing surface-ozone measurement programmes that are run in several nations.

Global Atmospheric Chemistry Survey

Activity 2

The global, three-dimensional distributions of solar ultraviolet radiation and the reactive gases O_3, CO, NO, NO_2, H_2O, CH_4 and VOC determine the concentrations of hydroxyl radicals and thus the oxidative efficiency of the atmosphere, affecting the removal of most chemical constituents in the atmosphere. Current knowledge of the global distributions and annual cycles of the above factors is insufficient in order to understand the fundamental oxidation processes operating over most of the globe and to establish trends of trace gases caused by theoretically expected alterations in the oxidative efficiency of the atmosphere. Particularly useful will be observations of industrially produced halocarbon gases, such as CH_3CCl_3 and the various replacement products that are being introduced for the fully halogenated, now internationally regulated compounds.

Because the former are broken down by reactions with hydroxyl radicals in the troposphere, their removal rates are a measure for average global concentrations of OH radicals. Their long-term, worldwide observations can thus reveal trends in global average OH concentrations.

Objective

- *To establish the spatial and temporal distributions of key chemically reactive species and photochemically active solar radiation.*

Task 1. Surface-based and aircraft-borne observations.

The most practical way of substantially improving our knowledge of the distribution of the gases mentioned above involves a series of regular coordinated campaigns of both surface-based and aircraft-borne observations over major regions of the globe. Other photochemically related, or otherwise important, species (H_2O_2, PAN, sulphur gases, CH_2O, organic acids, etc.) should also be included when possible. This work would be multinational: eight nations with suitable research aircraft and a total of some 16 aircraft potentially available for such an undertaking have been identified. There should be opportunities for multinational participation in each flight, to ensure that the more complex measurements with less available instrumentation can be made during as many campaigns as possible.

Intercalibration and intercomparisons between the individual instruments used for all the experiments is of the greatest importance to the success of this task. Also essential is a uniform approach to processing, analysis, archiving, distribution and publication of the data.

Data from regional air pollution oriented networks projects will be included to strengthen the global data base; strong links with those Activities will thus be established. This Activity will also profit greatly from those proposed under Activities (tasks 1 and 3), 2(4) and 3(1).

Task 2. Observations by remote sensing

The development of remote-sensing techniques for tropospheric composition measurements to support these Activities would substantially help in this task. Several proposals for this have been made within NASA, ESA, and national space agencies.

Task 3. Model development

The development of regional- and global-scale models should be an integral part of this Activity both for the interpretation of the observations, and the extrapolation of knowledge to times and regions where no measurements can be made.

Activity 3

Development of Global-Emission Inventories

Detailed emission inventories, if possible on a 1° x 1° global surface grid, should be developed for future detailed model simulations of the behaviour of chemically and radiatively important trace substances. A comprehensive and uniform international Activity needs to be initiated to establish an inventory of the natural and anthropogenic sources of the most important atmospheric constituents, such as NO, CO, CH_4, VOC, NH_3, CH_3CCl_3 and other halocarbon gases, especially those that are being introduced as replacement products for CFC-11 and CFC-12. Among the aerosol components, their nutrient element, trace metal and elemental carbon contents, are of special interest.

Objectives

- *To establish a framework for the development and evaluation of global emission inventories.*
- *To conduct a critical survey of emission inventories of compounds of major importance in global atmospheric chemistry and biogeochemical cycles.*
- *To publish inventories in the open literature and design easily accessible data bases for use by scientists worldwide.*

An international working group has been formed to review the inventories presently available both for natural and man-made substances. Based on this review, one or two substances will be chosen for a pilot study. For these an archive will be established. Problems such as consistency and coverage in these inventories will be examined as part of the programme to develop generalized strategies for the construction of accurate emission inventories. Further species will be added to the inventories depending on the judgement of the working group. Close coordination with ongoing national and regional Activities will be established.

Activity 4

Global Integration and Modelling of Fluxes

While many of the programmes for measuring the fluxes of trace gases are regional, IGAC is chiefly concerned with the global integration. This is especially true for the longer-lived species (e.g., CO_2, CO, CH_4, N_2O). Global extrapolation requires the ability to generalize flux measurements in space and time. Studies will be designed to rigorously test the models and methodology required to achieve this goal.

Objectives

- *To quantify fluxes of gases significant to global atmospheric chemistry*
- *Develop and test extrapolation approaches using combined ground-based process studies and mesoscale modelling and measurements.*

Task 1. Global synthesis of N_2O, CH_4 and CO fluxes.

This integration task will require a number of Activities, similar to those proposed within regional studies, but at a larger scale. These are, first, the development of a global geographic data base including a suitable classification of area by flux potential (i.e., soil, vegetation class) and distribution of driving variables (e.g., climate, N deposition). Second, measured flux rates or models of rates will be used to estimate fluxes from the various combinations of areas and driving variables in the GIS system to obtain global flux rates with the areal stratification and driving variables. Third, global fluxes must be compared to atmospheric sinks and to the predicted distribution of sources and sinks using inverse modelling. This final step constitutes the validation of the regional estimates and techniques used in global extrapolation. When these source-based extrapolations fail to match inverse predictions, both calculations must be examined.

Task 2. Flux extrapolation pilot study.

The extrapolation of small-scale field measurements to regional estimates is a crucial methodological problem due to heterogeneity in the land surface. The first step will be to establish a measurement network at a location which consists of a limited number of ecosystems (e.g., a study area consisting of a forest-agricultural land mixture).

The size of the study area should accommodate various observational and measurement scales including satellite observations (c. 30-1000 m), airborne measurements, eddy correlation flux measurements (c. 10-1000 m), and plot studies (c. 1 m). An ideal size is approximately 10 x 10 km.

Within the study area, a stratified measurement network will be established to determine the environmental variables controlling fluxes from the various ecosystems and the role of landscape characteristics contributing to variability in the emissions.

After one year of process-level measurements, a large boundary layer experiment will be performed. In this experiment, aircraft will be used in order to get estimates of fluxes over the region. These flux estimates will be compared with estimates derived from models capable of depicting fluxes over the same spatial and temporal scales. The results of these comparisons will be used to evaluate both the modelling and aircraft approaches to large area flux estimates. This evaluation is crucial for the development of flux models and better understanding of the spatial and temporal variability of fluxes, and thus leading to methodology for global evaluation of source/sink relationships in the terrestrial ecosystems.

Focus 6 — *Intercalibrations / Intercomparisons*

The use of the data from separate measurement programmes requires an understanding of the relative agreement of the separate standards used in each of them. There is not a well developed set of international standards for measurements of trace constituents in the atmosphere, and conflicting calibration standards exist for some species. The WMO has tackled the problems of standards for precipitation chemistry analyses and the International Ozone Commission has established recommended absorption coefficients for ozone. For most other species this problem still remains to be solved.

Activity 1 — *Gas Standards for CO, CH_4 and Chlorinated Hydrocarbons*

The use of the data from separate long-term measurement programmes requires an understanding of the relative agreement of the separate gas standards involved. Gases for which a start has been made are CO, CH_4, and certain chlorinated compounds. However, these gas standards are not known to a precision that allows differences measured by separate groups to be interpreted as real, rather than as differences among standards.

An inter-laboratory comparison of CH_4 measurements will be undertaken to be followed by the development of an absolute standard for CH_4. Methylchloroform (CH_3CCl_3) and HCFC-22 (CHClF2) have been identified whose absolute calibration is important in the determination of the average tropospheric hydroxyl radical concentration. A major uncertainty exists for CFC-113 (CCl_2FCClF_2), which should be resolved, since this compound is the fastest growing source of stratospheric chlorine.

Objective

- *To solve the current inadequacies in the standards for CO, CH_4 and some chlorinated compounds.*

Three phases are envisaged, including the following studies: (i) stability experiments on containers; (ii) inter-laboratory comparisons, so that various data sets collected around the world by various groups can be compared; and (iii) supply and dissemination of absolute standards.

Activity 2 — *Non-Methane Hydrocarbon Intercomparison Experiment*

The non-methane hydrocarbons (terpenes, isoprene, alkanes, alkenes, alkynes and aromatics) are involved in ozone formation and are sources of carbon monoxide and of reactive hydrogen species. To form a global picture of these abundances there is a need to know whether there are any systematic differences between the methods used by various investigators.

Objective

- *To assess how accurately the non-methane hydrocarbons can be measured.*

An intercomparison experiment will be conducted under typical field conditions with simultaneous measurements at the same place.

Task 1. Standards and cross referencing

A travelling standard will be made and circulated to groups for intercomparison

of individual standards used by the investigators and to determine the absolute accuracy of current and past measurements.

Task 2. Whole-air surface measurements

"Blind" whole-air samples will be circulated and this gas concentrations measured. There will also be simultaneous ground-based measurements at a mountain (free troposphere), a remote (low VOC levels) and a heavily forested site (high VOC levels).

Task 3. Aircraft intercomparison campaigns in background air and polluted areas

It will include onboard analyses and air sampling in flasks in order to obtain height profiles across the marine and continental boundary layer. The goals are, in this case, to assess inlet problems, storage and shipping.

Focus 7 — *Trace Gas Fluxes in Mid-Latitude Ecosystems*

Much of the temperate region of the Northern Hemisphere is densely populated and most of its ecosystems have been subject to strong human disturbances, such as the conversion of large areas of forests to grasslands and agricultural lands. In addition, as a result of industrial activity, since many decades the mid-latitude ecosystems have experienced strongly altered atmospheric chemical conditions such as enhanced ozone concentrations and acid deposition. Strong interactions occur between emissions of industrial and biological origin, such as NO_x and VOC, contributing to enhanced ozone concentrations with negative consequences for the biological functioning of affected ecosystems. These processes are partially being studied in some existing programmes in North America and Western Europe, but need to be expanded to other regions and extended to include their impact on overall nutrient cycling of ecosystems and exchange of trace gases, in particular of VOC, CH_4, CO, and N_2O. In addition to the disturbances affected by atmospheric inputs, the emissions especially of NH_3, NO, and N_2O, as well as soil uptake of CO_2, CO, and CH_4 may be strongly affected by intense agricultural activities and heavy-use of fertilizers.

Activity 1 — *Mid-latitude Ecosystems as Sinks for Atmospheric Oxidants and Sources of Oxidant Precursors*

Substantial ranges of the mid-latitude ecosystems are exposed to high oxidant levels due to large anthropogenic emissions of VOC and especially NO, which under the influence of solar radiation, induce reactions leading to photochemical ozone production. VOC emitted by plant canopies are important precursors for photochemical oxidant production. The magnitude of the production of VOC by vegetation and the uptake of NO_x, O_3 and other oxidants by the biosphere, as well as the controlling physical chemical and biological processes remain poorly understood.

Enhanced O_3 concentrations downwind of industrial regions may cause a phytotoxic stress on many plant communities. Effects of this stress on physiological processes and on the exchange of heat, water vapour, CO_2 and other trace gases, in particular VOC and NO_x have been observed but cannot yet be quantified sufficiently.

Objectives

- *To quantify source and sink strengths of NO_y compounds and volatile hydrocarbons and to determine the plant physiological processes responsible for them.*
- *To determine the effect of changes in physical and chemical conditions on the sources and sinks of NO_y and VOC*

Continuous field measurements will be set up in representative mid-latitude ecosystems, particularly in regions subjected to intensive ozone concentrations.

Activity 2

Exchanges of N_2O, CH_4 and CO Between Terrestrial Ecosystems and the Atmosphere in Mid-latitudes

Heavy fertilization of agricultural land and high inputs of nitrogen in precipitation to forests may have increased their capacity to produce N_2O. The regional magnitude of this increase is not well documented, although, at least for agricultural systems, they may be substantial. Drainage of wetlands and increased nitrogen inputs to both agricultural and non-managed ecosystems have an effect on production and consumption of methane. The importance of these factors on the global CH_4 and N_2O, budgets has yet to be determined; preliminary experiments indicate that they may be significant. In addition, it is known that CO can be exchanged between the biosphere and atmosphere. However, too few measurements have been made to assess the importance of this exchange process and how it may be influenced by environmental changes.

Objectives

- *To quantify the role of northern hemisphere mid-latitude ecosystems as sources for N_2O.*
- *To quantify the role of mid-latitude ecosystems as sources and sinks for CH_4.*
- *To define the processes and land management practices that control N_2O and CH_4 exchange in mid-latitude systems.*
- *To understand the biological sources and sinks of CO.*

This Activity will be undertaken by the establishment of several sites on different continents to examine the seasonal dependence of N_2O, CH_4 and CO emission and deposition. A range of cropping systems, forest and grassland types will be covered. At each site, time series of fluxes will be determined and related to the controlling factors, some of which (N-inputs, precipitation, etc.) may be manipulated. Fluxes will be measured for at least two years, after which sampling frequency at some sites may be reduced and intensified at others for conditions of particular significance. Models of both CH_4, CO and N_2O exchange processes from soils will assist in the integration of the results over larger spatial scales.

Activity 3

The Importance of Mid-latitude Ecosystems as Net CO_2 Sinks

Large portions of the mid-latitudes have undergone substantial land-use changes, including extensive reforestation with increased storage in woody biomass and soil organic matter. With much of the present forest area in the region now in a mid-successional stage, it is possible that they are a significant C-sink. Moreover, increasing, inadvertent, N inputs by dry deposition and precipitation due to industrial and agricultural activities and the increasing atmospheric CO_2 content may boost net primary production and carbon storage, implying a potential growing sink of CO_2. On the other hand, this potential may be reduced or reversed if the deposition of acidic compounds and ozone concentrations result in significant forest decline and soil organic matter losses in agricultural ecosystems. Because of the multiple controls over CO_2 exchange and C storage, manipulative experiments will be required to develop quantitative understanding on the importance of these alternative possibilities. This will be done in cooperation with GCTE (Chapter 6.1).

Objectives

- *To determine the consequences of changing land use (reforestation, succession, deforestation, urbanization) on CO_2 exchange between atmosphere and biosphere.*
- *To evaluate the effect of changing temperature and moisture on CO_2 exchange.*
- *To evaluate the effects of N and S species deposition on CO_2 exchange.*

Networks will be established in temperate forests around the world to include sites of varying successional age and management practices. Measurements of net primary production, soil respiration, decomposition, and the climatic and biotic variables that drive these processes will be made for at least one year. After this intensive year, measurements will be continued at a lower pace to determine interannual variation and long-term changes in site C-dynamics. Manipulative experiments to improve our understanding of the long-term effects of various climatic drivers on ecosystem functioning (e.g., water and nutrient use efficiency) and trace gas exchange will include elevated CO_2, soil temperatures, soil moisture, and increased N and S, and acid depositions.

Focus 8

Cloud Condensation Nuclei as Controllers of Cloud Properties

Clouds strongly influence global climate by their influence on the Earth's radiative balance. Chemical transformations in clouds also play a major role in the atmospheric chemical transformations of many compounds of global significance, and for the transfer of essential chemical elements and compounds, as well as pollutants to the biosphere. Central to all these influences, and greatly sensitive to human activities, are the chemical and physical characteristics of the nuclei on which all cloud droplets form. Of special importance in this regard are natural DMS emissions from the oceans, reduced sulphur gas emissions from continental areas and SO_2 emissions from fossil fuel burning. These are converted in the troposphere to sulphate particles, which may be the most important sources for the atmosphere's cloud condensation nuclei (CCN). However, other sources for CCN may also be important, such as smoke particles from biomass burning.

Although understanding the chemical and physical evolution of CCN is thus central to cloud and climate modelling, knowledge of the dynamics of this system is virtually non-existent. It is possible that these dynamics include feedback processes involving, for example, modification of the Earth's surface temperatures via anthropogenic S emissions, leading to CCN-modulated droplet size distributions and cloud reflectivities, modification of rainfall patterns and aerosol particle lifetimes. At present, mostly national efforts to address these issues are severely limited by the availability of instrumentation, observational platforms, and scientific personnel. International collaboration could achieve the critical mass for the necessary comprehensive studies.

Activity 1

Cloud Condensation Nuclei

Objectives

- *To develop a much improved data base on the chemical and physical characterization of particles that act as CCN in different climatic and ecological regions.*
- *To understand the sources and physical and chemical factors that produce CCN and that control their evolution.*
- *To relate the factors controlling CCN production and distribution to the large-scale factors that are carried in climate model calculations.*
- *To evaluate means to utilize remote sensing to estimate CCN concentrations.*

Simultaneous measurements are required of gas-phase precursor concentrations, especially SO_2 and DMS, primary aerosol production rates and properties, total particle (Aitken) concentrations, sub-cloud aerosol size distribution and size-dependent chemical composition of particles, as well as their morphology, physical state, and surface chemical properties. Also required are: CCN concentration, size distribution and chemical composition as a function of supersaturation, as well as size spectra and size-resolved chemical composition of cloud droplets in clouds, their relations to the optical and microphysical properties of clouds, and dependence on meteorological factors, such as updraft velocities and rate of air entrainment.

Because some of these measurements are slightly beyond the current technical capability, there is a need for instrument development, measurement standardization and intercalibration.

Models must be extended to link the chemical composition of various parts of the aerosol population to activation under conditions favourable to cloud formation and to describe the chemical changes of CCN after they are cycled through clouds.

Both the International Commission on Cloud Physics and the International Radiation Commission (of IAMAP) have parallel projects on aerosols and clouds in the International Aerosol Climatology Project (IACP), and the International Satellite Cloud Climatology Project (ISCCP), respectively. Collaborative opportunities with these projects, will be pursued.

Field studies of the evolution of CCN and their interactions with clouds will be conducted in three geographical regions as a part of the IGAC Activities Focus 1, Activity 1, 2, and 3, and Focus 2, Activity 3. An important aspect of the research will be intercomparisons of cloud properties in various atmospheric environments with widely different sulphur sources, such as pristine marine and continental environments, and their more polluted counterparts.

Implementation

The IGAC Core Project, will hold its first open meeting on 8 September 1990 in Chamrousse, France, as part of the Seventh International Symposium of the Commission on Atmospheric Chemistry and Global Pollution (CACGP), "Chemistry of the Global Atmosphere".

A Core Project Office (CPO) has yet to be identified, however, discussions are in progress for securing the adequate resources to fund the operation of the CPO. An IGBP Scientific Steering Committee (SSC) for IGAC has been formed (see Galbally 1989). Additional members will be selected to represent the biospheric components of the Core Project.

Several of the Activities listed in the IGAC Core Project have begun including:

Focus 1,	Activity 1:	North Atlantic Regional Study
	Activity 2:	Marine Aerosol and Gas Exchange: Atmospheric Chemistry and Climate
Focus 2,	Activity 1:	Biosphere-Atmosphere Trace-Gas Exchange in the Tropics: Tropical Land-Use Change and Trace-Gas Emissions
	Activity 3:	Impact of Biomass Burning on the World Atmosphere
Focus 4,	Activity 1:	High Latitude Ecosystem
Focus 5,	Activity 1:	Global Tropospheric Ozone Network
Focus 6,	Activity 1:	Gas Standards for CO, CH_4 and Chlorinated Hydrocarbons
	Activity 2:	Non-Methane Hydrocarbon Intercomparison Experiment

Others listed in this Chapter are expected to begin within the next two to three years.

References

Andreae, M. O. and Schimel, D. S. (eds) 1989. Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere. Report of the Dahlem Workshop. John Wiley & Sons, Chichester.

ESSC. 1988. Earth System Science: A Program for Global Change. Earth System Sciences Committee (ESSC), National Aeronautics and Space Administration Advisory Council. Washington DC.

EOS. 1988. From Pattern to Process: The Strategy of the Earth Observing System. EOS Science Steering Committee, NASA. Washington, DC.

Galbally, I. (ed) 1989. International Global Atmospheric Chemistry (IGAC) Program: A Core Project of the International Geosphere-Biosphere Programme.

Matson, P. A. and Ojima, D. S. (eds) 1990. The Terrestrial Biological Aspect of Global Atmospheric Chemistry: A Complementary Research Plan for Terrestrial Ecosystem Interactions with Tropospheric Chemistry. IGBP Report Series. (In Press)

Mooney, H. A., Vitousek, P. M. and Matson, P. A. 1987. Exchange of materials between terrestrial ecosystems and the atmosphere. Science 238:926-932.

Suggested Reading

Andreae, M. O. and Schimel, D. S. (eds) 1989. Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere. Report of the Dahlem Workshop. John Wiley & Sons, Chichester.

Bouwman, A. F. (ed) 1990. Soils and the Greenhouse Effect. Proceedings of the International Conference on Soils and the Greenhouse Effect. John Wiley & Sons, Chichester. 575 p.

ESSC. 1988. Earth System Science: A Program for Global Change. Earth System Sciences Committee (ESSC), National Areonautics and Space Administration Advisory Council. Washington DC.

OIES. 1986. Global Tropospheric Chemistry: Plans for the US Research Effort. OIES Report 3. Office for Interdisciplinary Earth Studies, UCAR, Boulder, CO.

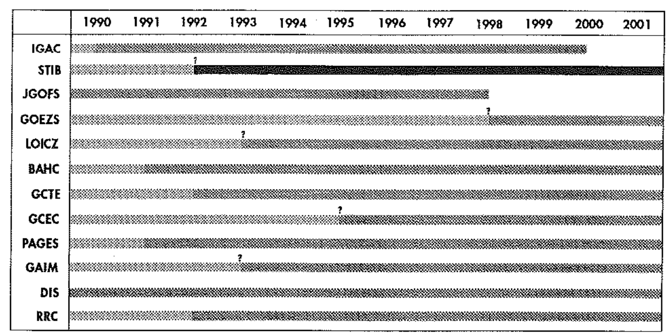
Mooney, H. A., Vitousek, P. M. and Matson, P. A. 1987. Exchange of materials between terrestrial ecosystems and the atmosphere. Science 238:926-932.

NRC. 1984. Global Tropospheric Chemistry. A Plan for Action. National Academy Press, Washington, DC. 194 pp.

Rowland, F. S. and Isaksen, I. S. A. (eds) 1988. The Changing Atmosphere. Report of the Dahlem Workshop. John Wiley & Sons, Chichester. WMO. 1985. Global Ozone Research and Monitoring Project.

WMO Report 16. World Meteorological Organization, Geneva.

Contents


1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
IGAC
STIB
JGOFS
GOEZS
LOICZ
BAHC
GCTE
GCEC
PAGES
GAIM
DIS
RRC

2.2 *Stratosphere-Troposphere Interactions and the Biosphere (STIB)*

A Proposed Core Project

Global Change and STIB

The Stratosphere-Troposphere Interactions and the Biosphere (STIB) project is concerned with the processes through which biogenic and anthropogenic emissions change the composition, radiation and dynamics of the stratosphere and how these changes in turn affect the biosphere. Trace substances in the stratosphere can modulate the intensity of solar UV-B radiation received at the Earth's surface, which has a direct effect on the biosphere and the chemistry of the troposphere. The chemical and dynamical state of the stratosphere can also influence the troposphere by exchange processes at the tropopause. Conversely, some of the gases emitted from the surface determine the concentrations of stratospheric ozone. These gases are relatively inert to oxidation in the troposphere and therefore have sufficiently long lifetimes to be transported into the stratosphere. They include the biogenic gases (N_2O and CH_4) and several industrial halocarbons. The photochemical breakdown of these gases under the influence of ultraviolet radiation in the stratosphere leads to molecules and atoms, such as NO, NO_2, Cl and ClO, which catalytically destroy ozone.

The concept of STIB is derived from earlier proposals by IAMAP/IUGG and IAGA/IUGG (Middle Atmosphere Response to Change - MARC and Role of the Middle Atmosphere in the Climate System - MACS). Unlike those proposals, the STIB project emphasizes the coupling between the stratosphere, the troposphere, and the biosphere. Within IGBP, STIB is complementary to the

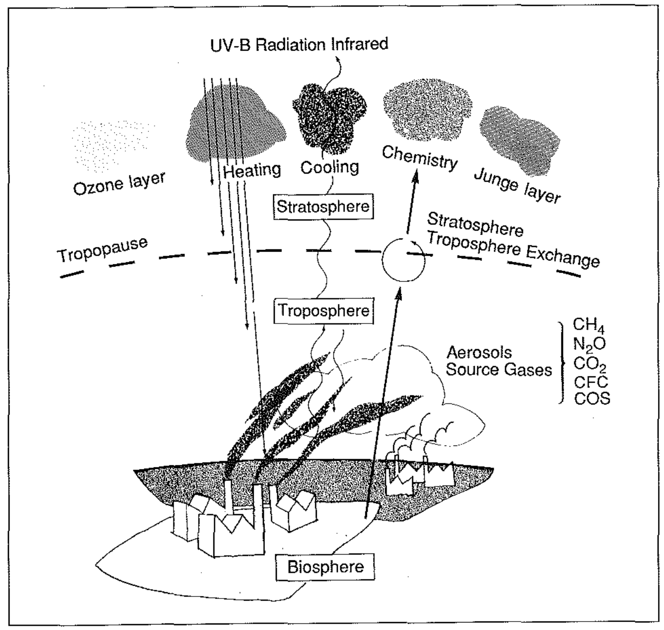


Figure 1. Couplings in the stratosphere-troposphere-biosphere system

IGAC (International Global Atmospheric Chemistry project) which focuses on studying tropospheric processes.

The basic motivation for the STIB project is provided by the critical influences of stratospheric processes on the global biosphere system. The stratosphere is coupled to the surface in a number of important ways (Fig. 1). The most familiar is the stratospheric ozone layer, which determines the amount of biologically harmful solar ultraviolet radiation reaching the surface. Less familiar, perhaps, is the fact that downward transport of stratospheric ozone into the troposphere via the formation of OH radicals plays a large role in determining the oxidative state of the troposphere, being responsible for the removal of many of the gases emitted from the surface, either from biogenic or anthropogenic sources.

Stratospheric composition also has two important climatic influences. The first is through the attenuation of solar radiation, which affects both tropospheric climate and biological activity at the surface. Again, we should note a two-way coupling. For example, when transported to the stratosphere, a biogenically produced gas, such as COS, is responsible for the stratospheric aerosol layer. Such aerosols reflect incoming solar radiation and thereby influence the climate of both the stratosphere and the troposphere. Direct emission of sulphur gases into the stratosphere by volcanoes also contribute to the aerosol layer in the stratosphere.

The second, less direct, influence of stratospheric composition is through the coupling of stratospheric and tropospheric climate and dynamics. Nitrous oxide, CH_4 and the halocarbons not only affect ozone concentrations, but are powerful infrared absorbers that contribute significantly to greenhouse warming. For example, methane oxidation is a major contributor to the stratospheric H_2O content, and methane is a strong greenhouse gas implicated in the formation of the Antarctic ozone hole. Increases in emissions of these gases, as well as of CO_2, lead to greenhouse heating of the troposphere and cooling of the middle and upper stratosphere. Radiative cooling of the stratosphere affects its climate and circulation. Dynamic coupling of the stratosphere with the troposphere, in ways which are still not completely understood, may influence the climate of the troposphere.

In addition, changes in the stratospheric temperature distributions resulting from increased emissions of greenhouse gases affect stratospheric ozone concentrations through temperature dependence on the rates of the chemical reactions that produce and destroy ozone. It should also be borne in mind that reactions in the stratosphere are the major sinks for N_2O and the halocarbons.

Major volcanic eruptions are known to put very large quantities of material directly into the stratosphere. The conversion of SO_2 of volcanic origin to sulphuric acid leads to the formation of particulate matter which can scatter solar radiation away from the earth. Their long residence time in the stratosphere can influence the global radiation balance. In addition, variations of solar intensity on a number of time scales induce variability in the temperature and chemical composition of the upper atmosphere.

Another issue to be considered is the possibility that hypersonic and other aircraft operations in the stratosphere will substantially increase in the near future, with potential consequences for stratospheric ozone and temperature.

In view of the above, the objectives of the STIB project are to gain predictive understanding of:

(i) the consequences of changes in stratospheric O_3 on penetration of potentially harmful UV radiation - this effort should be based on the comprehensive state-of-the-art review being currently conducted by SCOPE;
(ii) the stratosphere-troposphere exchange processes - this effort should be conducted in close collaboration with the IGAC project;
(iii) the natural variability of the stratosphere and the impact of anthropogenic activities - this effort should be conducted in cooperation with ICSU/SCOSTEP's STEP project.
(iv) the influence of stratospheric aerosols on climate - this effort should be carried out in cooperation with WCRP and IAMAP's International Global Aerosol Programme (IGAP).
(v) the impact of stratospheric changes on climate - this effort should be carried out in close cooperation with WCRP.

Stratospheric Changes and the Penetration of UV Radiation

The spectral distribution of solar radiation reaching the Earth's surface depends on the earth-sun distance, the irradiance emitted by the sun, and the transmission properties of the atmosphere. Changes due to orbital parameters will not be considered here; they are the subject of the IGBP Core Project PAGES (Chapter 7). As a result of the changing earth-sun distance, the irradiance received at the top of the atmosphere varies with an annual cycle, being 3.3% above and below the yearly mean in January and July, respectively.

Temporal variations of the total irradiance affect climate directly. Spectral changes in the ultraviolet range on the other hand, influence the ozone density profile and hence stratospheric temperatures. The stratospheric ozone content is perturbed by the release of man-made trace gases such as chlorine compound emissions (CFCs). The transmission of the atmosphere, mainly in the biologically active UV-B part of the spectrum, is strongly affected by changes in ozone abundance. The available UV radiation at the surface is variable due to both natural and anthropogenic causes.

Efforts to monitor the total solar irradiance, or solar "constant", have for many years been attempted from the ground without any conclusive evidence of change. During the past 11-year sunspot cycle, an apparent cyclic variation of about 0.08% was measured from space observations. Such a change, small in comparison with the day-to-day variability, probably will not have any significant direct influence on surface temperatures. As most of the variability is due to changes in the photochemically important ultraviolet radiation region, any climatic effect should be modulated through changes in the stratospheric ozone concentrations and heating rates. Despite considerable observational effort during the last solar cycle, the amplitude of the UV solar variations associated with the 11-year activity cycle is still uncertain, but the best estimate is 3% between 200 and 300 nm, the spectral range of importance for the stratosphere and troposphere with possible implications for the biosphere.

Knowledge of the amplitude of the solar-cycle irradiance variability is of fundamental importance to ozone-trend studies. Theoretical considerations imply that total ozone should vary in phase with solar activity. The maximum of the current 11-year cycle should be reached in 1990-1991, implying in turn that the solar cycle variation in irradiance over the past few years should have counterbalanced the expected decrease in ozone over this time due to anthropogenic CFCs. After the solar-cycle maximum in 1991, the total ozone column is predicted to decrease due both to increased CFC levels and the decline in the shorter wavelengths of the solar ultraviolet irradiance responsible for the ozone production.

UV Radiation Received by the Biosphere

Global-scale data on UV radiation reaching the surface of the Earth or penetrating to various levels in the ocean are largely lacking. It is theoretically possible to assess the amount of UV radiation reaching the biosphere, assuming that we know the incoming solar flux, atmospheric-ozone abundance, aerosol content and cloud optical depth. But, high variability over time and space in these variables make assessments of the time history of the local or global ultraviolet radiation environment very difficult.

The penetration of solar ultraviolet radiation through the stratosphere is determined primarily by the total amount of the absorbing stratospheric ozone. In the troposphere, UV is attenuated by molecular (Rayleigh) scattering, as well as scattering and absorption by aerosols and clouds. Tropospheric ozone and other absorbing gases may also play an important role in UV attenuation because the path length of photons in the troposphere is markedly enhanced (compared to that in the stratosphere). This is due to multiple scattering; therefore, a small increase in tropospheric O_3 may counteract a larger decrease in stratospheric O_3.

UV Monitoring

A UV-monitoring project in the United States (the Robertson-Berger (RB) meter network) has provided a long-term record of ultraviolet radiation at the Earth's surface. This data set is, however, limited to a single broad band obtained by weighing the spectrum by a response function designed to approximate the erythemal (sunburn) response of Caucasian skin. Analysis of data from this network have yielded inconclusive results regarding the trend in UV-B radiation. However, similar measurements over the Swiss Alps indicate a slight increase of about 1 percent per year in the flux of solar UV-B radiation since 1981 (Blumthaler and Ambach 1990), which can be related to a long-term ozone depletion.

Spectral measurements of solar radiation have been made in the Arctic and in Antarctica using double monochromators calibrated in absolute units. The data from Antarctica show that irradiances at wavelengths shorter than 310 nm measured in mid-to-late October often equal or exceed values measured through summer solstice, and that these enhanced levels of UV radiation are a direct consequence of the depleted ozone abundance during Austral spring.

Model Calculations

Radiative transfer models have been used to study the effect of varying ozone abundance and cloud cover on UV transmission. Such calculations have demonstrated that increased levels of UV-B radiation may be the result not only of an ozone depletion, but also of a decrease in cloud cover. The computed annual effective UV-dose using the action spectrum for erythema (Fig. 2) varies by approximately 4% per degree in latitude in the Northern Hemisphere. Based on the ozone-trend data, the corresponding annual UV-dose varies with latitude as shown in Table 1. The region 53oN to 64°N are calculated to have experienced the smallest increase in UV-dose (only 0.5%) in spite of the annual average reduction in ozone being rather large (2.3%). This is due to the fact that the largest ozone reduction takes place in winter at these latitudes. Hence, wintertime ozone reduction has a relatively minor effect on annual UV-dose.

The annual effective dose at 60°N is shown in Figure 3, as a function of ozone depletion. The amplification factor (rate of change of UV radiation to O_3 depletion) depends on solar zenith angle and therefore is latitude dependent, because with increasing solar zenith angle, radiation in the UV-B range (which is strongly absorbed by ozone) becomes depleted relative to radiation in the UV-A range. Ozone depletions of 10% and 20% yield 12% and 26% increases in annual UV-dose, respectively. Since the DNA action spectrum (Fig. 2) falls off very sharply with wavelengths longer than about 310 nm, this spectrum will yield a larger amplification factor than the erythema action spectrum. An amplification factor near 2 has often been adopted, implying that a 1% decrease in ozone gives rise

Table 1. Changes in the ozone layer in the period 1969 to 1986 as reported by NASA and the resulting changes in the calculated effective UV-doses. The deviation from zonal average normal values is given in percent. Winter values represent the months December to March and summer values May to August (after Dahlbeck et al. 1989).

Period for the Ozone Changes	Region 53 - 64°N (%)	Region 40 - 52°N (%)	Region 30 - 39°N (%)
Annual Average	- 2.3 + 0.7	- 3.0 + 0.8	- 1.7 + 0.7
Winter Values	- 6.2 + 1.5	- 4.7 + 1.5	- 2.3 + 1.3
Summer Values	+ 0.4 + 0.8	- 2.1 + 0.7	- 1.9 + 0.8
Annual UV-dose	+ 0.5%	+ 3.1%	+ 2.0%

Figure 2.

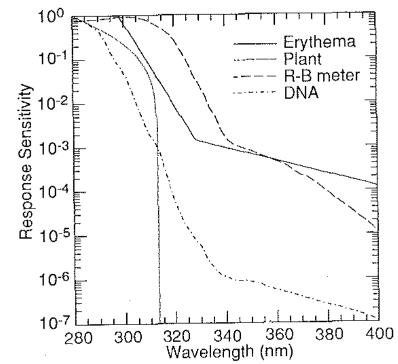


Figure 3.

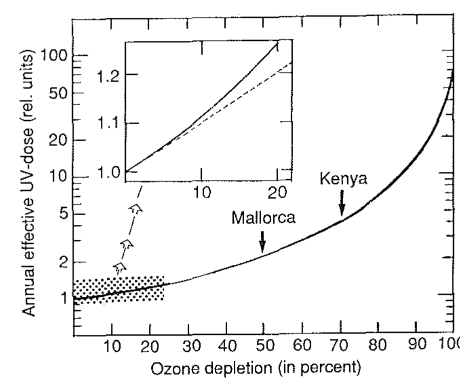


Figure 2. Action spectra for various biological responses (after Dahlbeck et al. 1989).

Figure 3. The annual effective UV-dose at 60°N as a function of the ozone depletion(logarithmic scale). The annual UV-dose, with normal ozone conditions throughout the year is set equal to 100. The inset exhibits the dotted area with the dose axis enlarged and given on a linear scale. The annual UV-dose for a latitude of 40°N (Mediterranean countries, California) and countries along the Equator, with normal ozone conditions, are indicated by Mallorca and Kenya, respectively (after Dahlbeck et al. 1989).

to a 2% increase in UV dose. Such a value is obtained for the DNA action spectrum for typical mid-latitude solar zenith angles and changes in ozone of 10% or less. Hence, the amplification factor will depend on the particular type of biological response considered, as well as on latitude and season.

Effects on the Biosphere

UV-radiation has been known to split nucleic acids, causing damage to higher plants, microorganisms, and plants and animals (Caldwell 1981). It is a well-known cause of melanoma in human tissue. Quantitative predictions of the potential direct effects of increased UV-B radiation on the human health and the environment are not possible at present. The principal limitation is lack of information and coordinated synthesis of research results in this area. This is particularly true with regard to the effect on plants. Even within species, different varieties may have different sensitivity to UV-B. Within aquatic ecosystems, increased UV-B irradiance may have a negative influence on a variety of organisms, such as phyto- and zooplankton, which form the base of the marine food web. Under decreased stratospheric O_3, major changes in ecosystem structure and functioning could occur as species sensitive to UV-B radiation are replaced by more resistant species, in both terrestrial and marine ecosystems.

Additional synthesis of existing information is needed to define the needs for additional research. In addition to tropical and sub-tropical regions, emphasis should also be placed on establishing the effects of increases in UV-B radiation in polar regions, where the largest variations in relative UV-B occur. However, the effects on adaptation and sensitivity to UV-B of organisms in these areas is not known with any certainty.

A review of the possible effects of UV-B on the biota will be carried out by SCOPE and on the basis of this review, a possible research activity for STIB will be formulated.

Research Recommendations

Measurements

In view of the potentially harmful biological effects of increased levels of UV radiation at the earth's surface and into the oceans, a global monitoring activity is urgently needed. Such a measurement activity would provide a direct link, which is currently lacking, between incoming solar flux, biological UV dose, atmospheric ozone abundance and cloud cover. Establishing this link is of crucial importance for progress in this area. The requirements for such a monitoring activity should be: (i) observations of solar spectral irradiance variations (both from space and at the surface) with a precision of 1% over at least a full solar cycle are needed to discriminate between natural changes and anthropogenic perturbations in the stratospheric composition; (ii) the spectral distribution of the UV-radiation, from which appropriate UV-doses can be derived, should be monitored at a surface network of properly chosen stations around the globe. The spectral resolution of the measurements should be sufficient to provide a simultaneous measurement of column ozone abundance and biologically relevant UV-radiation. It should also be capable of quantifying the influence of other environmental parameters on UV radiation levels, such as cloud cover, atmospheric aerosols and gaseous absorbers related to anthropogenic pollution.

Modelling

Accurate assessment of atmospheric heating rates is needed in global models aimed at predicting the impact of greenhouse gases on climate. Photolysis of several atmospheric trace constituents as well as many chemical reactions, important in ozone chemistry, occur at temperature-dependent rates. An accurate knowledge of atmospheric temperature variations and hence heating rates is therefore essential in photochemical models. Since both photolysis and heating rates depend directly upon the radiation field, an accurate description of the radiation field as a function of altitude and solar zenith angle is of paramount importance. As it is unlikely that monitoring of these effects would be feasible on a global scale, reliable and efficient modelling of the solar radiation penetrating to various levels in the atmosphere is important.

Prediction of UV doses received by the biosphere in the oceans requires coupling of the radiation field in the ocean and the atmosphere. This can be done in principle, but efficient numerical algorithms are still lacking. There is also a need to estimate UV penetration through ice and snow to determine the UV dose received by organisms at high latitudes.

Stratosphere-Troposphere Exchange

The troposphere and stratosphere are photochemically and dynamically very different regions. Exchanges of material between them not only determine the influx of H_2O, N_2O, CH_4 and the CFCs to the stratosphere, where their photochemical breakdown yields ozone-destroying radicals, but also transport ozone from the stratospheric reservoir to the troposphere, where it plays a large role in defining the oxidative efficiency of the troposphere via the formation of OH radicals.

Transport of air from the troposphere to the stratosphere takes place primarily in the equatorial region. The return flow in mid-latitudes occurs primarily through tropopause-folding events. The location and strength of troposphere-stratosphere exchange is linked to surface temperatures and to the general circulation patterns in the troposphere, both via the control of the convective upwelling in the tropics and by storm-track patterns in middle and subtropical latitudes.

Changes in the temperature structure of the troposphere caused, for example, by changes in surface temperatures and ocean circulations, affect the height and structure of the tropopause and the strength of the exchange processes across it. Thus, the flux of gases to the stratosphere may be affected; in particular, those gases that are involved in ozone destruction and those that are radiatively active, especially water vapour.

The tropopause is usually defined as the region in which a local minimum in the height profile of temperature is observed. The structure of the tropopause region is affected by the upper tropospheric waves as well as processes in the lower stratosphere. Polar ozone losses in the lower stratosphere, in which Polar Stratosphere Clouds (PSCs) are involved, have received much attention recently. PSC formation is forced from below by synoptic scale waves of the upper troposphere. The role of these waves in polar ozone losses, and also the nature of lower stratosphere transport and the possibility of transmitting polar ozone losses to lower latitudes are not well understood.

Conversely, it has been shown that stratospheric air may play an important role in the development of mid-latitude cyclones and general circulation models indicate sensitivity of the tropospheric circulation to the representation of stratospheric dynamical processes. Clearly, the dynamical, radiative, and chemical coupling across the tropopause is a two-way process, and not simply a case of the troposphere forcing the stratosphere.

Research Recommendations

Observations

Observational data of mid-latitude exchange processes between stratosphere andtroposphere are already available from a few ground-based atmospheric radar and lidar instruments. These need to be enhanced by a wider network to especially quantify the exchange in subtropical and equatorial latitudes. There is also a need for high resolution, *in situ* measurements from aircraft and balloons. The instruments required for aircraft measurements are only partially available. There is a need to develop and deploy state-of-the-art instrumentation to measure the radiative flux divergence in the short-wave and long-wave regions, and thereby measure the local radiative heating and cooling rates. It is particularly important for this to be done above and within cirrus cloud decks and polar stratospheric clouds. Measurements of tracer substances, such as N_2O and $CFCl_3$ that permit detection of diabetic descent, and CO_2 that allows stratospheric air to be dated, are essential. Further aircraft measurements in regions of convective upwelling are also required, as a follow-on to the recent NASA Stratosphere Troposphere Exchange Project. In addition, present and future measurements from satellite instruments (e.g., UARS and polar platform will supply data with extended coverage so that the larger scale processes may be examined.

Modelling

Improved (3-dimensional) numerical models are required that (i) include the troposphere and stratosphere with sufficient spatial resolution to allow a detailed study of the exchange processes and interactions outlined above; (ii) contain an adequate treatment of the radiative effects of tropospheric clouds and PSCs; and (iii) contain an adequate treatment of chemical processes in the stratosphere, so that the full feedback effects of the stratosphere-troposphere interactions may be represented.

To some extent these separate requirements may be tackled individually. For example, progress in understanding radiative feedbacks of PSCs does not require a GCM with complete treatment of chemical modelling and, similarly, the study of the detailed mechanisms of exchange processes is perhaps best conducted using trajectory analyses and extremely high resolution dynamical models. Ultimately, in order to fully assess the impacts of the interactions described in this section, the development of models that include the full range of radiative-dynamical-photochemical interactions between the stratosphere and troposphere and the radiative effects of sea-surface temperature are required. Hence, a hierarchy of models must be developed. These efforts must be carried out in collaboration with the WCRP Working Group on Numerical Experimentation.

Finally, as a test of these models, at all stages comparisons with observations are essential. To this end a close cooperation with IGAC field measurements (see Chapter 2.1) is essential so that the field campaigns of mutual interest can be coordinated for maximum benefit of both groups.

Anthropogenic Trends and Natural Variability

The stratosphere is the region of the atmosphere which to date has been impacted in a most dramatic and unpredictable manner through the formation of the Antarctic ozone hole. The stratosphere is also the place where the largest changes in both ozone and temperature profiles are expected to occur in the future. In fact, in the Antarctic lower stratosphere, large springtime ozone depletions several tens of percent have been observed over the past decade (Fig. 4).

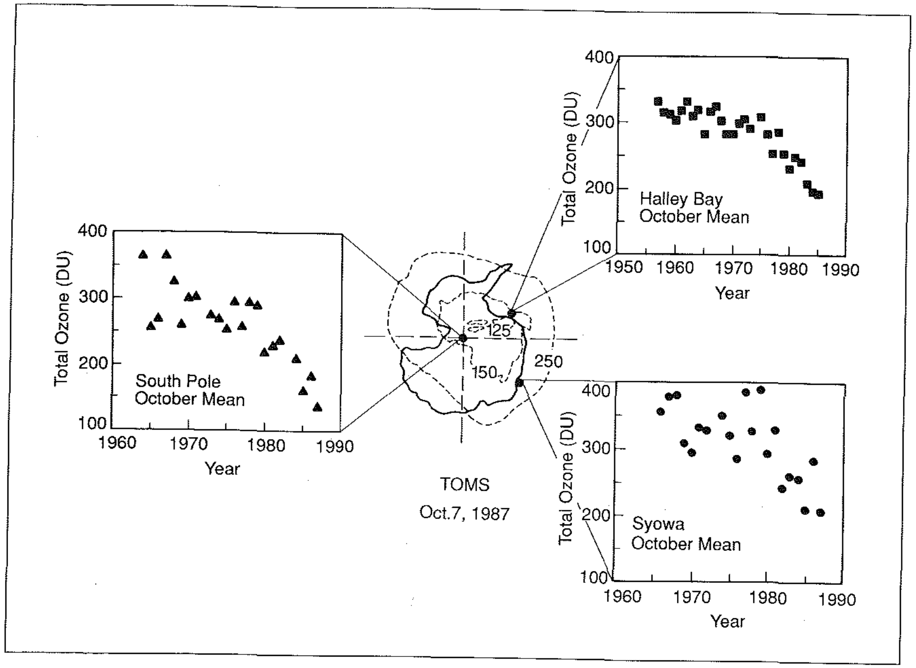


Figure 4. Total ozone. Observational data that first indicated the existence of the Antarctic ozone hole. DU, Dobson units; TOMS, total ozone mapping spectrometer (NRC 1989).

Recent reviews of ozone trends (e.g., UNEP-WMO 1989) were limited by the uncertainty regarding the impact of the El Chichon eruption and the role of the 11-year solar cycle on the stratospheric behaviour, despite the use of the highest quality satellite and ground data, which extended over less than 10 years. On this time scale the natural variability is due to two main causes; volcanic eruptions and solar variability. Major eruptions affect the net radiative balance of the Earth and atmospheric temperatures. The main consequence of volcanic eruptions for the stratosphere is related to the injection of sulphur dioxide into the stratosphere.

The response of climate to solar forcing may be due to either changes in orbital parameters or to changes in solar output itself. On decadal time scales the principal effect is that of the 11-year sunspot cycle. The higher frequency modulation imposed by the 27-day sun rotation cycle is too rapid to affect climate significantly. Nevertheless, a better understanding of shorter-term effects on the atmosphere may lead to a better understanding of the role of the cycles of longer periods on the atmosphere as well as on the climate. For these reasons the STIB project should encourage the study of both the influence of the 11-year and 27-day cycles. Both are associated with changes of about 3% in solar irradiance in the wavelength range of importance for the lower atmosphere and have a measurable and well-recognized impact on the structure of the atmosphere above approximately 40 km. The important question concerns the depth in the atmosphere to which the impacts of solar variability can penetrate and how/whether they can affect the climate and the biosphere.

Studies of satellite data have yielded significant correlation of both ozone and temperature with the 27-day solar cycle in the middle stratosphere, and major solar disturbances yield clear signatures in the ozone concentration. Recent studies by Van Loon and Labitzke (1990) suggest an association between the 11-year solar cycle and the atmospheric structure at different levels of the atmosphere. In the Northern Hemisphere, they identified a pattern of correlation between the 11-year solar cycle and temperatures and geopotential heights at 100 hPa and 30 hPa (16-25 km).

Research Recommendations

Reliable, detection of trends in thermal, chemical and dynamic properties of the middle atmosphere requires an accurate and long-term monitoring effort, using satellites and ground-based stations. Even though the ozone-trend issue has been the subject of intense research in the last two decades, the observational network and the data quality are still inadequate to provide the required accuracy on a global scale. Satellite data of appropriate spatial coverage are of too short a record length (about one 11-year solar cycle) to differentiate between the effect of natural and human-induced effects on ozone. Furthermore, most of the satellite data are not yet calibrated in absolute terms and need to be validated against ground-based measurements.

Thus, a comprehensive, consistent and long-term data collection effort is needed. SCOSTEP's STEP project seems to be the appropriate organization to lead an effort in this regard.

Stratospheric Aerosols and Their Climatic Effects

Stratospheric particles can influence the surface climate of the Earth through their effects on atmospheric radiation. They can also influence the trace composition of the atmosphere and ozone concentrations. In this regard, both natural and anthropogenic influences need to be considered.

It is now fairly well established that the stratospheric sulphate layer is formed by chemical transformation and condensation of sulphur-bearing gases (COS, SO_2) transported into the stratosphere from the troposphere or directly injected there by large volcanic eruptions. In addition to the chemical reactions of precursor sulphur gases leading to the production of condensable sulphur compounds, primarily H_2SO_4, evolution of the particulate layer involves a number of microphysical processes including aerosol nucleation, growth by condensation, evaporation, coagulation and gravitational sedimentation.

Studies indicate that anomalous weather patterns and regional to global-scale cooling are likely to follow major volcanic eruptions. Volcanically-induced sulphate aerosols can affect the global radiation budget. When injected in the stratosphere, volcanic aerosols can rapidly disperse around the Earth, increase the reflectivity of the atmosphere for solar radiation, thus reduce the incoming solar energy at the Earth's surface. The aerosols also produce a modest infrared trapping effect, which is insufficient to reverse the cooling caused by the increased reflectivity. A number of statistical correlations have been discovered between volcanic eruptions and global cooling in the following years, but the significance of these is not universally accepted. The net effect of major volcanic emissions of sulphur gases into the stratosphere appears to be a global surface cooling of less than 0.5 °C that may persist for 1-3 years. During previous centuries much larger volcanic eruptions, such as Tambora and Krakatao, may have had substantially larger effects. More intense or widespread volcanic activity may re-occur in the future.

Following major volcanic eruption, the stratospheric aerosols fall into the upper troposphere over a period of several years. These sulphate particles are highly soluble and enhance the cloud condensation nuclei (CCN) population of the upper troposphere. It has also been speculated that such soluble aerosols may provide nuclei for cirrus cloud formation. The stratospheric particles, acting as nuclei, could thus modulate the properties of upper tropospheric clouds, and hence have a global impact.

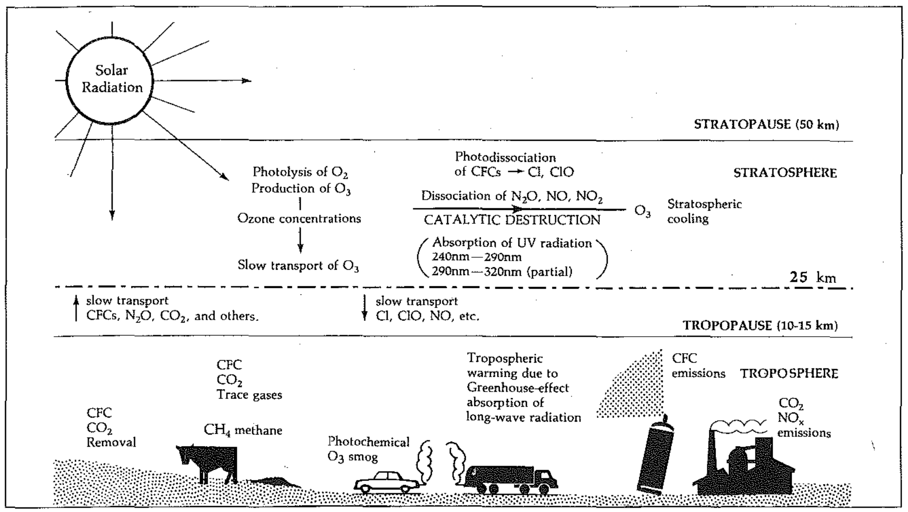
The recent discovery of an ozone hole over Antarctica in late Austral winter and early spring has led to considerable research on the causal processes. Current chemical theories assume that heterogeneous reactions occur on polar stratospheric cloud (PSCs) particles composed of HNO_3 and H_2O. Laboratory studies show that the ice-catalyzed reaction of HCl with chlorine nitrate ($ClONO_2$) produces active chlorine. Through known homogeneous photochemical processes, this enhanced activated chlorine can explain most, if not all, of the measured ozone loss.

The role of other stratospheric aerosols in heterogeneous chemical conversion processes that might affect stratospheric composition and ozone depletion needs to be investigated. In this regard, a principal concern for the future is that increasing concentrations of background stratospheric chlorine from chlorofluorocarbons might be extensively activated over the entire globe on sulphate aerosols generated by a major volcanic eruption. Accordingly, a reassessment of the potential importance of heterogenous stratospheric chemistry is timely.

Human activities can also affect the composition and structure of the stratosphere and stratospheric aerosols in a number of ways. In particular: (i) carbon-dioxide concentration increases lead to a significant cooling of the middle and upper stratosphere thereby altering the dynamics, chemical kinetics and thermodynamics of sulphate particle formation; (ii) tropospheric emissions of sulphur-bearing gases such as COS reach the stratosphere and, upon decomposition, modify the sulphate layer; and (iii) chlorofluorocarbons released at the surface diffuse into the stratosphere and are decomposed into chlorine species that react with stratospheric aerosols.

Research Recommendations

To achieve greater certainty of the possible connections between the stratosphere and the troposphere that involve stratospheric aerosols and that have



Selected physical and chemical processes affecting ozone concentrations and climatic processes

global change implications, specific cooperative research activities should be encouraged within WCRP, IGAC and the IAMAP/IGAP Project. These should include the following:

- Studies of volcanic aerosols to delineate the connection between volcanic emissions, aerosol formation and dispersion, and radiative/climatic impacts of volcanic eruptions. Such studies could in part be carried out using the existing satellite and ground- based data base for the El Chichon eruption of 1982, although the project would aim towards collecting new data, particularly through satellite observations, on future eruptions.
- Studies of aerosol heterogeneous chemistry, including accurate laboratory studies on the reactivity, particularly regarding chlorine species, of sulphate (sulphuric acid) aerosols should be carried out. If possible, chemical perturbations associated with enhanced sulphate aerosols should be studied directly following volcanic eruptions.
- Models capable of predicting the effects of various human activities on stratospheric aerosols, upper tropospheric aerosols, the global radiation budget and climate should be developed; such models should be global in scale and include accurate treatments of the appropriate dynamical, photochemical, microphysical and radiative processes.
- A global network for monitoring stratospheric aerosol trends, particularly those trends that may be associated with anthropogenic emissions, could be built upon existing satellite and lidar measurements projects.

The Impact of Stratospheric Changes on Climate

The stratosphere affects the troposphere through radiative, dynamical and chemical processes.

Radiative Processes

The stratosphere affects the radiative balance of the atmosphere by absorbing a fraction of the incoming solar radiation and by exchanging long-wave radiation with the troposphere and the Earth's surface. The absorption of solar radiation in the stratosphere, principally by ozone, reduces the net solar heating of the surface/troposphere system. The downward emission of long-wave radiation by the stratosphere contributes to tropospheric heating and stratospheric cooling. It is a significant component of the greenhouse effect, maintaining the surface temperature above the black-body temperature required for equilibrium with the insolation absorbed by the earth/atmosphere system. Trace gases such as ozone, water vapour, CO_2, and the chlorofluorocarbon gases $CFCl_3$ and CF_2Cl_2, the concentrations of which are changing with time, produce significant downward emission. Changes in stratospheric composition involving trace gases, especially CO_2 and ozone, lead to strong cooling of the upper stratosphere (Rind et al. 1990).

Dynamical Processes

Planetary scale (Rossby) waves and gravity waves propagate vertically out of the troposphere into the stratosphere, where they decelerate the mean winds and change the temperature distribution. Strongly modified waves are reflected back in to the troposphere. Simulations with general circulation models (e.g., Rind et al. 1990) have shown that the nature of wave propagation into the stratosphere has a significant impact on the troposphere. A joint effort with WCRP/WGNE is necessary to address this issue.

Research Recommendations

A thorough scientific understanding of the chemistry of the middle atmosphere and its effects on the troposphere requires a balanced approach involving laboratory measurements (reaction rates, molecular absorption cross sections), field measurements, long-term monitoring of crucial solar fluxes and atmospheric circulation, temperature and chemical distributions. Development of a hierarchy of computer models that include the radiative, dynamical and photochemical processes in the atmosphere and their feedbacks is also required. A cooperative effort with the WCRP is required to develop such models.

Plan for Action

The intention is to initiate research activities along several fronts that will address the scientific components and related issues discussed above. Specifically, the activities will involve field campaigns to make specific measurements, analysis of satellite observations, establishment of a complementary ground-based network for monitoring stratospheric variables and numerical modelling.

Field Programmes

In recent years, field programmes have been of immense value in obtaining answers to crucial questions dealing with the middle atmosphere. Several ground-based campaigns, e.g., balloon sounding programmes and aircraft missions directed to study the polar ozone problem, have proved to be essential in addition to the studies using satellite observations. There is a range of exciting experiments within reach, given the necessary investment in platform and instrument development. The most complete synthesis will be achieved by meshing field campaigns with their excellent spatial resolution and flexibility, with satellite observations, which yield global coverage.

The following is a list of initial priority issues which can be addressed in well-conceived field programmes. No attempt is made here at detailed definition, other than some fairly specific instrumental requirements discussed in the next section.

- Improve the understanding of the exchange of gases between the troposphere and the stratosphere. Recent work on the stratospheric water-vapour content suggest that not all air is dried to the lowest values allowed by the minimum temperature experienced upon entering the stratosphere in the tropics. The actual mechanism for drying most stratospheric air is still not known in detail; until it is established it is difficult to be as certain how air enters the stratosphere.
- Improve the understanding of the mechanisms for the large extent of diabetic descent in polar and subpolar latitudes in winter and spring. In this regard, measuring, analyzing and understanding the radiative and induced dynamical effects of high cold cirrus clouds may also be of interest.
- Improve the understanding of halogen-induced ozone loss around Antarctica and investigate the likelihood of this effect spreading to middle latitudes.
- Improve the understanding of the effects of aerosols from large volcanic eruptions on stratospheric chemistry.

Some Platform and Instrumental Requirements

Major requirements for aircraft are increased ceiling and range. Both are technologically feasible, at least to a 27 km (20 hPa) ceiling and 6000 nautical-mile range, with a one ton payload. Such an aircraft would probably be unmanned. In addition, long endurance balloons would be a very valuable development, particularly in the Southern Hemisphere.

Few instruments to measure parameters of interest are available. There is a need for state-of-the-art instrumentation to measure the radiative flux divergences in the short and long-wave regions and thereby determine the local radiative heating and cooling rates. Additionally, fast response *in situ* detectors of a number of reactive and tracer molecules are required to augment the existing capability for NO/NO_y, ClO, BrO, O_3, H_2O and N_2O. For large, lower-flying aircraft, the development of Differential Absorption Radar (DIAL) systems for extending the current capability for aerosols and ozone to water vapour and possibly other species should be encouraged.

Satellite Observations

Global, long-term monitoring of a wide range of atmospheric variables is essential if changes in the structure and composition of the stratosphere are to be quantified. Measurements from satellites with their global coverage will, when coupled with a suitable ground-based observation system, be crucially important if this aim is to be achieved.

Operational meteorological satellites make extensive measurements of the stratospheric temperature structure. Stratospheric ozone-profile measurements above the maximum are available from some satellites and some information on water-vapour abundances in the low stratosphere and upper troposphere can be obtained. These are likely to continue to play a central role in detecting stratospheric change.

Because of the long period between conception and execution, satellite platforms and instruments that will be available during the next decade are already largely known. A major data set will come from the Upper Atmosphere Research Satellite (UARS) to be launched in 1991. Global measurements of atmospheric wind and temperature structure and a wide range of molecules, including elements of the NO_y, HO_x and ClO_x families are expected to lead to a major improvement in understanding the photochemical, dynamical, and radiative processes controlling stratospheric ozone abundances. However, the lifetime of UARS (2-4 years) will limit the usefulness of UARS data for detecting stratospheric trends and there is expected to be a gap of several years before a new generation of instruments can fly on the polar platforms (EOS and the European and Japanese platforms).

Several proposals are being discussed by space agencies for satellite-borne instruments to measure a range of atmospheric variables, with improved height resolution, including stratospheric temperatures, the concentrations of a variety of molecules, stratospheric aerosol distribution and radiative budget parameters as well as the tropospheric concentration of several molecules (CH_4, N_2O, CO, O_3). Development of such satellites should be encouraged as they would be an important contribution to the IGBP in general and the STIB project in particular.

A Network for the Detection of the Stratospheric Changes

Ground-based measurements to complement satellite observations are an essential component of any observation system for global ozone and related stratospheric variables. Such measurements should be developed within a network of stations with appropriate locations to obtain optimum information possible. They should be performed using recently developed instruments, which will allow appropriate accuracy, precision, and vertical and temporal resolutions. It is essential that the network has an integral research-oriented approach to data analysis, since once any trend has been reliably characterized there will remain the task of interpretation.

Objective

- *To study temporal (diurnal to seasonal, annual, interannual and perhaps longer term) and spatial variability of stratospheric composition and structure, and to assess with such data the current status of stratospheric chemical and dynamical models.*
- *To provide the earliest possible detection of large-scale changes in the stratosphere and the means to understand them.*
- *To provide an independent calibration of satellite sensors.*

The scientific rationale for selecting such objectives is based on the follow-ing considerations.

- Changes in column ozone, leading to increasing surface UV-B radiation, may have consequences for human health, and terrestrial and oceanic ecosystems.
- The vertical distribution of ozone controls the temperature structure of the stratosphere, and changes in it can influence the climate of the Earth.
- The temperature profile of the stratosphere influences the rates of chemical reactions, and hence the abundance of ozone. In addition, the temperature structure of the stratosphere itself is controlled by the ozone distribution.
- The ClO radical is the chlorine species responsible for directly catalyzing the

destruction of ozone. Its atmospheric concentration is predicted to be increasing at a rate of at least 5% per year due to the increasing atmospheric concentrations of chlorofluorocarbons.

- NO_2 and NO are important for the catalytic control of ozone and play a vital role in coupling the NO_x and ClO_x families. Consequently, the atmospheric concentration of NO_2 may decrease in the future as increased concentrations of ClO will convert a growing fraction of it into $ClONO_2$. Conversely, the observed increase in the concentration of N_2O, the stratospheric precursor molecule NO_2, would offset some of these decreases.
- HCl is the key temporary reservoir species in the ClO_y family. It should be monitored in conjunction with ClO in order to see whether the partitioning of species within the chlorine family is changing over time.
- Aerosol particles are now thought to play a major role in the chemistry of the stratosphere, at least under ozone-hole conditions, through heterogeneous processes. Such effects may also be important following major volcanic eruptions. In addition, the presence of high levels of aerosols can influence the interpretation of some optical sensor data.
- Water vapour plays a vital role in controlling the radiative and chemical balance of the stratosphere. It is the dominant source for the hydroxyl radical, which influences the concentrations of HO_x, NO_x, and ClO_x molecules and in turn affects ozone. Its abundance is an important determinant for the formation of polar stratospheric clouds. The concentration of stratospheric water vapour is expected to increase due to increasing concentrations of atmospheric methane, and may also change if surface temperature in the tropics increase, leading to changes in the intensity of the Hadley circulation and the exchange of water across the tropopause.
- Nitrous oxide has a long lifetime in the stratosphere and quite simple photochemical removal mechanisms due to photolysis. This makes it an ideal tracer for studying changes in atmospheric circulation.

Modelling

Numerical models are essential for predicting and understanding the effects of changes in the meteorology and composition of the stratosphere on tropospheric climate. One-dimensional (altitude only) photochemical models have been useful in the initial examination of various photochemical scenarios. For instance, the first models of ozone depletion by the chlorofluorocarbons were made using such models. They have proved useful in initial examination of various trace-gas climate effects. Some assessment of feedback effects can also be made using one-dimensional climate models.

The next level of complexity in atmospheric modelling is the two-dimensional approach (altitude and latitude). Various approximations can be made in formulating such models. One of the better approximations is that of fixed dynamical heating. In this approximation, the temperature distribution is determined by the sum of the radiative heating and the dynamical heating (driven by the circulation). As the atmospheric composition changes, the radiative heating changes, but in many models currently in use, the dynamical heating (i.e., the circulation) is assumed to remain constant. Given this limitation, predictions using such models remain open to question.

One- and two-dimensional models cannot fully represent the three-dimensional complexity of the atmosphere. Ideally, numerical studies of atmospheric dynamics and chemistry should therefore be based on three-dimensional models. Because fully coupled 3-D models of dynamics and photochemistry are still very complex to run, with present day computers, simplifications must be introduced whereby the photochemical calculations are performed off-line. In this approach, winds and temperatures obtained from integrations with a purely dynamical model are used as input data to three-dimensional models of transport and photochemistry. This approach obviously has the limitation that the dynamics, being fixed, cannot respond to changes in composition.

A better approach is to use models in which the radiative, dynamical, photochemical processes are fully coupled. It is, however, a very expensive approach and has not so far been used to any great extent. Such models might be used in future to investigate the effects of the stratosphere on tropospheric climate.

Clearly, modelling is a major activity that needs to be further developed in close collaboration with the WCRP and other appropriate international and national efforts.

Implementation

To realize the objectives of STIB, coordination with several other organizations and development of a strategy to assure long-term international commitment is an obvious necessity. If the project becomes an established Core Project, then a Scientific Steering Committee will be appointed by IAGA, IAMAP, SCOSTEP and IGBP. Other international organizations, such as WCRP and SCOPE will also be invited to participate in the committee work. In addition, the STIB project must establish links with other existing programmes and projects, such as the already existing national or regional O_3 projects, IGAP, and STEP, as well as with other Core Projects of IGBP, especially IGAC, GCTE and PAGES.

For the present, the main effort should be directed to ensuring coordinated planning. This can be done in an open meeting that should be organized as early as possible in 1991 to refine the science plan and develop an implementation strategy to assign the responsibilities for the different sub-projects.

References

Blumthaler, M. and Ambach, W. 1990. Indication of increased solar ultraviolet B-radiation flux in Alpine regions. Science 248:1990-1992.

Caldwell, M. M. 1981. Plant response to solar ultraviolet radiation. In: Encyclopedia of Plant Physiology Vol 12 A:169-197. Springer-Verlag.

Dahlbeck et al. 1989. Photochem. Photobiol. 49:621.

NRC. 1989. Global Change and our Common Future. DeFries, R. and Malone, T. F. (eds), 227 pp. National Academy of Sciences, Washington, D.C., USA

Rind, D., Suozzo, R., Balachandran, N. K. and Prather, M. J. 1990. Climate change and the middle atmosphere. Part I: The doubled CO_2 climate. Journal of Atmospheric Science (in press).

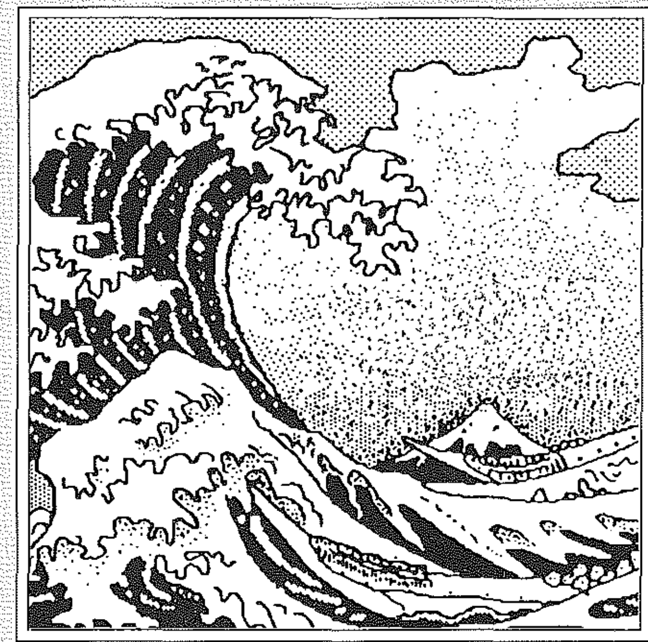
Sinclair, L. 1987. New WRI report details strategies for protecting ozone layer. Ambio 16:51-53.

UNEP-WMO. 1990. Scientific Assessment of Stratospheric Ozone. UNEP-WMO Report 1990.

Van Loon, H. and Labitzke, K. 1990. Association of the 11-year solar cycle and the atmosphere. Part IV: the stratosphere, not grouped by the phase of the QBO. J. Climate. (in press).

CHAPTER 3

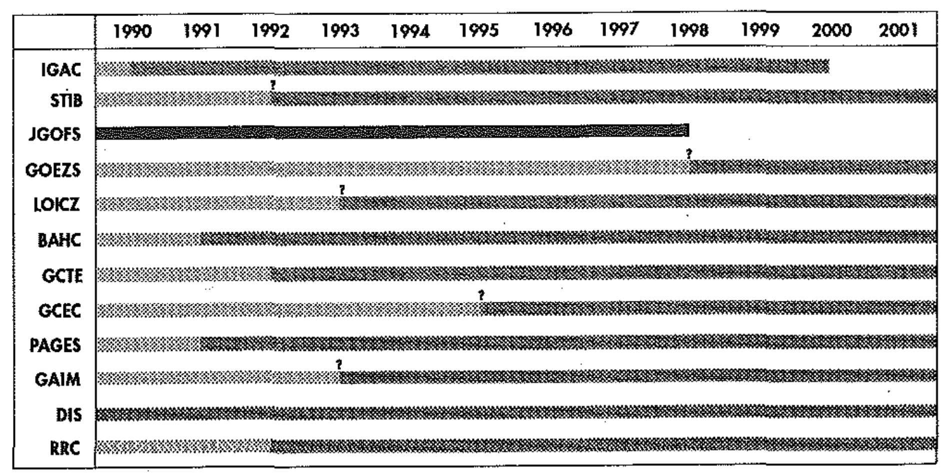
GLOBAL
IGBP
CHANGE



How Do Ocean Biogeochemical Processes Influence and Respond to Climate Change?

Through a combination of physical and biogeochemical processes the oceans function as both source and sink for carbon dioxide. Thus, the oceans play a key role in regulating the climate system, partly through biological processes such as marine primary production. Climate change will alter marine biogeochemical cycles, which in turn will affect the physical aspects of climate to an extent that is as yet unknown. Human-induced changes on land will influence coastal biogeochemical cycles, and expected sea-level rise, as a consequence of climate change, will have profound effects on coastal ecosystems. The specific role of the oceans in shaping the Earth's environment for life needs to be understood. In particular, a quantitative knowledge of the key interactions linking oceanic process and the climate system must be developed.

Contents


1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
IGAC
STIB
JGOFS
GOEZS
LOICZ
BAHC
GCTE
GCEC
PAGES
GAIM
DIS
RRC

3.1 Joint Global Ocean Flux Study (JGOFS)

An Established Core Project

Introduction

Scientific Rationale

Of the estimated input of carbon dioxide due to fossil-fuel burning and changing land use, less than 60% is now present in the atmosphere. The ocean is believed to be taking up much of the remainder, at a rate of about 2 Gt/yr; but we do not know how this capacity is regulated. The ocean stores some 50 times more CO_2 than the atmosphere, and a relatively small change in the oceanic carbon cycle (for example, in response to climate change) can have large atmospheric consequences. Moreover, the ocean has a more complicated CO_2 cycle than the atmosphere, involving many inorganic and organic forms. Various sophisticated measurements and models of the atmosphere and ocean give different estimates of how much CO_2 is exchanged and where. Clearly, we must improve the observational and conceptual bases of our estimates and predictions. JGOFS has therefore been designed to increase our understanding of the ocean carbon cycle, its sensitivity to change, and the regulation of the atmosphere-ocean CO_2 balance. More formally, it has two objectives (SCOR 1987).

Objectives

- *To determine and understand on a global scale the processes controlling the time varying fluxes of carbon and associated biogenic elements in the ocean, and to evaluate the related exchanges with the atmosphere, sea floor, and continental boundaries.*
- *To develop a capability to predict on a global scale the response of oceanic biogeochemical processes to anthropogenic perturbations, in particular, those related to climate change.*

The entry of anthropogenic CO_2 into the ocean is a net result of much larger carbon fluxes between the ocean and atmosphere and within the ocean. Any attempt at prediction has to consider likely changes in fluxes throughout this network. A reasonable target for JGOFS would be to reduce the uncertainties in the fluxes to the level of 2 GT/yr, the size of the anthropogenic input. Then if, as seems reasonable, the changes in the gross fluxes are a small fraction of the gross fluxes themselves, the precision of our prediction of the net uptake should be a small fraction of the net uptake. For some of the important fluxes this means improving precision by a factor of 10 over current knowledge.

Summary of Present Knowledge

The flow of carbon dioxide between atmosphere and ocean is dominated by ocean upwelling and downwelling. High latitude water cools and dissolves more CO_2 before it sinks; water upwelling at the equator warms and releases CO2. The rate of carbon entering the oceans at high latitudes and leaving at low by this route is about 40 (±10) Gt/yr (Moore and Bolin 1986). The gas flux across the sea surface at a point is a product of the partial pressure difference and a surface transfer coefficient. The transfer coefficient increases with wind speed in a known way, and global wind speed will be available from satellite measurements in the near future. Surface measurements of pCO_2 (ocean) are sparse, and therefore global estimates of net air-sea exchange must now depend on averages over large areas of ocean and over seasonal or even annual time scales: this is what contributes most of the uncertainty in our estimates of the net CO_2 flux. Much of JGOFS will therefore be devoted to determining how the key processes vary in space and time, to improve the accuracy of interpolations.

Surface transfer is closely related to vertical mixing in the water column, which determines the gradient of CO_2 concentration with depth and hence helps determine the surface pCO_2. The physics of vertical mixing is not an explicit component of JGOFS; but it is an active area of research in its own right, and it is an explicit component of the potential IGBP/SCOR project GOEZS (Chapter 3.2).

Chemical and biological processes determine pCO_2 away from the region of direct atmospheric exchange. Dissolved inorganic carbon (DIC) is divided between CO_2 and the much larger pool of bicarbonate and carbonate, the balance is determined by the reversible reaction:

$$CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2HCO_3^- \qquad (1)$$

The rates of the reaction in each direction depend on pH, alkalinity, and temperature. Changing the reaction rates in this reversible reaction can change the endpoint concentrations. The half-time for the air-sea exchange and water chemistry equations to approach equilibrium is about 5 months (Broecker and Peng 1982). Another important process is photosynthesis in the well-lit surface layer, say the top 100 m. At some times of year this reaction is so fast that CO_2 is driven far from its physical-chemical equilibrium. The amount of carbon taken up depends on inorganic nutrients like nitrogen (unlike terrestrial ecosystems, marine primary production is never carbon limited), and in low-latitude regions basically all the nutrients are used up in the summer and therefore as much carbon as possible is taken up. At high latitudes, for example in the Southern Ocean, large amounts of nutrient remain in the water all year round. If they were taken up then pCO_2 (ocean), and therefore pCO_2 (atmos), could be drawn down further. There is evidence that this happened during glacial periods. Ice-core records show that changes as large as (though much slower than) the anthropogenic input occurred between glacial and inter-glacial periods.

Much of the biological production is quickly recycled back to CO_2 through respiration, and therefore does not represent a net removal. Total primary production in the ocean is perhaps 40 Gt/yr, of which perhaps half sinks out of surface waters as particles (plant cells, faecal particles, etc). The fraction of recycled primary production is not at all well known. Recent measurements (Sugimura and Suzuki 1988) suggest that a large amount is locked up in high molecular weight, non-volatile organic molecules, which are broken down only very slowly. These measurements imply a downward net DOC flux of 4 (± 2) Gt/yr.

The recycling of production through respiration can be difficult to estimate. There is no way to distinguish "new" or "recycled" CO_2 in primary production, and only the "new" production has any net effect on reducing pCO_2. However, nitrogen is taken up as well in an almost constant proportion of 1 nitrogen atom for every 7 carbon; and we can distinguish "new" nitrogen (primarily in the form of nitrate) from "locally regenerated" nitrogen (primarily ammonia or urea). So new and regenerated production, defined operationally by the kind of nitrogen taken up, are equated to exported and recycled carbon uptake (Eppley 1989). Measurements of the "f-ratio", the ratio of new to total production, have been made in many places and related to many features of the water (e.g., nitrate concentration), but the relations are at best tentative and empirical, and model studies suggest no theoretical basis for them.

The calcium carbonate components of some phytoplankton and zooplankton also contribute to the downward flux of carbon. When organic carbon sinks, it is typically regenerated as CO_2 in the top 100 m; when shells sink they are dissolved and CO_2 is regenerated at much greater depths. As carbonate is removed from the water, the reaction depicted in equation (I) must move to restore carbonate and therefore increase CO_2, leading to a potential reduction in the oceanic drawndown of atmospheric CO_2.

Many attempts have been made to describe the processes that produce the distributions of bio-active compounds in the ocean using mathematical models. Simple chemical models, in which the role of the biota was either ignored or parameterized by simple linear models, have proved very useful in trying to understand the role of the ocean in modifying atmospheric CO_2 concentrations in the geological past (Sarmiento et al. 1989) and in understanding the controls on CO_2 uptake in the present world ocean (Volk and Liu 1988). Biological models have from their earliest development used more detailed nonlinear functions to describe the interactions between organisms, but a global perspective has, until recently, been lacking.

Summary of JGOFS Structure

There are three different directions along which we can divide this massive task into more manageable parts: according to what processes JGOFS will study, or how, or where they will be studied. In addition, as a basis for prediction, there is the need to survey the present values of key variables, and to establish strategies for detecting long-term changes in ocean cycles above the background of natural variability.

Carbon Transformations and Transports

This division centres on what the main carbon fluxes are, and how they respond to physical and chemical forcing on time scales from sub-seasonal events to decades. JGOFS will consider the following questions:

(i) What processes change the phase, or form, of organic and inorganic carbon in the ocean?

(ii) How does carbon move with and through the water, via ocean currents, mixing, diffusion and sinking?

(iii) What exchanges occur at ocean boundaries? These include air-sea exchanges (those most directly related to the rationale for JGOFS), exchanges at the bottom (both benthic communities and buried sediments), and exchanges at continental margins. Processes on continental shelves are considered in the proposed IGBP project LOICZ (Chapter 3.1). JGOFS and LOICZ each represent a crucial boundary condition for the other. At the moment, neither project is in a position to measure transboundary flow over the continental shelf, but this is recognized as an important area for future research.

Approaches

JGOFS will combine the strengths of many ways to study the ocean (Fig. 1). The global view will come from satellite measurements of key variables like wind speed, temperature and chlorophyll. A global survey from ships will establish the present distribution of DIC and its seasonal variation. Detailed, long-term variability in time will be studied at a few time-series stations. Both the global survey and the time-series studies will measure more variables than the satellites, and with vertical resolution in the water column, while remotely sensed observations will put the detailed observations in their space-time context.

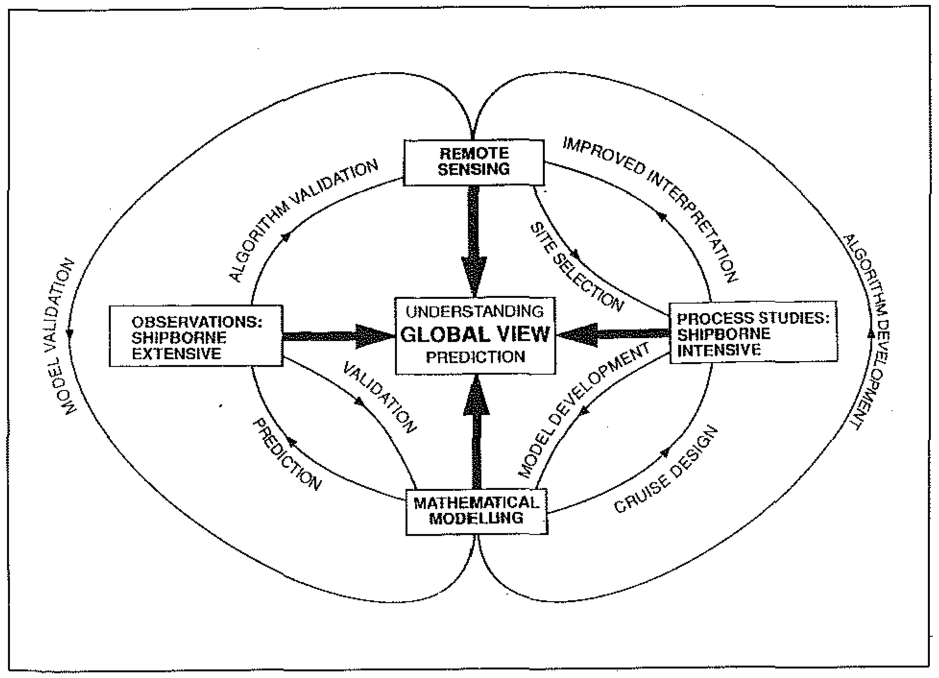
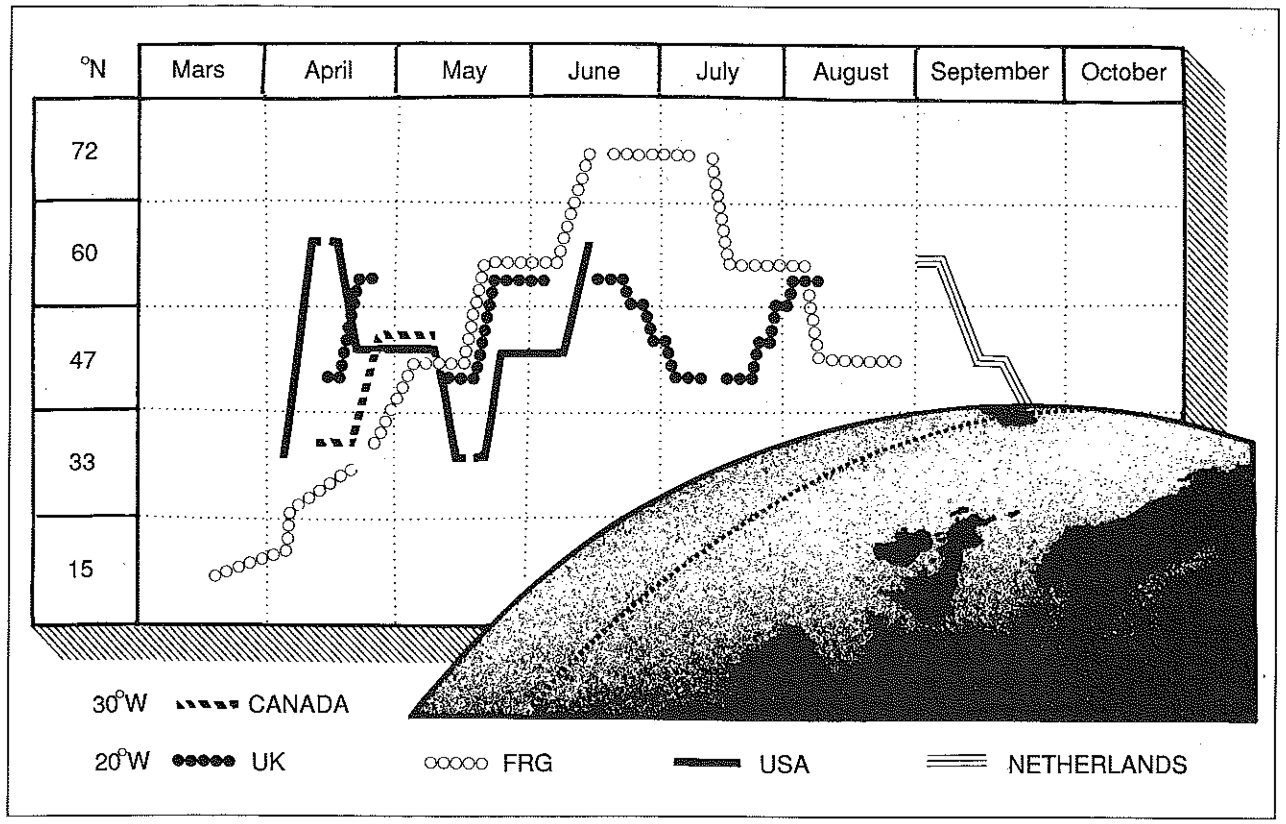


Figure 1. The JGOFS approach

A series of process studies will investigate the factors determining the important rates, and provide the basis for making predictions. They will be much more intensive than the other studies, typically involving hundreds of ship days, many countries, and measurements of more standing stocks and rates. Tracers preserved in the sedimentary record will extend our knowledge to the scale of hundreds to tens of thousands of years, a time over which there have been very large changes in atmospheric CO_2. Models that embody and reflect the knowledge gained in the above studies will be used to fill in the picture of the ocean as it is now, and to predict its response to change.

Regional and Basin-Scale Processes

Time-series stations have been established near Bermuda and Hawaii, and others will be set up in representative ocean regions. The first process study began in early 1989 to study the spring bloom and associated reduction of CO_2 and downward flux of particulate carbon in the North Atlantic Ocean. Data from a five-nation, 400 ship-day study are now being analyzed and combined. Follow-on research will take place in 1990-1991.



JGOFS Pilot Study in the North East Atlantic, 1989. Cruise transects and stations around 20°W (except Canada, 55-40°W) with NASA aircraft overflights at 34°, 47° and 59°N between late April and early June.

Planning for a process study in the Equatorial Pacific is now underway. This is an important upwelling, outgassing region, and also a region where the sedimentary record is particularly well studied. The study will last for at least five years, because interannual variability (e.g., related to the El Niño/Southern Oscillation phenomenon) is important in the region.

Future process studies will take place in the high latitude Southern Ocean, to address questions of downwelling and nutrient use; and the Indian Ocean, where the monsoon circulation of the atmosphere induces large seasonal variation in ocean circulation.

More details of the areas of process studies and the coverage of the global survey are given in the JGOFS Science Plan (SCOR 1990).

Participating Nations and Other Programmes

JGOFS includes scientists from many countries around the world; Canada, FRG, the Netherlands, UK, and USA took part in the first major coordinated JGOFS activity, the North Atlantic Bloom Study. Other countries with activities planned in the near future include Australia, China, France, Japan, the Nordic countries, South Africa, and USSR. Studies of the processes listed above necessitate cooperation between JGOFS and other international projects, specifically; with WOCE (WCRP) for (ii), and with TOGA (WCRP), IGAC (Chapter 2.1), LOICZ (Chapter 4.1) and PAGES (Chapter 7.1) for (iii). The global survey will be carried out partly in cooperation with the WOCE Hydrographic Programme.

Process Studies

Process studies are designed to provide an understanding of the biogeochemical processes that govern global patterns of element cycling between the atmosphere, ocean and sediments. They will use many observational techniques, some of which are too time consuming or technically demanding to be employed in other JGOFS operations. They will often be carried out from drifting platforms, to stay with the processes as they evolve. Experiences from the JGOFS North Atlantic Bloom Study, a year-long, international, multi-platform investigation of the spring phytoplankton bloom in the eastern North Atlantic Ocean, will help in the design, planning and execution of future process studies.

Aims

JGOFS proposes a series of measurements of the rates of key processes (e.g., new production, vertical transport, air-sea gas exchanges) in the major biogeochemical provinces of the global oceans, and how they vary in response to regional variations in physical driving forces (e.g., convective overturning, solar irradiance, upwelling, storm frequency), and differences in the ecological structure of foodwebs and the taxonomic composition of biological communities. The physical and biological mechanisms leading to spatial variations in geochemical fluxes will be explained by properly designed studies tailored to each particular situation.

Many important parameters are at present poorly defined or difficult to evaluate. Examples include physiological parameters characterizing the photosynthesis-irradiance and nutrient uptake-concentration relationships in phytoplankton, physical parameters such as particle adsorption-desorption and gas exchange coefficients, and geochemical rate constants governing diffusion of solutes out of sediments. Process studies will estimate these parameters and try to determine how and why they vary in space and time.

Process studies are limited by logistic considerations to variations that can be studied during research vessel cruises, although multiple cruises can be coordinated with each other and with moored instruments to extend the period of study. Ideally each observational programme will allow extended periods of observation at each site, enabling studies of processes to be carried out over at least 3-10 days.

Process-study observations require some combination of observations at fixed locations and observations that follow advecting water masses. Observations of upper-layer processes should be made while following drifters and using remotely sensed information on surface fields to supply the larger-scale context in which individual sampling operations are embedded.

A common set of core measurements will allow comparison of processes in different parts of the ocean, and of the results of different national programmes. The kinds of measurements currently believed to be of greatest importance to JGOFS process studies are described briefly below:

(i) Meteorological measurements relating to air-sea fluxes of heat, solar radiation, and dissolved gases.
(ii) Water column measurements

- Physical properties: Specifying the structure of the vertical and horizontal fields in which biogeochemical measurements are made.
- Optical properties: Photosynthetically active solar radiation, profiles of plant pigments and light absorption by particulate matter.
- Biological standing stocks: The organisms regulating the cycling of carbon, nitrogen and other elements. Resolution of taxonomic identity, size and chemical composition will depend on the needs of each study. Current modelling efforts suggest resolving phytoplankton into 2-3 size classes.
- Chemical stocks: The elements and compounds of greatest importance to the carbon cycle and the biogeochemical cycles that drive it, including CO_2 and total dissolved inorganic carbon, dissolved and particulate organic matter, the plant nutrients nitrate, ammonium, urea, reactive inorganic phosphorus, silicate, and trace metals (particularly iron, which may limit phytoplankton growth). Dissolved oxygen and certain other dissolved gases will be measured primarily to specify important fluxes (photosynthesis, respiration, denitrification). Additional chemical species will be important as tracers of fluxes and other biogeochemical processes; for example thorium, uranium, lead, polonium, palladium, and organic biomarkers such as individual pigments, lipids, and structural polymers.
- Biological and chemical fluxes: The following processes ideally require several independent measurements; primary production (total and new production), zooplankton grazing, bacterial production, nitrogen regeneration. Vertical transport will be measured by moored and floating sediment traps.
- Benthic fluxes: Processes at the seabed are important because the sediments are the largest and slowest changing store of carbon. Some of the organic matter that reaches the benthic boundary layer is converted to CO_2 and released into the water, the rest is permanently buried. One can measure benthic fluxes with benthic chambers, porewater gradients, *in situ* electrode measurements, sediment composition studies. Bioturbation can be studied with radiochemical measurements, field observations and modelling.

JGOFS will provide a firmer understanding of the biogeochemistry of the deep ocean so that better models of remineralization can be developed. Most recent models have parameterized this process by using a depth-related function empirically derived from sediment-trap data. Observations of deep-ocean trace-metal distributions will help to resolve this problem.

JGOFS will parameterize the response of chlorophyll to available light. In most empirical regression methods, this parameterization is buried in the regression coefficients connecting biomass and production. One advantage of using a more mechanistic formulation is that such coefficients can be interpreted directly in terms of known physiological variables, such as the quantum yield of photosynthesis. Moreover, these physiological properties can be measured at sea during process and time-series studies.

A key aim of process studies is to determine new production and what controls it. At present this requires detailed, careful measurement at sea. The ultimate hope is that new production, or the f-ratio, can be related to some variable that is accessible to remote sensing. Perhaps in future we will learn how to account for local and transient variations in the f-ratio within biogeographic provinces. Perhaps some oceanographic property field other than ocean colour (e.g., temperature) could serve as a proxy index of local perturbation in water-column structure leading to local change in nitrate supply and, therefore, in f-ratio. Regional and annual estimates of new production would then be calculated as weighted integrals of the local results. Another possibility is offered by some recent global or basin-scale biogeochemical cycling models. Such models could combine satellite data on the biomass field with model-derived data on nitrate supply and f-ratio to calculate new production.

Processes that lead to the permanent burial of sediments will be studied. These include the fate of calcite and aragonite and the coupling of organic-inorganic carbon; for example, sedimentary carbonate dissolution by metabolically-produced CO_2. Process studies concerned with formation of permanent sediments will help in the interpretation of the historical sedimentary record. In this regard close collaboration must be maintained with PAGES (Chapter 7).

Large Space/Time Scale Surveys

The Global Survey

JGOFS will need a global survey of the important biogeochemical variables. It should be possible, in cooperation with other international programmes, to achieve a reasonable global survey using the following strategy:
- A suite of biogeochemical core measurements will be made throughout the water column at a regular spacing on all JGOFS transects. Such a suite would include pigments, nutrients, biomass components, gases, dissolved organic species, particulate organic carbon and nitrogen, and radionuclides.
- The same suite will be measured during passage to JGOFS process studies.
- A global array of sediment traps will be deployed near the JGOFS transects, to estimate the vertical particle flux.
- A set of benthic measurements will be made to provide boundary constraints.
- Along-track observations of surface pigments, nutrients, CO_2, and O_2 will be made on all JGOFS cruises.

JGOFS will benefit from the extensive spatial and temporal coverage of the WOCE Hydrographic Programme (WHP), and will make the CO_2 measurements on WHP cruises. The specification for these measurements is to measure full-depth profiles of total CO_2, alkalinity, and pCO_2 2 to within 1 µmol/kg, 1 µeq/kg, and 1 µatm, respectively. A fully documented and internally consistent description of the oceanic carbon dioxide system will be produced for the first time. If such a survey is repeated in the late 1990s the anthropogenic increase in oceanic CO_2 could in principle be detected. The existence of the WOCE nutrient data set will also be of great significance for JGOFS. Such data provide a powerful check on modelling the oceans' biogeochemical cycles. When space is available, JGOFS will also undertake a survey of pigments like chlorophyll on WOCE cruises.

Seasonal Survey of pCO_2

There is an urgent requirement to document more accurately the seasonal cycle of pCO_2 in the North Atlantic, North Pacific, and Southern Ocean, in order to constrain more closely the estimate of net annual flux of CO_2. Logistically, seasonal surveys of the North Atlantic would be the easiest to achieve. The minimum requirements would be underway measurements of pCO_2 and total CO_2 along the cruise track, backed up by measurements of chlorophyll. Use of satellite ocean-colour data would then allow the effective integration of pCO_2 in areas and seasons where pCO_2 and chlorophyll are correlated (and most likely show patchy distributions).

In spring and summer it is known that pCO_2 in surface waters is reduced sharply, leading to a flux from the atmosphere to the ocean. Recent results from the JGOFS North Atlantic Bloom Study have shown this very clearly. Ongoing CO_2 analysis methods have revealed a very patchy distribution, and cast doubt on the accuracy of basin-wide integration of pCO_2 based largely on data from bottle samples, particularly when comparable data from other seasons are not available.

Long Time-Series Observations

Much of the data obtained during the JGOFS programme will be collected during cruises lasting a few weeks. Examination of the few long term data sets we already have shows the importance of understanding the variability of marine ecosystems at time scales ranging from seasonal to interannual periods. Therefore, JGOFS requires a network of Time Series Stations at which regular measurements of key properties and processes are made once or twice a month, or continuously for those properties measurable by untended, automated sensors.

Perhaps the best known time series is the three years of regular primary production measurements made at Station S near Bermuda (Menzel and Ryther 1960). Station S is also the site a the longer series of observations of hydrography and of a continuous deployment of deep ocean sediment traps. These data demonstrate strong seasonal variations in primary production and vertical transit fluxes forced by annual episodes of convective mixing and vernal restratification. The US JGOFS Programme has recently established new time-series stations at Bermuda and in the central North Pacific off Hawaii. These initiatives will identify the biogeochemical consequences of periodic ecological events and, if continued over the longer-term, may detect changes in the ecological and chemical state of the ocean brought about by global climate change.

There are several other series of observations made at fixed locations, notably at the ocean weather stations in the Subarctic Pacific and Atlantic Oceans, and two examples of long-term measurement programmes made over regional areas. The CalCOFI data series contains data on plankton properties in the California Current since 1950. Analyses of these data show that much of the variability in macrozooplankton abundance, and perhaps other plankton properties, is concentrated at interannual periods with little, if any, contributed by seasonality. The Continuous Plankton Recorder Survey in the North Atlantic Basin has demonstrated a long-term decline in plankton abundance, which may have reversed in the mid-1980s. The causes of these trends and cycles are not well understood, and the consequences for the global cycles of carbon and other elements are completely unknown.

For logistic reasons, most ocean observatories need to be located near islands or coastal nations with well-equipped marine laboratories and research vessels capable of performing, high precision measurements of chemical, biological and physical variables. At present, both JGOFS time-series sites are located in tropical, oligotrophic waters. Additional stations are needed in higher latitude, coastal, upwelling and boundary current regimes. Once established, these sites will provide the means to define the time varying behaviour and spectral properties of the physical, ecological and biogeochemical system in each area. These data sets will also provide invaluable material for calibration and validation of biogeochemical models. Furthermore, these sites will attract many other short- and longer-term investigations, which can draw on the resources and historical data base collected at each place. Time-series observatories also provide useful centres for the development and testing of new instruments. Each site requires a dedicated team of 5-10 individuals to make measurements, collect and analyze samples and process, tend instruments and interpret and report data.

Remote Sensing

Synoptic observations on global scales over at least several decades, frequent enough to resolve the dominant scales of variation in space and time, can now be made using untended observational platforms in space. Only through the use of such remote observations can the objectives of JGOFS on the global scale be achieved. For the first time, it will be possible to estimate wind speed and direction, the fluxes of heat, momentum and material, including carbon dioxide, at the sea surface, the biological production of organic matter and the variability of the surface currents at the requisite scales. The ready availability of these data on an international basis will permit answers to questions that have heretofore been impossible to address.

Air-Sea Fluxes of Heat, Momentum and Mass

Estimation of these fluxes from remote observation is now within reach in a form and on scales appropriate for JGOFS. Statistics of cloud distributions, from remote observations of visible radiances, can be used to estimate the solar radiation flux at the sea surface with considerable skill. Microwave radiometers can be used to estimate wind stress. Accurate measurement of sea-surface temperature from passive radiometers permits acceptable estimation of latent heat fluxes. The importance of global wind speeds for air-sea gas exchange has already been mentioned.

An area of concern involves the flux of materials from land to ocean via aeolian transport (see LOICZ, Chapter 4.1). Dust from the Asian desert can be detected in the marine atmosphere; trace metals in this dust may stimulate primary production. Observation of the marine atmosphere in the visible bands may permit quantification of this flux.

Biological Production of the Ocean

The remote measurement which has caused the greatest interest within JGOFS is the estimation of basin and global-scale variability in the concentration of chlorophyll in the upper ocean. The images of the global distribution of these pigments, derived from the Coastal Zone Color Scanner (CZCS), have revolutionized the way biological oceanographers view the oceans. For the first time, the blooming of the ocean basins in the spring has been observed, as has the extent of the enriched areas associated with the coastal ocean.

A number of methods, using either empirical transfer functions or more mechanistic physiological models, have been proposed for estimation of total primary production from remotely-sensed data. The signal received by the colour scanner contains information from only the upper one fifth or so of the photic zone. Any bias due to high concentrations of chlorophyll below the depth of penetration of the colour-scanner signal can be removed if independent information is available on the shape of the vertical pigment profile (Platt and Sathyendranath 1988).

Well-established algorithms exist for estimating the biomass field from the CZCS data, and processed data are now available on a routine basis from NASA. New algorithms are now emerging for estimation of primary production using remotely-sensed data, and there is a need for further testing and improvements to these algorithms. However, the next generation of sensors will have improved capabilities, and there will be a need for development of new biomass algorithms to capitalise on the better-quality data. An important element of the JGOFS field programme will be to provide sea-truth data for verification of algorithms relating to pigment concentration, total primary production and new production.

Aircraft Surveys

Airborne lidars now available offer some advantages over satellite sensors, especially; (i) higher spectral resolution and therefore scope for more rigorous algorithms and for retrieval of more variables; (ii) capability of obtaining depth-resolved data; and (iii) operation under dense cloud conditions. In addition, when available concurrently, the fluorescence technique of the lidars can be used to check or validate the ocean-colour algorithms applied to satellite data. The depth-resolved signals from aircraft lidars will be a valuable tool for extending local ship observations, and for parameterizing the biomass profiles of a given biogeographic zone. Major JGOFS field studies would therefore benefit from concurrent lidar overflights. In the JGOFS North Atlantic Bloom Study, for example, aircraft data proved extremely useful in identifying bloom areas and, therefore, in effecting mid-course cruise corrections for the research vessels in the field.

The Future

There is now no satellite ocean colour sensor in orbit. JGOFS crucially needs the new ocean colour sensor planned for 1992/1993, the Sea-viewing Wide Field of View Sensor (SeaWiFS). It will produce images of global distributions of plant pigment and productivity with a resolution of two days and 4 km. In addition, higher spatial resolution will be available for selected regions, for example, the sites of process studies. These data will be a cornerstone of the JGOFS effort and will drive new modelling efforts as well as serve as a base upon which the success of models can be evaluated.

The Sedimentary Record

JGOFS proposes to use the Quaternary palaeoceanographic record to determine the relation of ocean circulation, productivity and CO_2 content of the atmosphere, to aid in the prediction of CO_2-related climatic change. Variations on time scales within the Quaternary represent a period when large shifts in atmospheric carbon-dioxide concentrations have occurred and are associated with periods of major climatic change. Ice-core studies have established that atmospheric carbon dioxide is about 80 parts per million by volume lower during cold glacial climates than it is during warm interglacial times. The past variations in atmospheric CO_2 are recorded in sediment cores and examination of the sedimentary record provides a major (perhaps the only) means by which models of carbon fluxes, nutrient balances, ocean circulation and climate can be integrated.

There are two complementary approaches to be used. One is to estimate fluxes of substances (organic and carbonate carbon, opal, aeolian dust, etc.) from their rates of accumulation in the sedimentary record. The other is to use proxy indicators (O and C isotopes, Cd/Ca and other palaeochemical tracers, organic biomarkers, etc.) to reconstruct the temperature, chemical composition and circulation of past oceans and atmospheric composition. Central to both approaches is the requirement for precise chronology and for this there is a need to supplement classical oxygen isotope stratigraphy and conventional radiocarbon dating with radiocarbon dating of foraminiferal species by accelerator mass spectrometry.

Benthic studies address the processes by which the sedimentary record is formed. As new palaeochemical tracers are explored and old ones are used more extensively their calibration will be firmly established, comparing water column properties with their record in foraminiferal calcite, opal, and sediment geochemistry.

It will be important to document changes in the fluxes of the relevant JGOFS variables for comparison of contemporary benthic fluxes with the historical record. It will be necessary to evaluate glacial-interglacial differences in carbon fluxes and their regional variability and to decide whether they reflect productivity changes or changes in carbon preservation, possibility through the development of low-oxygen bottom waters. Property distributions for critical variables (CO_2, nutrients, hydrography) must be obtained for crucial oceanic sections. The time variability of carbon fluxes should be determined at sites within different oceanographic provinces. Other approaches include high-resolution studies of the transition from the last glacial maximum to the present; a history of low- and mid-latitude upwelling as related to the accumulation of organic matter in sediments in order to deduce relationships between atmospheric CO_2 variations and productivity changes. The North Atlantic Ocean has experienced the largest climatic change of any ocean during the last 25 000 years. It is therefore an excellent place to study the effects of migration of the polar front on productivity, particulate-matter fluxes and atmospheric carbon-dioxide concentrations. The activities of JGOFS on this topic will be coordinated with PAGES (Chapter 7.1).

Modelling

The ultimate aim of modelling in JGOFS is to embody, reflect, test and advance our understanding of, and ability to predict, the evolution of carbon and other biologically important elements throughout the world oceans decades to centuries ahead. JGOFS observations will help to provide a firm conceptual understanding of many key processes in the ocean biogeochemical system, and also data with which to test the models. Sufficient computing power will become available during the decade. The time is therefore ripe to embark on an ambitious modelling programme, both for interpreting the process studies and for making global extrapolations and predictions.

JGOFS process studies must be designed specifically to obtain the information required by the global models discussed below. Furthermore, the local hydrography of each area will present specific sampling problems. Each process study should be preceded by a modelling exercise in which the present level of understanding of the biogeochemical and physical processes are incorporated in models which can provide a theoretical underpinning for designing and interpreting the observational programme. Sensitivity analysis techniques should be used to identify the critical variables and parameters. For example, in temperate latitudes, the winter values of primary production and zooplankton biomass have a critical effect on the development of the spring phytoplankton bloom, and winter sampling is needed. Also modelling has highlighted the potentially important role played by dissolved organic matter in the ocean and, therefore, the importance of obtaining accurate estimates of this quantity.

The process studies will also feed back into the JGOFS modelling programme. They can provide estimates of parameters required for process sub-models, such as photosynthesis, zooplankton grazing, or particle sinking; they will provide data with which to test the validity of these sub-model parameterizations; and will provide time series of biological stocks, chemical concentrations, and biogeochemical fluxes with which to test both local and global models.

A longer-term aim is to develop process-oriented equation models that can predict the time evolution of biogeochemical fluxes from given starting conditions. Such models will use state-of-the-art General Circulation Models (GCMs) driven by observed surface boundary conditions to predict the fields of advection, convection, and mixing in the ocean. When supplemented with equations representing nutrients, dissolved inorganic carbon, and some depiction of the biogeochemical transformations near the ocean's surface and in the interior, these models will predict full three-dimensional concentrations fields for comparison with JGOFS observations. As such, these models focus on oceanic processes with longer time scales. Preliminary models of this type are currently operational at Princeton University and at the Max-Planck-Institute in Hamburg, where they have been used with some success to predict the observed distribution of bomb-produced tritium and ^{14}C distributions. Initially, such models will be used in a hindcasting role to predict the evolution of, say, the satellite-derived surface chlorophyll distribution over a given time period. Success with this sort of prediction is an essential precursor to the next stage of the modelling enterprise, which is the prediction of the future evolution of ocean variables, such as the CO_2 concentration, that are implicated in scenarios of climate change.

Until recently, global biogeochemical models have not explicitly modelled the surface-water biological production, or this production has been rather simply parameterized by restoring the surface nutrient concentrations to the observed values. Sarmiento et al. (1989) have made a first attempt at explicitly modelling the biological nitrogen cycle in the euphotic zone of the North Atlantic. Preliminary results show rough agreement with satellite-derived patterns of the spatial and seasonal pattern of surface phytoplankton; areas of disagreement indicate where more theoretical or observational work is needed. For example, the present generation of GCMs do not adequately model some of the key physical processes such as equatorial upwelling. We are therefore dependent on progress being made on the next generation of GCMs. Furthermore, if upwelling associated with mesoscale eddies is a key process in providing nutrients to the euphotic zone, then it will be necessary to use eddy-resolving models with their attendant computational demands.

Recent research has demonstrated the potential importance of small organisms, such as bacteria and protozoa, in the recycling of dissolved and particulate organic material, and a number of recent models have incorporated these ideas. We must compromise between the need for a parsimonious model for incorporation in a GCM, and the requirement to capture the complexity of the actual biological interactions that is valid in all geographical regions. We do not yet know how well the biological size distribution needs to be resolved in order to attain the predictive goals of JGOFS. Research into the effect of different levels of physical and taxonomic detail will be an important component of JGOFS modelling efforts.

In the past most oceanographic biological models have been constructed using equations describing the flow of one particular element between the various compartments, and carbon and nitrogen have been the most commonly used "currencies". However, elements other than nitrogen may limit primary production. Moreover, the formation of calcium carbonate hard parts by, for example, coccolitheophorids, has a direct effect on alkalinity and thereby the partial pressure of carbon dioxide. Such considerations lead to a requirement for multi-element models that can predict the concentrations of these specific components of the phytoplankton.

The interaction of the biological and chemical processes at the ocean margins with processes in the open ocean looms as one of the most difficult issues in JGOFS. Direct measurements of offshore and onshore fluxes are extremely difficult, if not impossible, to make. GCMs run with current levels of resolution do not resolve the shallow water regimes near the margins. The best hope for progress in this field lies with nested high-resolution models of particular ocean margins within basin-scale GCMs. The two models would use the same physics and algorithms for transformation at much different levels of resolution. Key predictions of coupled margin-basin models involve the onshore and offshore transport of nutrients, dissolved organic matter, and particulate organic matter. The ground truth provided by JGOFS data includes the margin-basin contrast and seasonal changes in phytoplankton biomass and nutrient fields.

Because these models are likely to be used to make predictions for the coming decades and centuries, it is important that they be constructed using rules that we believe will continue to be true in a different climate. Modelling tricks, such as restoring the surface temperature, salinity, or nutrient fields to observed values, or introducing empirically determined geographical variations in biological rate parameters, may be valuable during the learning process, but are not suitable for long-term prediction.

Data Management

To date, biogeochemical observations have not been readily catalogued or exchanged, because of the labour-intensive nature of the analysis process, differences in analysis protocols, lack of confidence in the data product, etc. The JGOFS observational and analysis framework is based on a distributed international approach to the observing system, and requires rapid, easy sharing of data, models, analyses, and observation systems.

We foresee international data exchange occurring through interactions between national oceanographic data centres. In each national centre, a JGOFS data coordinator will be responsible for acquiring national data sets, analyses, etc., for extra-national use; acquiring extra-national data sets, etc., for national use; ensuring conformity with agreed international data exchange modes and formats; maintaining inventories of national holdings; and interacting with the JGOFS Data Management Working Group as needed. Individual scientists will interact with their national JGOFS data coordinator.

The JGOFS Data Management Working Group has proposed a common self-describing data format for data archiving and exchange and use of modern object-oriented data-management approaches for retrieval, merging and analysis. Development of portable accession software and network-based distributed data-accession models should provide scientists with direct paths to observations, model results, and related products as they become available. Until this software is ready, provision of data in any commonly used format, with complete documentation, is acceptable.

As a trial of the proposed data-exchange formats, the Data Management Working Group focused on the needs of the 1989 JGOFS North Atlantic Bloom Study. A set of twenty core measurements, to be conducted on all cruises in the Bloom Study, was defined early in the planning stages for the study. For each of these, agreement was reached on a standard measurement protocol and level of accuracy to be attained. The success of the proposed formats was tested at the JGOFS Bloom Study Data Analysis Workshop in Kiel in March 1990. Cruise participants from all nations involved brought their data to Kiel for a week-long "hands on" session at which the various data sets were merged and preliminary scientific findings discussed. Some problems were identified in the way the data were collected — it was difficult for all parties to adhere to agreed protocols — but there were no serious incompatibilities in the way data were handled subsequent to collection.

The JGOFS Committee considers that free exchange of information is essential for the success of JGOFS and at its 1989 meeting in Hawaii the following policy regarding data access and submission was adopted.

- Recognizing that science is best served by free and open communication of findings, including data in raw form; and,

- in view of the enormous value of uncorrupted data sets as input to models useful in the design of field projects and in hypothesis testing; and,
- noting that JGOFS will produce, at public expense, high quality data sets of extreme value to ocean biogeochemistry;

The JGOFS Committee believes that reading access to this JGOFS Data Base(s) should be without restriction for any interested user. The information in the Data Base(s) will be labelled as to its originator and it is expected that readers would obey the normal scientific obligation to contact the originator for permission to make further use of those elements of interest to them.

The JGOFS Committee hopes that every national committee for JGOFS will endorse this policy on data access.

Implementation

The JGOFS Science Plan, from which this chapter is freely adapted, was discussed, and approved in principle, at the 4th meeting of the SCOR Committee for JGOFS in Kiel, FRG, March 1990. The implementation plan is to be prepared by Planning Groups and Task Teams. Thus, there will be planning groups, like the Cruise Coordinating Committee for the North Atlantic Bloom Study, to plan the details of ship scheduling and coordination for future process studies in different regions. Studies are now planned for the Equatorial Pacific 1991, the first planning meeting took place in Tokyo in April 1990; the Southern Ocean 1991-92, planning will start at a meeting in Brest in July 1990; and the Indian Ocean, a planning group is being formed. Less definite plans are sketched in for western boundary currents, the large warmwater pools, a comparison of the North Pacific and North Atlantic, and eastern upwelling regions. There will also be groups for the different approaches; global surveys, process studies, time series, the historical sedimentary record, modelling, and data management. A JGOFS International Planning Office has been set up at the Institut für Meereskunde at Kiel University, and a Scientific Secretary has been appointed to run it. This office will provide the focus for developing the Implementation Plan, aiming for completion early in 1991.

Projects of this scope require some years before their results are assimilated, and national legislators and planners will increasingly be asking for guidance for policies for climate change. JGOFS is envisaged as a ten-year programme starting in 1989, and should aim to finish the main cruise programmes by 1996-1997, to allow for the data assimilation and modelling activities to be completed by the end of the decade. The availability of suitable satellite sensors will also be a factor to be taken into account.

The SCOR Committee for JGOFS has met four times so far, most recently in March 1990. Its next meeting is planned for November 1990. A workshop involving all interested participants in the North Atlantic Bloom Experiment was held in March 1990, and an open meeting on the experiment is planned for November 1990. In addition, many international meetings have had parts devoted to JGOFS, for example, the American Geophysical Union meeting in February 1990 and the planned meeting on the Southern Ocean in Brest, July 1990.

References

Broecker, W. S. and Peng, T.-H. 1982. Tracers in the Ocean. Lamont-Doherty Geological Observatory, Columbia University, Palisades, NY. 690 pp.
Eppley, R. W. 1989. New production: history, methods, problems. In: Berger, W. H., Smetacek, V. S. and Wefer, G. (eds) Productivity of the Ocean: Present and Past, pp 85-97. Dahlem Conferences. John Wiley & Sons, Chichester.
Menzel, D. W. and Ryther, J. H. 1960. The annual cycle of primary production in the Sargasso Sea off Bermuda. Deep-Sea Res. 35:177-196.
Moore, B. and Bolin, B. 1986. The oceans, carbon dioxide, and global change. Oceanus 29:9-15.
Platt, T. and Sathyendranath, S. 1988. Oceanic primary production: Estimation by remote sensing at local and regional scales. Science 241:1613-1620.
Sarmiento, J. L., Fasham, M. J. R., Siegenthaler, U., Najjar, R. and Toggweiler, J. R. 1989. Models of Chemical Cycling in the Ocean: Progress Report II. Ocean Tracers Laboratory Technical Report 6, Princeton, N. J. 46 pp.
SCOR. 1987. The Joint Global Ocean Flux Study - background, goals, organization, and next steps. Report of the International Scientific Planning and Coordination Meeting for Global Ocean Flux Studies sponsored by the Scientific Committee on Oceanic Research held at ICSU headquarters, Paris, 17-19 February 1987.
SCOR. 1990. The JGOFS Science Plan. JGOFS/SCOR, Halifax, Canada (in press).
Sugimura, Y. and Suzuki, Y. 1988. A high-temperature catalytic oxidation method for the determination of non-volatile dissolved organic carbon in seawater by direct injection of liquid samples. Mar. Chem. 24:105-131.
Volk, T. and Liu, Z. 1988. Controls of CO_2 sources and sinks in the earth scale ocean: temperature and nutrients. Global Biogeochem. Cycles. 3:179-189.

Suggested Reading

Longhurst, A. R. and Harrison, W. G. 1989. The biological pump: profiles of plankton production and consumption in the upper ocean. Prog. Oceanogr. 22:47-123.
Sarmiento, J. L., Toggweiler, J. R. and Najjar, R. 1988. Ocean carbon cycle dynamics and atmospheric pCO_2. Phil. Trans. R. Soc. A325:3-21.

3.2 *Global Ocean Euphotic Zone Study (GOEZS)*

A Potential Core Project

The role of the oceans in climate change is understood only very generally, and it is anticipated that contemporary global-scale research projects, such as the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS) will significantly improve this understanding. WOCE, under the auspices of the WCRP, focuses on the physical processes responsible for the transport of energy and momentum within the oceans and between the oceans and atmosphere. JGOFS, a Core Project of the IGBP initiated and organized by SCOR, focuses on the biogeochemical processes responsible for the fluxes of carbon and associated biogenic elements within the oceans and between the oceans and their boundaries.

The interaction of the physical and biogeochemical processes associated with atmosphere-ocean exchanges of heat and radiatively active gases, such as carbon-dioxide, is central to the linkages between the atmospheric and oceanic processes that determine the Earth's climate. The records of glacial-interglacial cycles of the past contain clues about the linkages of the physical and biogeochemical processes that are responsible for global climate. The patterns of change in global temperature and atmospheric carbon-dioxide content, for example, point to feedback relationships among atmospheric processes and the global carbon cycle, with significant involvement of the ocean. To determine how these natural linkages can be perturbed by an increasing carbon-dioxide content in the atmosphere, and the accompanying atmospheric warming, remains an urgent task. Important aspects of this problem including the oceans' capacity to absorb carbon-dioxide, will be addressed by JGOFS. However, without a knowledge of the manner and degree to which physical and biogeochemical processes in the ocean will respond to an anthropogenically induced climate change, it is impossible to assess the consequent feedbacks between the oceans to the atmosphere via the carbon-dioxide cycle.

Thus, it is timely to anticipate the new level of understanding that will evolve as WOCE and JGOFS are completed, and to formulate the next generation project that will build upon the data and understanding obtained and that will also address fundamental questions regarding global change in atmosphere-ocean interactions.

Whereas the fundamental scope of both WOCE and JGOFS includes (with WOCE in particular paying little attention to the time varying properties of the mixed layer), investigations that consider the full depth range of the oceans, this new project will focus primarily on approximately the upper hundred meters of the ocean (the euphotic zone), in the context of the decade-to-century tme-scale priority of the IGBP. This is the region where physical mixing processes are most intense and where the penetration of sunlight is sufficient to support primary production. It is here that the small time constants for atmosphere-ocean exchange allow for highly significant effects of atmospheric change on ocean biological processes with a correspondingly large potential for biogeochemical feedback to the climate.

Because of its focus on the upper ocean zones, where biological processes are most intense, this new project is termed the Global Ocean Euphotic Zone Study (GOEZS). It will require balanced and highly interactive efforts in observation (both in situ and from space), in process studies, and in modelling. It will also require new efforts to synthesize the physical, conceptual, and disciplinary interfaces. Its time frame for implementation will be the late 1990s, i.e., when the field phases of WOCE and JGOFS are completed. This project will require the deployment of next-generation technology for remote and automated sensing of ocean properties.

One rationale underlying the conceptual development of GOEZS is the

3.2-2

growing evidence that biological equations that describe the dynamics of phytoplankton and zooplankton processes can be used to characterize the regional biological response to physically driven ocean processes. It can be anticipated that further refinements of this approach, using the existing and the evolving (WOCE and JGOFS) data sets, will permit extrapolation to different climate conditions, thereby allowing the addition of these equations to coupled ocean-atmosphere circulation models that are designed to predict climate change.

Specific goals of GOEZS include:

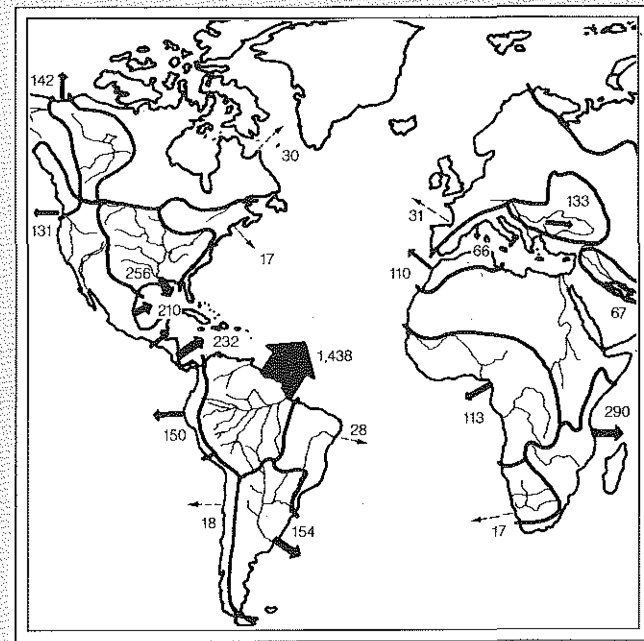
- developing models that accurately simulate biological conditions in the euphotic zone as a prerequisite for predicting how these conditions will adjust with changing climate, and how in changing they will modify climate through their action on production or consumption of radiatively active gases and atmospheric aerosols;
- assembling a global data set suitable for use in establishing the necessary biological equations and their associated parameter sets for use in computer models of climate change; and
- developing large-scale experiments to improve basic understanding of the interactions between the physical, chemical, and biological properties of the euphotic zone.

The GOEZS data set, which will build upon the WOCE, JGOFS, and other existing and evolving data sets, has yet to be specified in detail. In order to be used in predicting biogeochemical responses to climate change the implementation of GOEZS will, however, require new physical, chemical, and biological data for the euphotic zone of all oceans and for all seasons. The requisite synopticity for certain physical, chemical, and biological observations will be made available by new analytical methods capable of higher sampling and data processing speeds than those currently available. Some of these methods are now being developed, and will probably be deployed in WOCE and JGOFS for the first time. Although a detailed science plan for GOEZS has yet to be developed, the need for additional developments in upper ocean sampling can be envisioned in the following areas:

(i) remote sensing from aircraft and polar-orbiting satellites;
(ii) optical and acoustic remote sensing within the ocean;
(iii) autonomous unmanned vehicles for more efficient ocean sampling; and
(iv) novel methods of sampling and analyzing chemicals and plankton, including molecular genetic probes.

The development of GOEZS will be guided by an IGBP Scientific Steering Committee appointed in consultation with SCOR. A science plan should be developed in the 1990-1992 time frame, with the modelling component to be initiated soon after. Field campaigns will be timed post WOCE and JGOFS, when the Earth Observing System Polar Platforms are operational, and will continue for 5-10 years. The development of the GOEZS project will be facilitated by an International Planning Office to be located at the U.K. Institute of Oceanographic Sciences, Deacon Laboratory, Wormley and supported by NERC.

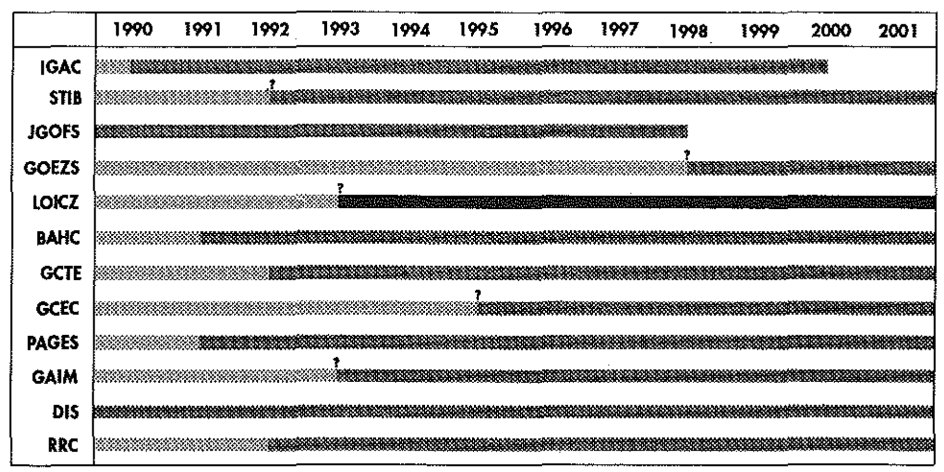
GLOBAL IGBP CHANGE



How Changes in Land Use Affect the Resources of the Coastal Zone, and How Changes in Sea Level and Climate Alter Coastal Ecosystems?

In many parts of the world human activities, including fishing, mariculture, agriculture, forest clearance, urban development and freshwater management, are altering the properties of coastal seas. Any rise in sea level and modification of climate will further influence directly the sustainability of marine living resources, the stability of coastal habitats, and the biogeochemical cycling of carbon, sulphur and other important elements. The overall, longterm impacts of these changes in the coastal zone are largely unknown on both regional and global scales. Severe environmental problems are already being experienced in major delta systems, and along the coasts of certain tropical countries.

Contents



1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
IGAC
STIB
JGOFS
GOEZS
LOICZ
BAHC
GCTE
GCEC
PAGES
GAIM
DIS
RRC

4.1 Land-Ocean Interactions in the Coastal Zone (LOICZ)

A Proposed Core Project

Introduction

Properties of Coastal Zones and Interactions Between Land and Sea

The coastal zone, where land, air and sea meet, is a region of high physical energy and biological diversity that is heavily exploited by man. It is also a zone particularly vulnerable to global change. For these reasons, the IGBP proposes a core project on the coastal zone with special emphasis on the interactions between land and sea under changing global conditions.

Definition of Coastal Zone

The coastal zone includes the area extending from the landward margin affected by salt water to the outer edge of the continental shelf (Fig. 1). It is "that space in which terrestrial environments influence marine (or lacustrine) environments and vice versa" (Carter 1989).

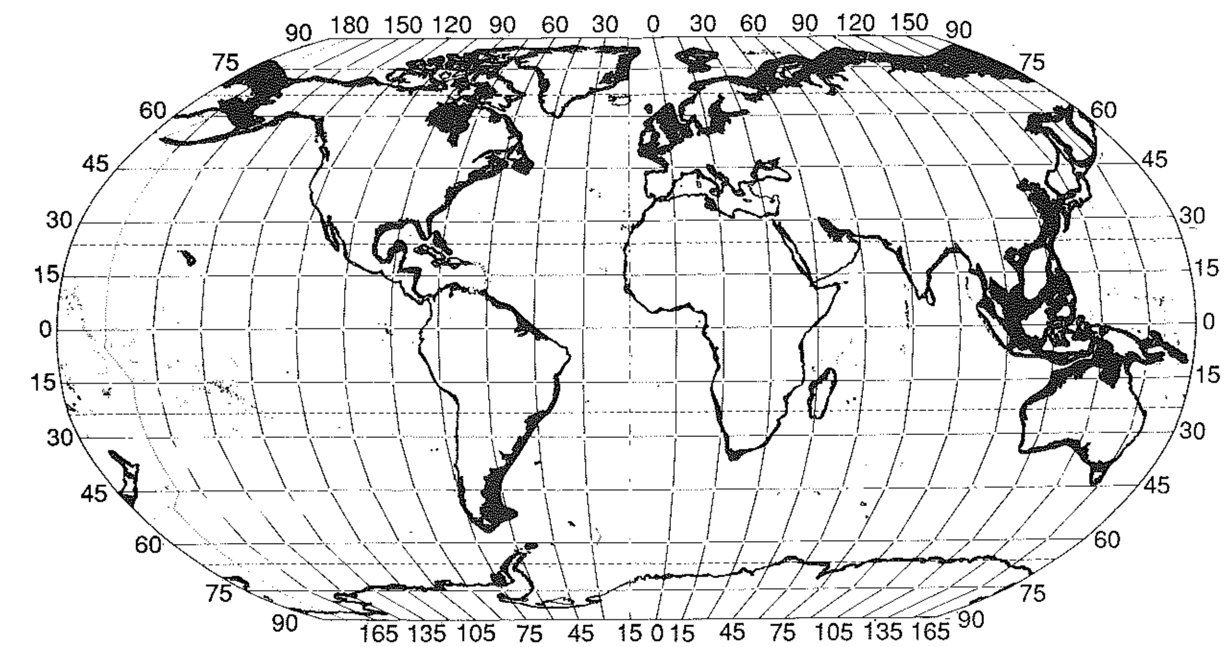


Figure 1. Distribution of continental shelves (<150 m; from Postma and Zijlstra 1988).

This definition covers a wide range of terrestrial, intertidal and subtidal ecosystems. It includes at least parts of coastal plains where they exist; sea cliffs, beaches, lagoons, estuaries, salt marshes, and mangrove swamps, that are under the influence of tides and storm surges. It also includes aquifers overlying salt wedges. The definition of the landward boundary varies for different phenomena. For example, the extent of coastal terrain affected by salt-spray aerosols will be much greater than that influenced by storm-driven erosional processes. The seaward boundary is set by the shelf break and continental slope, thereby including submarine features varying in depth, currents, turbulence, and sediment type.

An important political/legal definition of the coastal zone has been set by international agreement as the Exclusive Economic Zone (EEZ), the 200 nautical mile limit from land (or agreed coastal reference line in the case of archipelagic states) over which coastal nations exert certain rights with respect to resources. As a legal boundary it is important in terms of rights of access for scientific research as well as economic exploitation.

General Properties of Coastal Zones

Important factors determining the nature of the coastal zone in a particular region are geomorphology and climate. Shoreward margins, associated with river mouths or subsiding coastlines of divergent land margins, may have little elevation gradient thus featuring extensive intertidal areas. On tectonically convergent land margins where crustal uplift dominates, there may be high relief above and below the shoreline so that intertidal areas and the continental shelf are more limited in extent and different in kind. Classifications of coastlines and their geological and geomorphological causes are discussed in Inman and Nordstrom (1971) and Kennett (1987).

At smaller scales, well-defined boundaries are usually observed within the coastal ocean related to horizontal gradients in density (temperature, salinity). Water tends to move along rather than across these frontal boundaries, inhibiting exchanges of energy and matter between inner and outer coastal regions. Fronts often mark transitions between distinct hydrological and sedimentological regimes, characterized by different communities of pelagic and benthic organisms. Intertidal and terrestrial environments are also clearly demarcated by the effects of tidal amplitude, wave action, sea-spray deposition or soil conditions.

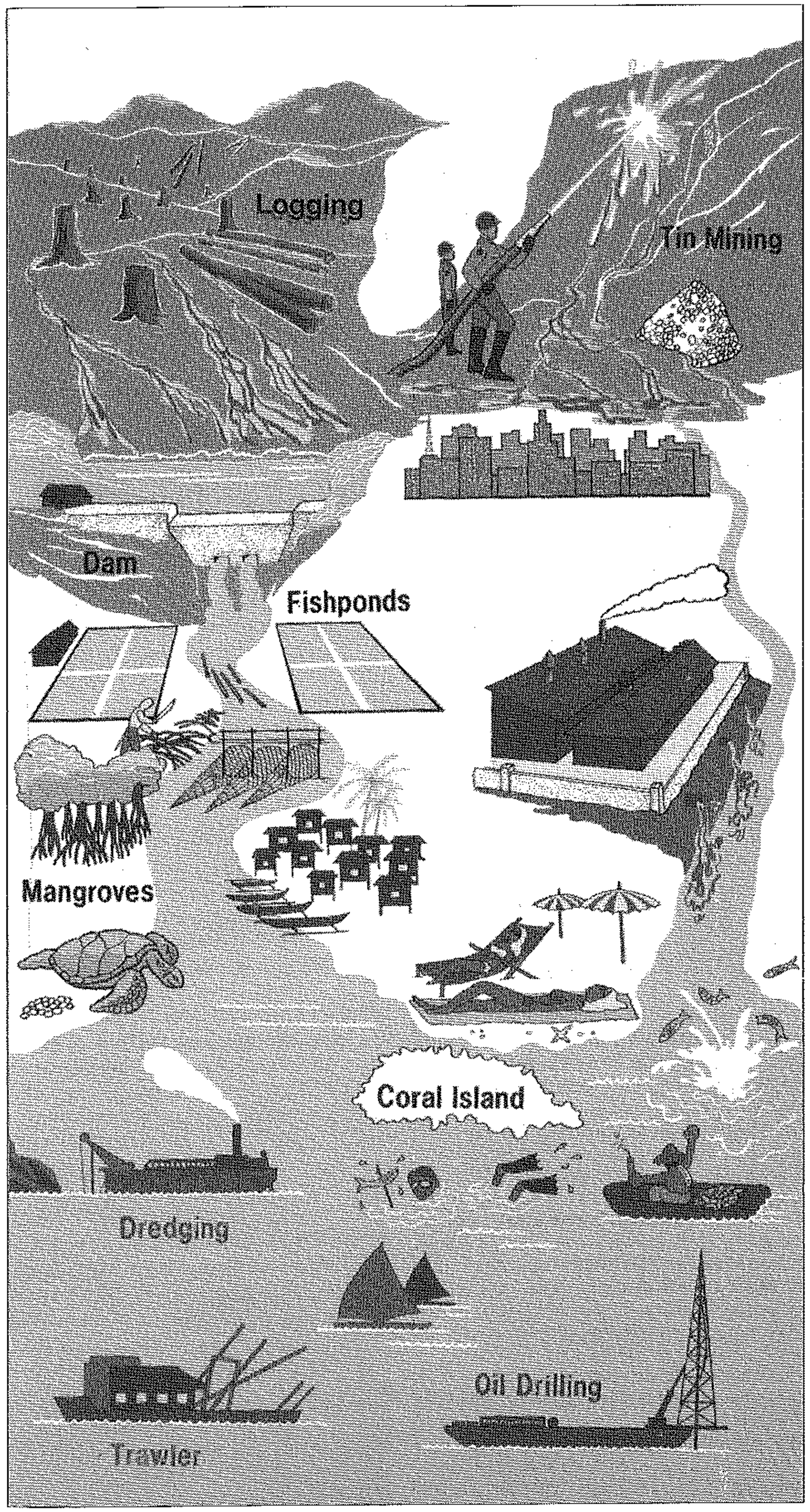
The high physical energetic states of coastal zones are caused by the combined effects of ocean currents, tides, wind and freshwater buoyancy. Ocean tides and shelf flushing frequencies, related to river inputs and shelf edge exchange, determine relatively high and low energy shelf systems which, in turn, define the spatial extent and boundary dynamics of associated ecosystems. These physical characteristics underlie many of the biological properties of these zones.

Favourable conditions of light and nutrient availability, controlled by the turbidity and surface mixing depth and by inputs of nutrients from ocean and land, maintain relatively high rates of primary production in coastal seas. Inputs of dissolved and particulate organic material from land provide additional organic energy for consumer organisms (Berger et al. 1989). Consequently, coastal zones are typically areas with living resources (fish, crustaceans, molluscs) of great commercial value.

Cycles of biogenic materials in the coastal zone oscillate rapidly between organic immobilization and heterotrophic mobilization (or mineralization). In addition, the accumulation of organic carbon in muds of marshes, lagoons or bays creates low redox conditions promoting the biological formation of nitrogen oxides; sulphides; and molecular nitrogen (Koike and Sørensen 1988), as well as soluble reduced forms of transition metals, such as iron and manganese. These reactions can also alter the availability of other biologically important substances such as phosphorus and accumulated pollutants. Interfaces of high and low redox sites are often loci of intense nitrogen fixation as well (Capone 1988).

In other parts of the coastal zone, high redox conditions dominate so that reduced substances are reoxidized (Henriksen and Kemp 1988), providing a chemoautotrophic energy base for other organisms. Such reactions are not unique to coastal zones, but the variety of physical environments and abundant supply of organic energy maintain high rates of many types of biogeochemical transformations. Collectively, these reactions lead to the rapid cycling of the elements involved so that coastal zones are important zones of biogeochemical activity, especially for the carbon cycle and production of some trace gases.

The land boundary largely determines the particular physical properties of a given stretch of coast and, for inshore waters, provides many of the chemical resources through groun- water and river water that drive the biological and biogeochemical processes described above. Furthermore, all land surfaces are



Range of coastal activities occurring along South-East Asian seas and impacting the fishery sector in various ways (from a brochure of the ASEAN/USAID/ICLARM Coastal Resource Management Project, based on a painting by Mark Anthony Go-oco, from Pauly and Thia-Eng 1988).

connected with the sea through the transport of materials via fluvial and aeolian transport.

The ocean influences land through the influx of salt above and below the surface, the erosive energy of waves and tides, the deposition of marine aerosols and, to a variable extent, the regional climate of the coastal zone. Changes in either land or ocean parts of the coastal zone will create changes in the other so that a holistic approach is imperative to understanding and predicting the effects of global change.

Mankind continues to exploit intensively the coastal zone in many way (Goudie 1989). The intensity of use is growing through time, with some of the highest rates of population increase occurring in the coastal zone. Seventy percent of the world's human population lives on coastal plains and another large fraction on major river systems, which can be regarded as physiographic extensions of coastal plains up to the river fall lines. Much of the world's arable lands and industrial investment lie on coastal plains and in lower river valleys. Thus, human impacts are greatest on land areas directly adjacent to the sea.

Because there is intensive human occupation of coastal plains, and because rivers serve as natural conduits in transporting materials to the seas, coastal zones have become the depositories of human waste through both deliberate dumping and inadvertent action (river and ground water pollution). The effective value of this activity in terms of costs of alternative methods of disposal is immense.

Historically, the major use of coastal zones was through harvesting the secondary productivity of these unique environments. Even today, about 87% of the total marine catch of fin fish comes from these waters (Postma and Zijlstra 1988) as well as most of the shellfish catch. Many coastal habitats function as recruitment (spawning) grounds and/or nurseries for migratory fin fish that are captured offshore. Sheltered nearshore waters are increasingly being transformed into maricultural farming areas (Bardach 1989), and sports fishing is an economically important use of coastal waters in developed countries.

Collectively, coastal zones are important to human welfare in a wide variety of ways, not all mutually compatible if carried to extremes and each with different management obejctives. Further, many are vulnerable to, and could be seriously affected by, aspects of global change.

Questions and Issues about Global Change and Impacts on the Coastal Zone

A wide range of general questions is being raised within the scientific community regarding the response of coastal zones to global change. These are discussed below as a means of evaluating issues upon which the design of this proposed core project is based. From the coastal zone perspective, the major issues of global change affected by human actions are: (i) climate change; (ii) sea-level change (itself a derivative of climate change); and (iii) change in uses of land and freshwater. Two additional issues, namely changes in atmospheric trace gas (including CO_2) concentrations and ultra-violet radiation received at the surface will not be discussed here. Concentrations of trace gases will have little direct impact on the coastal zones (except, perhaps in the case of CO_2 for growth of coral reefs), although emissions of certain greenhouse gases may be important. Regarding UV, it is still uncertain whether there will be a general decrease of ozone in the stratosphere, and whether a widespread increase in surface UV-radiation at the land/sea surface is of importance to marine systems.

How will changes in climate and land use affect delivery of materials from land to rivers and the coastal zone?

Issue 1: Erosion and basin geomorphology

Fluvial erosion rate is a function of rainfall, slope length, vegetation cover and a soil erodability factor (Mulkey 1980). Aeolian erosion operates similarly but with different values placed on these parameters together with the dominant influence of wind (Pye 1987). Each is a function, to some degree, of other aspects

of climate, geological substrate, weathering rate, regional geomorphology, fire frequency and land use. Clearly, all these conditions are susceptible to alteration in the coming decades so that changes in the amount and distribution of fluvial erosion on land, in surface water flows and soil erosion, in other geomorphological processes and in land forms can be anticipated. The delivery of sediments to coastal zones as well as maintenance of agricultural lands, river transport and urban protection structures in these basins will be affected.

Issue 2: Basin hydrology

The distribution of incoming precipitation into evapotranspiration, groundwater and surface water flows is a function of climate, topography, soils, geology and vegetation (Baumgartner and Reichel, 1975). Both groundwater and surface runoff vary with changes in climate, soil conditions and vegetation cover. While groundwater is considered to be much less important than surface water in terms of total water flux, it may be relatively important in geochemical terms due to its dissolved constituents (UNESCO 1978, Zektser et al. 1983). Any change in flows will affect erosion and the delivery of sediments, nutrients and organic carbon to drainage basins and coastal zones.

Issue 3: Fluvial transport

Rivers are a major means of transport of material including suspended sediment, organic matter and nutrient salts, to the coastal zone. The rate of delivery of sediment, showing great variations worldwide (Fig. 2), together with erosional agents at the coastal zone, largely controls levels of deltas, distributions and sizes of depositional features such as mudflats, beaches and bars, and the derivative ecosystem properties such as wildlife habitat and fishery nurseries (Carter 1989). Delivery of dissolved materials, including inorganic nutrients and contaminants, depends on riverine geochemical and hydrological processes. River geochemistry varies considerably with the types of lithology, topography, hydrology, agricultural development, and vegetation cover of the river system. Understanding this variability in relation to changes in climate, land use, hydrology, etc., will be critical to the prediction of nutrient budgets for coastal zones.

A key question involving the global carbon cycle is how much terrestrially-derived organic carbon is buried in coastal oceans (Degens et al. 1984), particularly in deltas and estuaries (Ittekkot and Haake 1990). Rivers are possibly the most important source of carbon buried in recent marine sediments. More

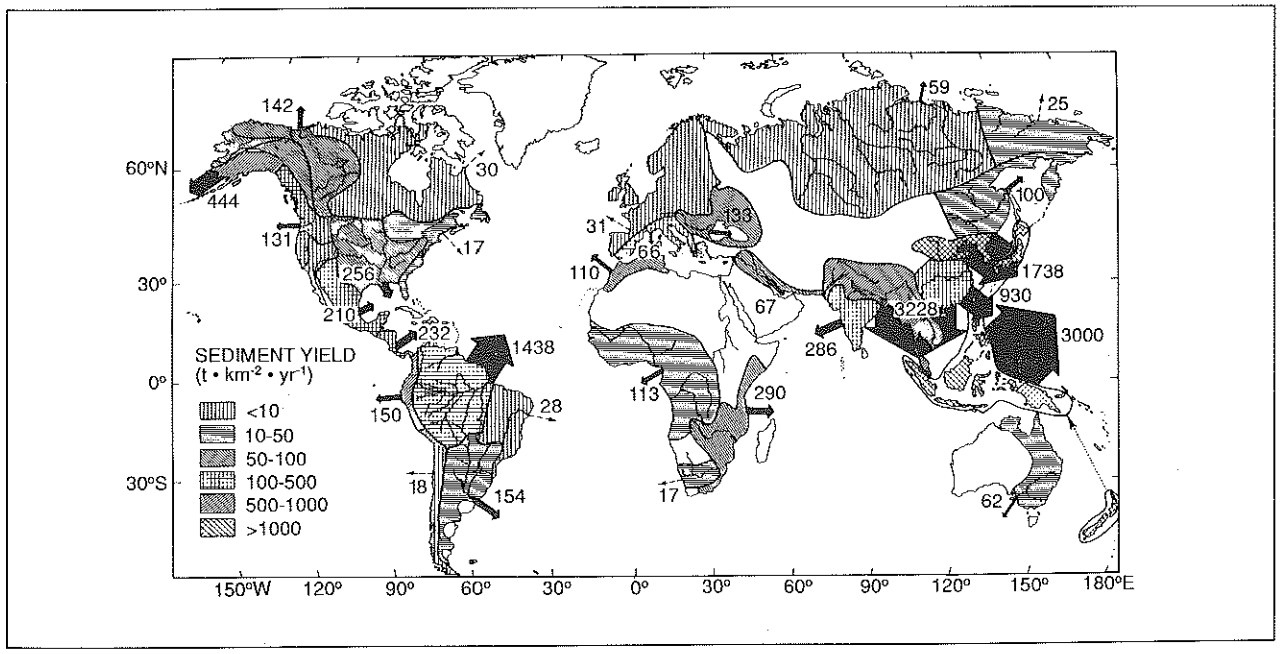


Figure 2. Annual fluvial sediment flux from large drainage basin areas to the ocean. Numbers in millions of tons per year; arrows proportional to the numbers (Milliman and Meade 1983).

detailed budgets for changes in the riverine delivery of particulate and dissolved organic carbon (POC, DOC) and for its fate in coastal waters are needed to evaluate this part of the global carbon cycle (Degens et al. 1990), especially as significant increases in the rate of delivery of organic matter to the sea are thought to have occurred already as a result of changes in land use (Berner 1989).

Issue 4: Aeolian transport from land to sea

Removal of soil from land surfaces by wind and atmospheric transport to sea is another important aspect of land-sea interactions. As with fluvial erosion, wind erosion processes are likely to be altered in spatial distribution and intensity by other factors of global change. The dust is mostly lithogenic (Pye 1987) and the degree of atmospheric loading significantly affects the input of solar radiation globally, thus altering photosynthetically available light and even surface temperatures. When deposited, dust enhances the sinking and consequent burial of organic matter (Ittekkot and Haake 1990, Buat-Menard et al. 1989), and may stimulate photosynthesis by providing iron and other limiting trace nutrients to phytoplankton (Duce 1986, Martin and Fitzwater 1988).

How will changes in riverine discharge, sea-level rise and episodic storms influence geomorphological processes in the coastal zone?

Issue 5: Coastal geomorphology

The complex geomorphology of highly dynamic nearshore features, such as sea cliffs, beaches, barrier bars, submerged bars, marshes and mangroves and their associated channels, lagoons, etc., will be affected by changes in sediment delivery, sea level and climate, particularly the incidence of storms (Bird 1986, Bardach 1989). While these geomorphological features are evanescent in geological terms, they are regarded as permanent on the time scale of human occupation of the coastal region, leading to huge efforts to maintain them.

Sea level rise will have a very large influence on erosion since, for every linear unit of sea level rise, geomorphological zones will tend to move shoreward on average 100 units (Bruun 1983). The impact will be critical in the short term to the maintenance of human structures and activities and of existing ecological systems. In the long term, human activities will either have to be defended at great cost or relocated as the distributions of natural coastal features are altered.

Sediment supplied by rivers is a crucial to many geomorphological processes in the coastal zone. The causes and possible effects of alterations in sediment supply are discussed above. As coastal geomorphological features are modified, the spatial distribution of biologically productive and regenerative zones will undergo extensive changes that may alter the overall energy flow and biogeochemical interactions within coastal ecosystems (Constanza et al. 1990). Some zones could be lost permanently if their maintenance is restricted by geomorphological barriers such as sea cliffs or by engineering structures. It is conceivable that some changes could be of such magnitude as to have very high regional importance. For example, rises in sea level could result in the loss of barrier islands that produce and protect extensive lagoons important to wildlife, fish and the air-sea exchange of trace gases.

Issue 6: Structure and function of deltas

Deltas include diverse range of topography including distributary channels, river-mouth bars, open and closed interdistributary bays, tidal flats, tidal ridges, beaches, beach ridges, dunes and dune fields, and swamps and marshes. They are extremely important in terms of human habitation so that the influences of environmental change on delta systems deserves special attention (Bardach 1989, Day and Templet 1989, Milliman et al. 1989).

Deltas are constantly changing as the balance between tectonic forces, eustatic changes in sea level, and the rates of deposition of sediments and of subsidence through consolidation and dewatering varies. Fluctuations in sediment supply through climate and land use change, through channel diversion, variations in sea level, change in deltaic vegetation management, or groundwater or hydrocarbon extraction determine the altitude and thus, composite structure and functioning of deltas. The serious threats to vitally productive agricultural and aquatic ecosystems that may be suffered through on deltas through global change are vividly described by Milliman et al. (1989).

Issue 7: Coral reefs and low-lying islands

Low relief islands and barrier reefs in tropical areas are particularly vulnerable to global change. Because coral reefs are constructed and maintained by living organisms, they are sensitive to changes in temperature freshwater surges, sediment deposition (Rogers 1990), eutrophication and pollution (Bardach 1989). In some cases, ecological structure and human welfare may be altered by diminution in freshwater lenses underlying these islands. In other cases, major parts of countries may be lost or rendered inhabitable through these changes.

Issue 8: Arctic coastlines

Climatic warming as well as sea level rise will seriously affect arctic coastal systems. Loss of permafrost in coastal zones could bring about large-scale disruption of the structure and stability of soils and of bottom sediments offshore. On land, loss of permafrost typically leads to surface collapse and accelerated erosion, and even widespread subsidence where the terrain is flat. These effects, in turn, can cause reorganization of hydrological, geomorphological and ecological features for entire stretches of coastline.

Issue 9: Coastal zone habitats

The high productivity and unique qualities of the coastal zones provide a range of critical habitats for many organisms, that are vulnerable to severe change or loss. Changing conditions in coastal zones could threaten the survival of certain species and communities of plants and animals.

How will changes in climate, land use and sea level influence saltwater intrusion to freshwater aquifers?

Issue 10: Aquifer volume

Freshwater meets saltwater below ground as well as in estuaries on top of saltwater wedges. Relative volumes of salt and freshwater vary with variations in the flow of groundwater to these marginal aquifers as a result of changes in precipitation and/or land use (Williams 1989), of loss of recharge area, of rise in sea level (Vellinga and Leatherman 1989), and of loss of the aquifers themselves through erosion as discussed above or through groundwater pumping (Carter 1989). It is important to note that increased retention of fresh water on land through the creation of reservoirs, irrigation and other schemes has significantly slowed down the rate of sea-level rise over the last few decades (Newman and Fairbridge 1986).

Issue 11: Aquifer contamination

Shallow coastal aquifers are also vulnerable to pollution through inflows of noxious materials derived from human activities, as well as intrusion of saline sea water. Such pollution may affect human occupation of these areas as well as natural ecosystems themselves.

How will changes in climate, and sea level alter transport of materials from sea to land?

Issue 12: Sea-spray aerosols

The sea produces between 1,000 and 10,000 Tg/yr of atmospheric sea salt particles with radii less than ca ≈20 µm (Duce 1983). The chemical constituents of these aerosols was reviewed in Buat-Menard (1986). The dominant ions of sea water, as well as trace quantities of organic compounds, are transferred to land in this form, sometimes with important ecological and agricultural implications. Sodium chloride is generally deleterious to land plants but in some regions essential sulphate and borate is supplied by these aerosols. Changes in sea level, prevailing wind direction and storm frequency are likely to alter the flux of these materials to land with varying effects on terrestrial ecosystems.

Issue 13: DMS aerosols

Dimethyl sulphide (DMS) is a breakdown product of cellular solutes of many species of macroalgae and phytoplankton (Andreae 1986). DMS is volatile and lost at least in part to the atmosphere where it is oxidized to sulphate. This non-sea salt sulphate is thought to be the major source of cloud condensation nuclei in the marine atmosphere and to play an important role in cloud formation (Charlson et al. 1987). If the abundance of DMS-producing algae changes with nutrient conditions, water temperature, sunlight or other factors related to global change, then variations in DMS production may act as a feedback effect to climate change. The release of DMS is not a special phenomenon of coastal zones, but in as much as the coastal zones are biologically active regions vulnerable to global change, then the potential for significant variations in emissions of DMS must be considered (see also IGAC, Chapter 2.1). Also the lifetime of biogenic sulphur compounds in the atmosphere is relatively short so that climate effects and acid deposition (see Turner et al. 1988) over the land margin will be most influenced by coastal sources of DMS.

How will climate change affect physical dynamics of coastal oceans?

Issue 14: Ocean boundary conditions

Important processes at the shelf edge that influence shelf-ocean exchange include interactions due to ocean and slope currents, mesoscale eddies and internal waves all of which are affected at least indirectly by climate (Csanady 1982). The direct effects of climate include variations in wind-induced upwelling (Bakun, 1990) and off-shelf cascading following strong wintertime cooling. All these processes contribute to large-scale exchanges of energy, momentum and matter between the oceans and shelf seas.

Issue 15: Land boundary conditions

Close to land, variations in the inputs of freshwater and suspended material largely determine the nature of the physical environment, affecting buoyancy-driven circulation patterns and the properties of the bottom fluid-sediment boundary layer. Interactions with tide and wind are complex. Estuaries may be well ventilated with a consistent throughput of materials from land to sea, or act as efficient traps (Nichols 1986) for both terrestrial and marine particulate matter. The dynamics of coastal jets constrained by offshore density gradients (fronts) are important for the transport of dissolved and suspended material from rivers and estuaries (Skreslet 1986, Jansson 1988). The formation and melting of winter ice at high latitudes also strongly affects the physical properties of inshore waters, as well as erosion/deposition processes at the land interface. The implications of sea-level rise in terms of mixing and circulation on shelves are not well known, although tidal models suggest that significant changes are possible especially in large, elongated estuaries.

Issue 16: Shelf processes

Rates of tidal energy dissipation are extremely variable from one shelf to another and within any particular shelf area, so that mixing and advective processes may be dominated by tide or wind. Much progress has been made recently with models to predict the positions of tidal fronts (e.g., Pingree and Griffiths 1978), but the interactive effects of wind, buoyancy, air-sea heat exchange and coastal topography remain poorly understood. At higher latitudes, especially climatic changes are likely to affect the timing and rate of development of seasonal stratification and, therefore, primary production.

Issue 17: Episodic events

Climate change will influence extreme as well as mean climate conditions.

Anomalous conditions of wind direction and strength, freshwater input, ocean dynamics and winter cooling affect a wide range of chemical and biological processes in coastal seas including estuarine flushing and shelf export of organic carbon (Yoder and Ishamaru 1989), but the understanding of such phenomena remains poor due to the difficulties of sampling over appropriate scales.

Issue 18: Cross-shelf exchange

An assessment of rates of cross-shelf exchange in relation to both physical and biogeochemical properties at a global scale is urgently needed for understanding contemporary condition as well as predicting future ones. It should take account of regional variations in topographic factors (shelf width, shape of coastline, water depth), input of freshwater, wind and tidal mixing, ocean boundary conditions, and the significance of different time scales of physical events for particular biological and chemical processes.

How will factors of global change affect primary and secondary production in the coastal zone?

Issue 19: Primary production

Changes in climate, sea level and human activities will modify the effective availability of light and nutrients for photosynthesis in the coastal zone. The cyclic effects of ENSO in this regard are indicative of how dramatic such changes can be at the scale of the oceans. In general, changes in primary production (Paasche 1988) may be expected due to increases in the areal extent of the coastal environment under the influence of sea water and to changes in riverine and ocean inputs of nutrients. Better information on the physical and chemical environment is needed to and allow the development of coupled hydrodynamic and ecosystem models (Uncles 1988, Wroblewski and Hofmann 1989) and to predict such changes globally.

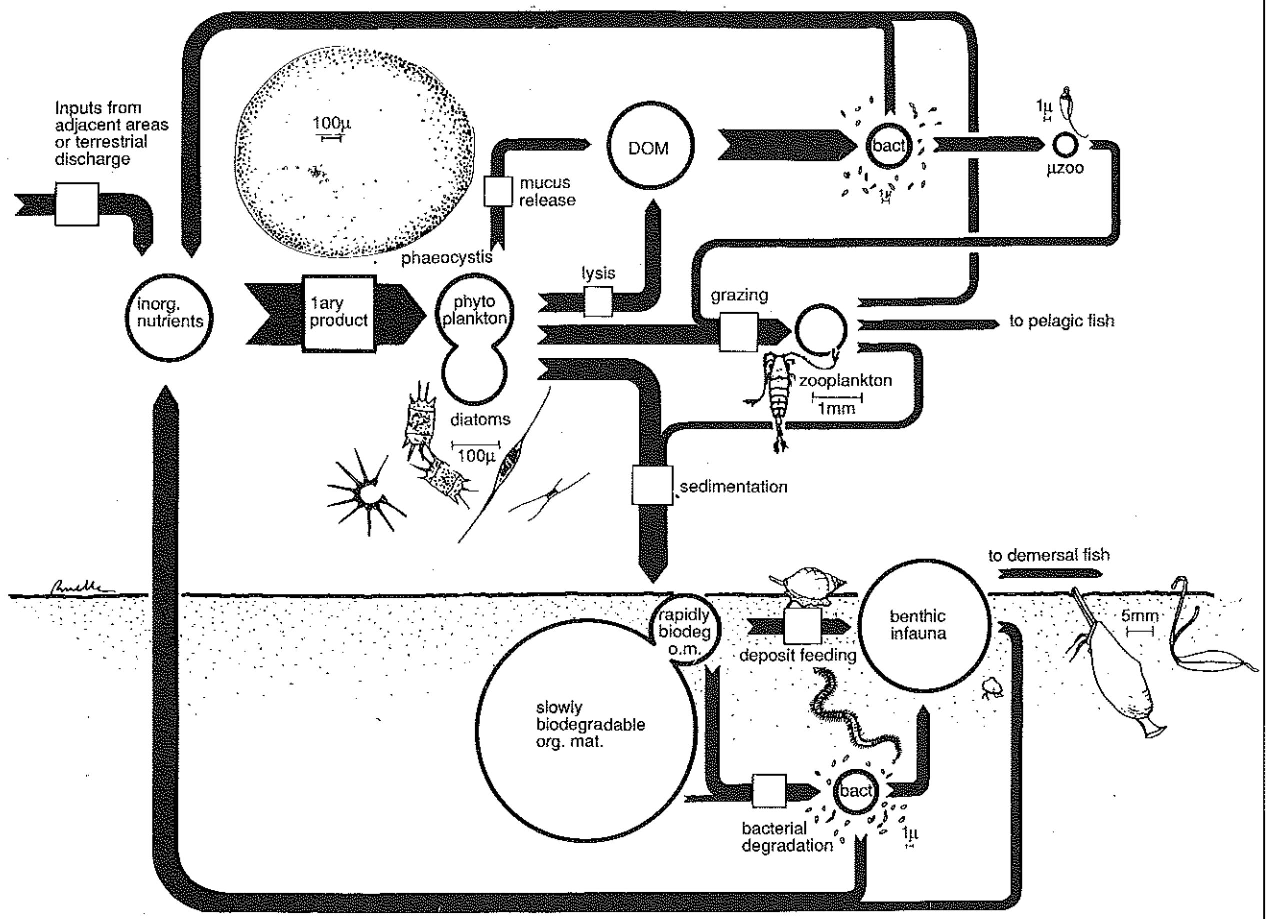
Issue 20: Eutrophication

Eutrophication of the coastal zone, through altered land use and waste disposal practices of man, affects the productivity and structure of coastal ecosystems as a result of absolute or relative changes in the abundances of nutrients (P or N relative to Si, trace metals, etc.). For example, algal blooms that are sources of natural toxins and volatile sulphur compounds, or that are unpalatable and consumed less efficiently within the pelagic food chain, thus leading to bottom water oxygen depletion, appear to be increasingly frequent in shelf and or semi-enclosed seas (e.g., Lancelot et al. 1987, Richardson 1989). Such changes often involve a shift in the dominance of phytoplankton communities from diatoms to flagellates. Although the ecological implications can be far-reaching (Elmgren 1989), the effects on global emissions of biogenic trace gases, including nitrous oxide and methane from the degradation of organic matter in anoxic sediments (Heinrichs and Reeburgh 1987) are not well quantified.

Growing use of coastal regions and riverine basins for habitation and development may be contributing to an increase in frequency and spatial extent of nuisance blooms. Once local problems are now becoming more regional in character, and it is important to determine just what factors are responsible. In some areas increasing eutrophication threatens the development of mariculture to its full potential.

Issue 21: Secondary production and fisheries

Climate influences the timing and dynamics of plankton production through the effects of wind mixing and surface heat exchange on the vertical stability of the water column. The way in which the seasonal thermocline develops and breaks down largely determines the overall duration of the growth season and relative phasing of primary and secondary production. Plant material is generally efficiently consumed (e.g., Rowe et al. 1986) except when dominated by certain types of noxious blooms, but the partioning of food between pelagic and benthic herbivores is strongly affected by hydrographic conditions (Townsend and Cammen 1988) and, in turn, influences the feeding and growth of pelagic and demersal fish.



Schematic representation of the dominant fluxes of nutrient elements through the first topic levels of the foodweb of a coastal ecosystem (DOM = dissolved organic matter; Lancelot et al. 1987).

Fluctuations in the abundance and yields of fish are associated with overfishing (Pauly and Thia-Eng 1988) and also with changes in climate (Southward et al. 1988), including the effects of prevailing winds on upwelling and shelf circulation (e.g., Dickson et al. 1988; also see Bakun 1990). Other impacts on fisheries include the direct influence of climatic temperature shifts (see Frank et al. 1990) and indirect effects related to various forms of habitat modification such as the destruction of marginal ecosystems (mangroves, saltmarsh, seagrasses, etc.) the manipulation of river discharges (e.g., Milliman et al. 1989).

Issue 22: Mariculture

Increased demand for aquaculture products, increased competition for space, and changes in climate and sea level are expected to affect mariculture (Bardach 1989). By comparison to natural fisheries, additional factors such as site exposure, variations in freshwater outflows, winter temperature minima, and the impact of derived waste products must be taken into consideration.

How will changes in climate, land use and sea level alter biogeochemical processes in the coastal zone?

Issue 23: Estimates of global fluxes

Considerable advances have been made over the last two decades in elucidating the nature of important biogeochemical transformations in coastal oceans, including aerobic and anaerobic degradation of organic matter, denitrification and the production of sulphur gases all of which directly affect the composition of the atmosphere. However, from a global perspective, the particular environmental conditions that determine total fluxes between the ocean and atmosphere are not well known. Changes in external inputs (for example, of organic matter or particular nutrients from land) can alter biogeochemical balances in the coastal ocean. Thus, an important priority for any new research programme on the coastal zone must be the development of observational methods and of a biogeochemical classification system for the construction of accurate regional budgets for biological consumption and production of atmospheric trace gases.

Issue 24: Carbon cycle

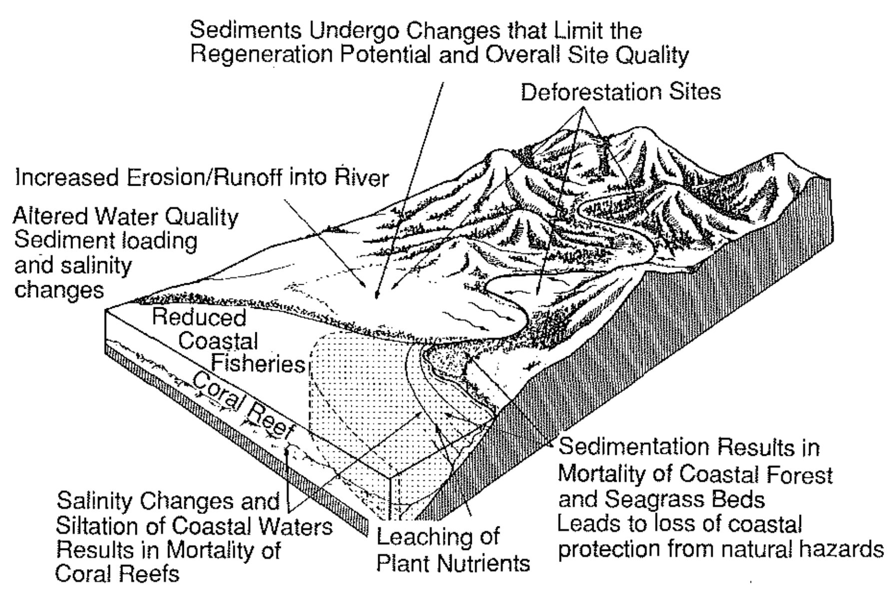
Most of the attention on the marine portion of the carbon cycle by JGOFS has focussed on the open ocean. The crucial role of the coastal seas as the interface to land and as a zone of relatively high biological activity is well recognized, however, through studies on the input of organic matter from land (e.g., Mantoura and Woodward 1983, Ittekott 1988), and by studies on sedimentation processes (see Berner 1982). A consistent picture has emerged of a net consumption of organic matter in the oceans (i.e., land + atmospheric inputs exceed sedimentary outputs), making the marine system effectively heterotrophic (Smith and Mackenzie 1987), and therefore a source for CO_2 and a sink for O_2 in terms of the cycling of organic matter. This conclusion has important implications for the control of the cycles of other important elements such as N and P (Smith and Mackenzie 1987).

With the present conditions of flooded continental shelves, most of the terrestrial organic matter is trapped within deltas and estuarine systems except where large rivers such as the Amazon discharge material directly to the ocean (Muller-Karger et al. 1988). Changes in the total flux of organic matter from land to sea and the relatively efficiency with which it is degraded or buried (Mann 1986) in the marine environment are important variables in the ocean-atmosphere exchange of CO_2. Whether anaerobic processes in coastal marine sediments are a significant global source of methane is not certain (Heinrichs and Reeburgh 1987).

Another controversial aspect of the role of the coastal ocean in the global C cycle is the hypothesis that biological activity on the shelf is a significant source of organic matter buried on the continental slopes (Walsh 1989). Opposing this view are geochemical arguments (Peng and Broecker 1984), and ecological data for efficient utilization of organic matter in shelf ecosystems (Rowe et al. 1986), suggesting that there is little net export of organic carbon to the slope. It is important to resolve this problem as well as the important ancillary question of whether primary productivity on the shelf might be enhanced by anthropogenic sources of nutrients (Wollast and Mackenzie, 1989).

Issue 25: Nitrogen cycle

Several aspects of the marine nitrogen cycle are important within the context of global change effects on coastal zone ecosystems (Blackburn and Sørensen 1988). First, the problem of distinguishing between N and P limitation is fundamental to our understanding of what determines primary productivity. Recent observations suggest that the geochemical conclusion that P is limiting in the global ocean (Smith and Hollibaugh 1989) must be modified due to significant losses of inputs of N by denitrification (Seitzinger 1988). This latter process is considered the main marine source of nitrous oxide, a greenhouse gas (Christensen et al. 1987). Total marine emissions of N_2O are uncertain, especially with respect to the contribution of the coastal seas.



Coastal effects of excessive clear-cutting (Snedaker and Getter 1984).

How do toxic wastes affect marine organisms and communities?

Issue 26: Exotoxicology

Many substances (metal, hydrocarbons, synthatic organic compounds, etc.) which cause adverse effects on the marine biota, continue to be released into coastal seas as a result of the agricultural, urban and industrial activities of man. Considerable research is being carried out on such pollutants in relation to mechanisms of transport and chemical transformation and to ecological impacts (Kullenberg 1984, Salomons et al. 1988). However, much better data are needed for predictive purposes on the ways in which toxic materials are accumulated by marine organisms, on the biochemical and physiological causes of stress, and on interactions of pollutants and environmental conditions (temperative, salinity) on stress. Improved methods of evaluating community responses to pollution, including changes in species and genetic diversity and in productivity and biogeochemical fluxes (Bayne et al. 1988, Levin et al. 1989) are also required, especially in relation to the problems of sustainability of living resources.

Science Components

General Design of the Core Project

Objective

- *To develop predictive understanding of the effects of changes in climate, land use and sea level on the global functioning and sustainability of coastal ecosystems, with emphasis on the interactions between changing conditions on land and sea, and on possible feedback effects physical environment.*

There are several significant words in this statement deserving comment. An explicit goal of the proposed research is to be able to predict outcomes of particular properties and processes based on well-specified scenarios of environmental change.

The term ecosystems places a particular emphasis on the role of the biota and how coastal systems operate as physical-chemical-biological systems.

Attention to land-sea interactions requires a close link with land-centred IGBP projects such as GCTE (Chapter 6.1) and BAHC (Chapter 5.1). At the same time, the core activities of the LOICZ should also interface study with other core projects involving marine ecosystems including JGOFS (Chapter 3.1) and GOEZS (Chapter 3.2).

The term functioning explicitly denotes a selection of some of the issues outlined above that call for concerted attention under the auspices of IGBP. These issues must be of general significance globally, and require coordinated interdisciplinary attention not likely to be given by other organizations. The selected key issues are reorganized into the following topics: (i) the effects of change in delivery of water, nutrients and sediments from land to sea; (ii) the role of the coastal zone in the global carbon cycle; and (ii) the effects of rising sea level and storms on the land-sea boundary.

Some important issues raised above are not addressed in the proposed core project because the scales, *modus operandi*, and scientific communities involved in those subjects are substantially different than those for the focus defined by the objective of this project.

The above key issues are organized into Foci in this chapter. Figure 3 shows the proposed structure of the whole Core Project in terms of the impacts of global change, the linkages between activities of this and other core projects of IGBP, and the product of the project — predictive capacity.

Integrated Catchment-Coastal Zone Study — *Focus 1*

Objective

- *To develop a predictive capacity for responses of catchment-coastal zone complexes to different scenarios of global change.*

This is to be a holistic approach in order to understand the relationships between the many interacting factors we can expect to act in new ways under conditions of global change. Such an activity should address the following phenomena in the context of changing climate, land use and sea level conditio; (i) rates of weathering and erosion in the catchment; (ii) material transport from the catchment to river valleys; (iii) changes in river valley geomorphology; (iv) transport of sediments, nutrients and organic carbon to deltas and the coastal zone; (v) the combined effects of material transport, sea-level change, climate change and resulting land margin and water movements on the physical structure and dynamics of the coupled coastal area; and (vi) the effects of the above changes on central aspects of biogeochemistry and energy flow in the coastal area.

Research on these component parts is being done or planned in various parts of the world. What is lacking is a programme explicitly linking the component parts in order to provide the broadest possible vision of these complex relationships.

Just as the coastal zone is inherently heterogeneous, catchment-costal zone complexes are inherently individualistic. Thus, it is unlikely that a thorough analysis, understanding and predictive capacity for any one catchment-delta complex will be readily applicable generalizable to other such zones. However, a coordinated programme of a small number, of detailed studies, executed through common approaches on highly contrasting catchment- coastal zone complexes, could yield the following three kinds of positive results: (i) detailed knowledge about the properties of those particular catchment-delta complexes; (ii) experience across the broadest range of conditions providing a framework in which interpolative predictions might be made; and (iii) development of technical, organizational and modelling methods that might be readily deployed for similar studies on other catchment-delta system of importance to particular regions.

Plan Development

This focus is too complex in nature and immature in development to permit any detailed description of methods. Generally, it requires interdisciplinary teams to understand, measure, experiment and develop models for:
- erosion rates on land (e.g., Ahnert 1987, Eybergen and Imeson 1989, Kirkby 1989, Bork et al. 1989);
- hydrological fluxes across land and through river channels (BAHC, Chapter 5.1);
- material transport down rivers, through reservoirs and into the coastal zone with consideration of changing geomorphological alterations in the riverways (e.g., Richey 1983, LICC 1990);
- physical oceanography, in particular changes in oceanic currents and tides related to modification of climate and sea level;
- material discharge, distribution, transformation and deposition in the coastal zone (e.g., Constanza et al. 1990, Dyer 1989) in conjunction with,
- changing configurations of the land margin and physical movements of waters, including storms (e.g., Carter 1989);
- the relationships of organisms and coupled biogeochemical and energetic processes in the full complex of coastal zone ecosystems from swamp forests to deep shelf waters (e.g., Wollast 1983).

These tasks should be undertaken for each of the catchment-coastal zone complexes, but should be cross-linked between the study units to share new discoveries or innovative methods, and to ensure common measurements of comparable resolution.

To obtain broadest interpolative predictive power for other catchment-coastal zone complexes the selected study complexes must be as contrasting as possible. Possibilities are temperate zone, industrialized river-delta complexes like that of the Rhine; agricultural, temperate zone rivers like the Mississippi or Yellow River; tropical shelf zones like the Indonesian shelf; and Arctic river-shelf complexes like the Lena or McKenzie.

Focus 2

Organic Carbon Dynamics in the Coastal Zone

Objective

- *To evaluate the role of the coastal environment in the global carbon cycle and to develop predictive capacity for change in net organic carbon storage for different scenarios of change in climate, land use, and sealevel rise.*

Whereas Focus 1 is site-specific and intensive in nature, this Focus would be extensive, in fact, global in nature.

While the focus is on carbon, behaviour of other elements such as P, N and Si must become involved because of the intimate interactions between the cycles of these elements (e.g., Wollast 1983). Thus, this would be a biogeochemically-centred activity but with specific questions focused on carbon. The project must rest on the best predictive capacity for changes in physical oceanography. Fundamentally, these questions are whether, when, where and how much organic carbon is being deposited in the coastal zone, and how would these variables be affected by global change?

Physical, chemical and biological dynamics at the continental shelf break, are certainly of global significance in relation to land-ocean interactions. Moreover, this domain is recognized to play an important role in the ocean carbon cycle which is the focus of JGOFS (Chapter 3.1). It is suggested that the topic of exchange processes and biogeochemical process at the shelf break, including deposition of organic carbon on the slope, be considered as soon as possible by a joint JGOFS/LOICZ panel. Such mutual effort should provide guidance for developing a specific research proposal on this topic.

Plan Development

As with Focus 1, a detailed plan needs to be developed. Perhaps with both extensive and intensive components. The extensive component might be the accumulation of data from the literature and from short-term campaign-style sampling efforts over a wide range of coastal situations. The intensive component could include process studies and field measurements of carbon fluxes in selected field sites. These extensive and intensive components must be coupled with other core activities, the best possible physical oceanographic modelling, and proper data-base management to achieve the general objective.

Impacts of Global Change on the Land Margin-Sea Boundary

Focus 3

Objective

- *To develop a predictive capacity for predicting the effects of global change on the geomorphological and hydrological relations between sea and land, with an ecosystem focus, and including studies of habitat stability and the ecological and genetic viability of communities.*

This Focus will take into account climate, sediment transport by rivers, storm patterns, and changes in tides and currents as well as sea level rise.

Ecosystem focus denote all marginal systems, excluding those controlled by human structures (harbours, marinas, etc.). It also entails attention to the influence of global change on the structure and function of coastal ecosystems such as barrier island vegetation or coral reefs. Sea margin systems would include subtidal and supratidal terrains that might be geomorphologic-ally altered by rising sea and storm surges, and would include salt penetration across broad fronts into freshwater aquifers and through estuarine surges. This focus would be highly interactive with other Foci as shown in Figure 3, and would require strong coastal zone physical oceanography linked with larger-scale circulation models as will be developed by WOCE. This activity would be extensive in its goals, to make predictions for all kinds of land margins, but not geographically bound as in Focus 2.

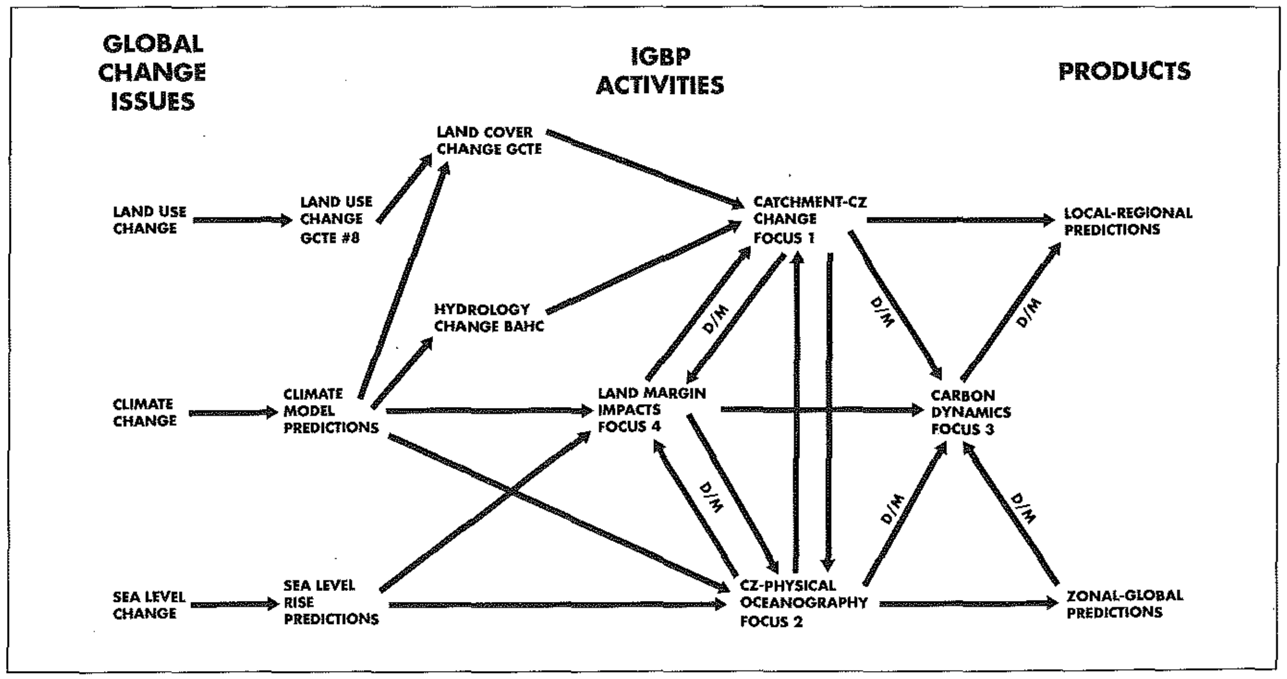


Figure 3. Relationships between major global change issues, other IGBP Core Projects, LOICZ Foci, and Core Project products. D/M = data base development/modelling. Arrows represent the main directions of physical influence in phenomenological terms, and/or information flows in Core Project operational terms.

Plan Development

In general terms, this focus might take the same kind of extensive and intensive divisions described for Focus 2. One activity might be to gather data on geomorphological conditions for the coastal zones of the world and seek a classification that would break these down into model systems for more direct analysis. It would require a strong, data base support system (see below).

A second activity could be to make appropriate observations on test case systems defined by the first activity, which would run concurrently with incorporation and further development of extant geomorphological and hydrological models. To a degree, the geomorphology and hydrology (aquifer invasion) may be treated as separate tasks in this activity but at some level they should be tightly linked because of their interdependency.

Ultimately, these predictive models will be coupled with hydrodynamic and geomorphological models developed in the integrated catchment-coastal zone activity for concerted scenario simulation (Fig. 3).

Special Project Needs

Common Modelling Support

Modelling will be an explicit function in each of the foci but some common modelling capacity will be needed to address difficult issues common to all. These include: (i) modelling across scales; (ii) scaling-up; (iii) modelling for episodic events; (iv) modelling feedbacks existing between subject areas of this core project and with other core projects; (v) developing and coordinating scenarios for model testing, and (vi) providing linkages between models.

Appropriate models or modelling techniques do not now exist for some of these problem areas and will require development. Examples of models are illustrated in Krysanova et al. (1989), Constanza et al. (1990), and Wroblewski and Hofmann (1989). In addition to these common areas of need, coordinated modelling will play a leading role in bringing about integration between the predictive models developed by the individual Core Activities to provide a predictive capacity.

This is a research area requiring planning by teams of modellers and process-centered scientists in each of the core activity areas. An organizational device must be developed to ensure satisfactory cross-activity modelling capacity.

Data Acquisition and Management

An imperative need of any coastal zone core project is a comprehensive and responsive system for data acquisition and management. Such a system must include a global, geographically specific, data base for several kinds of coastal zone variables used by this project, other marine scientists, governments, policy makers, etc. These variables include the following, some of which would be available as global coverage, others for intensive research areas of the core activities: (i) topography from upper edge of coastal plain to shelf break world wide; (ii) hydrography currents, tides, freshwater inputs, temperature, salinity, nutrients (Si, N, P, C in their several forms), inorganic particulates in terms of size class distributions and total bulk, locations of frontal boundaries; (iii) meteorology-solar radiation, air temperature, humidity, wind, precipitation, and (iv) biology-chlorophyll, plant biomass, animal biomass.

This data bank will be essential for identifying further information needs including localized data collection, providing the GIS base for extensive activities, and for applying the results of and model predictions to parts of the world outside of specific study areas. In addition, general questions of global relevance might be addressed immediately by the use of such a data base. Examples are: (i) How much new shelf area would be added world-wide if a 0.1 m sea level rise result from global change? (ii) How much land might be lost to subsidence due to permafrost melting and sea-level rise along the Arctic Ocean? (iii) How would

length of global shoreline be changed by inundation due to sea level rise combined with changes in storm activity? (iv) How would the area of lagoonal habitats worldwide be changed by alteration of sea level and storm frequency? (v) How would barrier island freshwater aquifers be influenced by prescribed changes in sea level and climate?

It is not clear how such a data base might be organized, but its existence is necessary for the success of this core project.

Core Project Development

This core project has not benefited from the series of workshops. Consequently, the science plan is not yet sufficiently developed to be considered for implementation.

The first planning workshop should be a general one involving all pertinent disciplines: soil science, upland geomorphology, riparian and coastal zone geomorphology, hydrology, physical oceanography, sedimentology, biogeochemistry, coastal zone ecology, meteorology, data management, remote sensing and modelling. This initial workshop should also involve representatives of IGAC (Chapter 2.1), GCTE (Chapter 6.1), BAHC (Chapter 5.1), JGOFS (Chapter 3.1) core projects and IGBP-DIS (Chapter 9).

The first task would be to examine the strategy of the project. The second task is to identify further organizational leadership and to plan subsequent workshops for each of the core activities. These more focused workshops are needed to modify, expand and detail each of the foci, in order to present a mature plan for implementation.

References

Ahnert, F. 1987. Process-response models of denudation at different spatial scales. Catena Supplement 10:31-50.

Andreae, M. O. 1986. The ocean as a source of atmospheric sulphur compounds. In: Buat-Menard, P. (ed). The Role of Air-Sea Exchange in Geochemical Cycling. NATO ASI Series C, Vol. 185:331-362. D. Reidel Publishing Company, Dordrecht.

Bakun, A. 1990. Global climate change and intensification of coastal upwelling. Science 247:198-201.

Bardach, J. E. 1989. Global warming and the coastal zone. Climatic Change 15:117-150.

Baumgartner, A. and Reichel, E. 1975. The World Water Balance. R. Oldenbourg Verlag, Munich.

Bayne, B. L., Clarke, K. R. and Gray, J. S. (eds). 1988. Biological effects of pollutants. Results of a workshop. Marine Ecological Progress Series 46:1-278.

Berger, W. H., Smetacek, V. S. and Wefer, G. (eds). 1989. Productivity of the Ocean. Present and Past. Wiley-Interscience, New York. 470 pp.

Berner, R. A. 1982. Burial of organic carbon and pyrite sulphur in modern ocean: its geochemical and environmental significance. American Journal of Science 282:451-473.

Berner, R. A. 1989. Biogeochemical cycles of carbon and sulphur and their effect on atmospheric oxygen over phanerozoic time. Palaeogeography, Palaeoclimatology, Palaeoecology 75:97-122.

Bird, E. C. F. 1986. Potential effects of sea-level rise on the coasts of Australia, Africa and Asia; In: Titus, J. G. (ed) Effects of Changes in Stratospheric Ozone and Global Climate. UNEP/USA EPA, Washington, DC.

Blackburn, T. H. and Sørensen, J. (eds). 1988. Nitrogen Cycling in Coastal, Marine Environments. SCOPE 33. John Wiley & Sons, Chichester. 480 pp.

Bork, H.-R., de Ploey, J. and Schic, S. (eds). 1989. Theory and Simulation of Infiltration, Overland Flow, Erosion, and Deposition Processes and Their Relevance to Landscape Evolution. Landschaftsgenese und Landschaftsökologie. Heft 16. Selbstverlag Abteilungen für physische Geographie und Landschaftsökologie und für Physische Geographie und Hydrologie der Technischen Universität Braunschweig. 178 pp.

Bruun, P. M. 1983. Coastal Engineering 7:77-89.
Buat-Menard, P. (ed). 1986. The Role of Air-Sea Exchange in Geochemical Cycling. NATO ASI Series C. Vol. 185. D. Reidel Publ. Co., Dordrecht.
Buat-Menard, P., Davies, J., Remoudaki, E., Miquel, J. C., Bergametti, G., Lambert, C. E., Ezat, U., Quetel, C., LaRosa J. and Fowler, S. W. 1989. Non-steady-state biological removal of atmospheric particles from Mediterranean surface waters. Nature 340:1-3.
Capone, D. G. 1988. Benthic nitrogen fixation. In Blackburn and Sørensen (eds). SCOPE 33:85-123. John Wiley & Sons, Chichester.
Carter, R. W. G. 1989. Coastal environments. An introduction to the physical, ecological and cultural systems of coastlines. Academic Press, Orlando Florida.
Charlson, R. J., Lovelock, J. R., Andreae, M. O. and Warren, S. G. 1987. Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate. Nature 326:655-661.
Christensen, J. P., Murray, J. W., Devol, A. H. and Codispoti, L. A. 1987. Denitrification in continental shelf sediments has major impact on the oceanic nitrogen budget. Global Biogeochemical Cycles 1:97-116.
Constanza, R., Sklar, F. H. and White, M. L. 1990. Modelling coastal landscape dynamics. BioScience 40:91-107.
Csanady, G. T. 1982. Circulation in the Coastal Ocean. Reidel, D. 279 pp.
Day, J. U. and Templet, P. H. 1989. Consequences of sea level rise: implications for the Mississippi Delta. Coastal Management 17:241-257.
Degens, E. T., Kempe, S. and Spitzy, A. 1984. Carbon dioxide: a biogeochemical portrait. In: Hutzinger, O. (ed). The handbook of environmental chemistry. Vol. 1/C:127-215. Springer-Verlag, Heidelberg.
Degens, E. T., Kempe, S. and Richey, J. E. (eds) 1990. Biogeochemistry of major world rivers. SCOPE 42. John Wiley & Sons, Chichester (in press).
Dickson, R. R., Kelly, P. M., Colebrook, J. M., Wooster, W. S. and Cushing, D. H. 1988. North winds and production in the eastern North Atlantic. Journal of Plankton Research 10:151-169.
Duce, R. A. 1983. Biogeochemical cycles and the air-sea exchange of aerosols. In: Bolin, B. and Cook, R. B. (eds). The major biogeohemical cycles and their interactions. SCOPE 21:427-456. John Wiley & Sons, Chichester.
Duce, R. A. 1986. The impact of atmospheric nitrogen, phosphorus, and iron species on marine biological productivity. In: Buat-Menard, P. (ed). The role of air-sea exchange in geochemical cycling. NATO ASI Series C, Vol. 185:497-529. D. Reidel Publishing Company, Dordrecht.
Dyer, K. R. 1989. Sediment processes in estuaries: future research requirements. Journal of Geophysical Reseach 94 (C10):14.327-14.339.
Elmgren, R. 1989. Man's impact on the ecosystems of the Baltic Sea: energy flows today and at the turn of the century. Ambio 18:326-332.
ERF (Estuarine Research Federation). 1989. At the land-sea margin: a call for basic research. Draft report to the National Science Foundation. 28 pp.
Eybergen, F. A. and Imeson, A. C. 1989. Geomorphological processes and climatic change. Catena 16:307-319.
Frank, K. T., Perry, R. I. and Drinkwater, K. F. 1990. The predicted response of northwest Atlantic invertebrate and fish stocks to CO_2-induced climatae change. Transactions American Plankton Society (in press).
Goudie, A. S. 1989. The human impact: man's role in environmental change. MIT Press. Cambridge, MA. 316 pp.
Heinrichs, S. M. and Reeburgh, W. S. 1987. Anaerobic mineralization of marine sediment organic matter: rates and role of aerobic processes in the oceanic carbon economy. Geomicrobiology J. 5:191-237.
Henriksen, K. and Kemp, W. M. 1988. Nitrification in estuarine and coastal marine sediments. SCOPE 33:207-249. John Wiley & Sons, Chichester.
Inman, D. L. and Nordstrom, C. 1971. On the tectonic and morphologic classification of coasts. Journal of Geology 71:1-22.
Ittekkot, V. and Haake, B. 1990. The terrestrial link in the removal of organic carbon in the sea. Ittekkot, V., Kempe, S., Michaelis, W. and Spitzy, A. (eds) Facets of modern biogeochemistry. Springer-Verlag, Berlin. pp 318-325.
Jansson, B. O. (ed) 1988. Coastal-offshore ecosystem interactions. Lecture notes on coastal and estuarine studies. Vol. 22. Springer-Verlag.

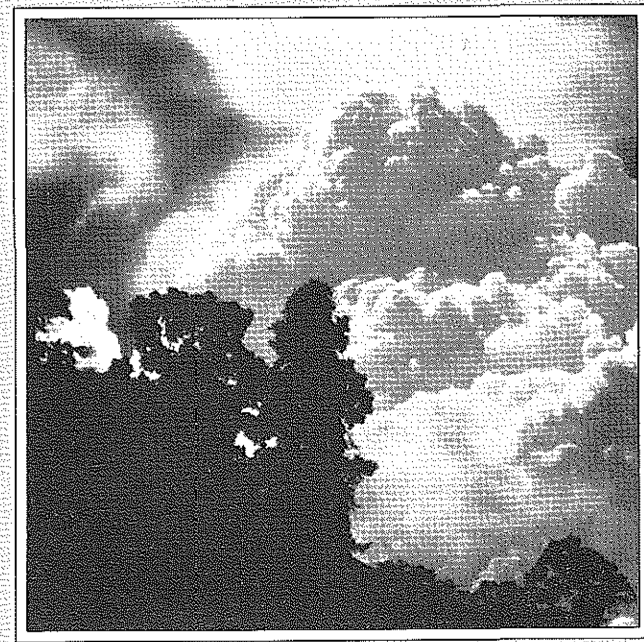
Kennett, J. P. 1982. Marine Geology. Prentice-Hall, Inc., Englewood Cliffs, N. J. 813 pp.
Kirkby, M. J. 1989. A model to estimate the impact of climatic change on hillslope and regolith form. Catena 16:321-341.
Koike, I. and Sørensen, J. 1988. Nitrate reduction and denitrification in marine sediments. SCOPE 33:251-273. John Wiley & Sons, Chichester.
Krysanova, V., Meiner, A., Roosaare, J. and Vasilyev, A. 1989. Simulation modelling of the coastal waters pollution from agricultural watershed. Ecological Modelling 49:7-29.
Lancelot, C., Billen, G., Sournia, A., Weisse, T., Colijn, F., Veldhuis, M. J. W., Davies, A. and Wassman, A. 1987. *Phaeocystis* blooms and nutrient enrichment in the continental coastal zones of the North Sea. Ambio 16:38-46.
Levin, S. A., Harwell, M. A., Kelly, J. R. and Kimball, K. D. (eds) 1989. Ecotoxicology: problems and approaches. Springer-Verlag, New York. 547 pp.
LICC Executive Committee (eds) 1990. Landscape ecological impact of climatic change. Proceedings of the First European LICC Conference, December 3-7, 1989, Lunteren, the Netherlands. IOS, Amsterdam (in press) ca 350 pp.
Mann, K. H. 1986. The roel of detritus at the land-sea boundary. In Biogeochemical Processes at the Land-Sea Boundary. Laserre, P. and Martin, J.-M. (eds). Elsevier Oceanography Series 43:123-140. Elsevier.
Mantoura, R. F. C. and Woodward, E. M. S. 1983. Conservative behavior of riverine dissolved organic carbon in the Severn Estuary: chemical and geochemical implications. Geochem., Cosmochem Acta 47:1293-1309.
Martin, J. H. and Fitzwater, S. E. 1988. Iron deficiency limits phytoplankton growth in the north-east Pacific subarctic. Nature 331:341-343.
Milliman, J. D. and Meade, R. H. 1983. World-wide delivery of river sediment to the oceans. Journal of Geology 91:1-21.
Milliman, J. D., Broadus, J. M. and Gable, F. 1989. Environmental and economic implications of rising sea level and subsiding deltas: the Nile and Bengal examples. Ambio 18:340-345.
Mulkey, L. A. 1980. An approach to water resources evaluation and nonpoint silvicultural sources: a procedural handbook. EPA-600/8-870-012. USA EPA, Environmental Research Laboratory, Athens, GA.
Muller-Karger, F. E., McClain, C. R. and Richardson, P. L. 1988. The dispersal of the Amazon's water. Nature 333:56-59.
Newman, W. S. and Fairbridge, R. W. 1986. The management of sea-level rise. Nature 320:319-320.
Nichols, M. M. 1986. Consequences of sediment flux: escape of entrapment. Rapport Procès-Verbaux de Reunion Conseil Internationale Exploration de Mer 186:343-345.
Paasche, E. 1988. Pelagic primary production in nearshore waters. In: Blackburn, T. H. and SørensenJ. (eds). Nitrogen cycling in coastal marine environments. SCOPE 33:33-57. John Wiley & Sons, Chichester.
Pauly, D. and Thia-Eng, C. 1988. The overfishing of marine resources: Socioeconomic background in Southeast Asia. Ambio 17:200-206.
Peng, T.-H. and Broecker, WS. 1984. Ocean life cycles and atmospheric CO_2 content. J. Geophys. Res. 89: 8170-8180.
Pingree, R. D. and Griffiths, D. K. 1978. Tidal fronts on the shelf seas around the British Isles. J. Geophys. Res. 83, 4615-4622.
Postma, H. and Zijlstra, J. J. (eds). 1988. Ecosystems of the world 27. Continental shelves. Elsevier, Amsterdam, 421 pp.
Pye, K. 1987. Eolian dust and dust deposits. Academic Press, Orlando, Florida. 334 pp.
Richardson, K. 1989. Algal blooms in the North Sea: The Good, the Bad and the Ugly. Dana 8:33-43.
Richey, J. E. 1983. Interactions of C, N, P, and S in river systems: a biogeochemical model. In: Bolin, B. and Cook, R. B. (eds) The major Biogeochemical Cycles and Their Interactions. SCOPE 21:365-383. John Wiley & Sons, Chichester.
Rogers, C. S. 1990. Responses of coral reefs and reed organisms to sedimentation. Marine Ecology Progress Series 62:185-202.
Rowe, G. T., Smith, S., Falkowski, P., Whitledge, T., Theroux, R., Phoel, W. and Ducklow, H. 1986. Do continental shelves export organic matter? Nature 324:559-561.

Salomons, W., Bayne, B. L., Duursma, E. K. and Forstner, U. (eds). 1988. Pollution of the North Sea. An Assessment. Springer-Verlag, Berlin. 687 pp.
Seitzinger, S. P. 1988. Denitrification in freshwater and coastal marine ecosystems: ecological and geochemical significance. Limnology and Oceanography 33:702-724.
Skreslet, S. (ed) 1986. The role of freshwater outflow in coastal marine ecosystems. NATO ASI Series 67. Springer-Verlag. 453 pp.
Smith, S. V. and McKenzie, F. C. 1987. The ocean as a net heterotrophic system: implicaations from the carbon biogeochemical cycle. Global Biogeochemical Cycles 1:187-198.
Smith, S. V. and Hollibaugh, J. T. 1989. Carbon controlled nitrogen cycling in a marine "mesocosm": an ecosystem scale model for managing cultural eutrophication. Marine Ecology Progress Ser. 52:103-109.
Southward, A. J., Boalch G. T. and Maddock, L. 1988. Fluctuations in the herring and pilchard fisheries of Devon and Cornwall linked to change in climate since the 16th century. Journal of the Marine Biological Association of the United Kingdom 68:423-445.
Townsend, D. W. and Cammen, L. M. 1988. Potential importance of the timing of spring plankton blooms to benthic-pelagic coupling and recruitment of juvenile demersal fishes. Biol Oceanogr. 5: 215-229.
Turner, S. M., Malin, G., Liss, P. S., Harbour, D. S. and Holligan, P. M. 1988. The seasonal variation of dimethyl sulphide and dimethylsulphonioproprionate concentrations in nearshore waters. Limnology and Oceanography 22:264-375.
Uncles, R. J. 1988. Coupling of hydrodynamic and ecosystems modelling applied to tidal estuaries. In: Jansson, B. O. (ed) Coastal-offshore ecosystem interactions. Lecture notes on coastal and estuarine studies 22. Springer-Verlag. pp 309-354.
UNESCO. 1978. World water balance and water resources of the earth. USSR Committee for the International Hydrological Decade. Unesco, Paris. 663 pp.
Vellinga, P. and Leatherman, S. P. 1989. Sea level rise, consequences and policies. Climatic Change 15:175-189.
Walsh, J. J. 1989. How much shelf production reaches the deep sea? In: Berger, W. H. et al. (eds) Productivity of the Ocean: Present and Past. John Wiley & Sons, Chichester. pp 175-191.
Williams, P. 1989. Adapting water resources management to global climate change. Climatic Change 15:83-93.
Wollast, R. 1983. Interactions in estuaries and coastal waters. In: Bolin, B. and Cook, R. B. (eds) The Major Biogeochemical Cycles and Their Interactions. SCOPE 21:385-407. John Wiley & Sons, Chichester.
Wollast, R. and Mackenzie, F. T. 1989. Global biogeochemical cycles and climatic. In: "Climate and Geo-Sciences", Berger, A. (ed) Kluwer Acad. Publ., pp 453-473.
Wroblewski, J. S. and Hofmann, E. E. 1989. US interdisciplinary modelling studies of coastal-offshore exchange processes: Past and future. Progress in Oceanography 23:65-99.
Yoder, J. A. and Ishimaru, T. 1989. Phytoplankton advection off the southeastern United States continental shelf. Continental Shelf Research 9:547-553.
Zektser, I. S., Dzhamalov, R. G. and Safronova, T. I. 1983. The role of submarine groundwater discharge in the water balance of Australia. In: Unesco-IAH-IAHS.
Groundwater and water resource planning. Proceedings of the International Symposium. 1987. Vol. 1:209-219. Unesco, Paris.

Suggested Reading

Bardach, J. E. 1989. Global warming and the coastal zone. Climatic Change 15:117-150.
Bolin, B., Döös, B. R., Jäger, J. and Warrick, R. A. (eds). 1986. The Greenhouse Effect, Climatic Change and Ecosystems' SCOPE 29. John Wiley & Sons, Chichester.
Constanza, R., Sklar, F. H. and White, M. L. 1990. Modelling coastal landscape dynamics. BioScience 40:91-107.
Degens, E. T., Kempe, S. and Richey, J. E. (eds). 1990. Biogeochemistry of major world rivers. SCOPE 42. John Wiley & Sons, Chichester (in press).
Lasserre, P. and Martin, J.-M. 1986. Biogeochemical Processes at the Land-Sea Boundary. Elsevier Oceanography Series 43. 214 pp.
Milliman, J. D., Broadus, J. M. and Gable, F. 1989. Environmental and economic implications of rising sea level and subsiding deltas: the Nile and Bengal examples. Ambio 18:340-345.
OCEANUS 32(2). 1989. The Oceans and Global Warming.
Peltier, W. R. and Tushingham, A. M. 1989. Global sea level rise and the greenhouse effect: Might they be connected? Science 244:806-810.
Walsh, J. J. 1988. On the Nature of Continental Shelves. Academic Press Inc. 520 pp.

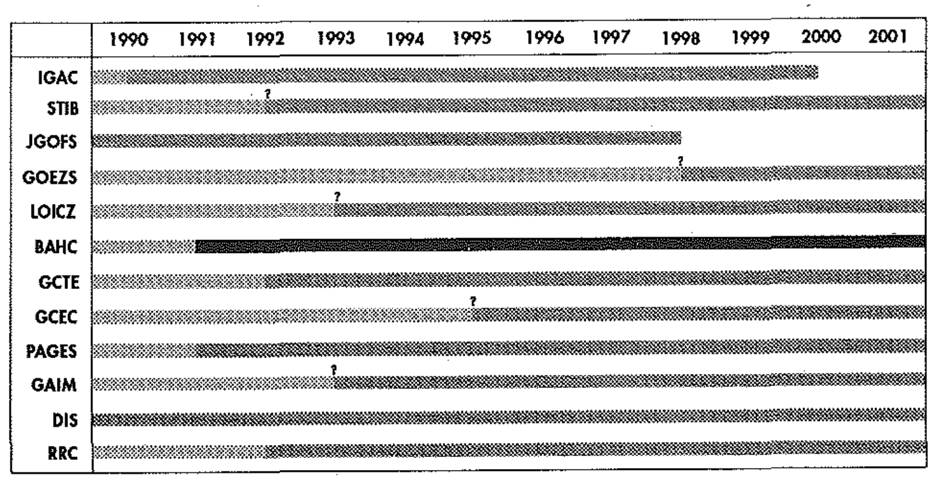
GLOBAL IGBP CHANGE



How Does Vegetation Interact with Physical Processes of the Hydrological Cycle?

Climate and land-surface systems are dynamically coupled through the physical processes of energy and water fluxes. Vegetation plays a major role in regulating water transport to the atmosphere. Changes in land use, such as conversion of forests to agricultural land, affect physical aspects of the climate system, for example, through changes in patterns of transpiration and runoff. Interactions of terrestrial ecosystems with the hydrological cycle at continental scales need to be coupled to global climate models. The processes governing the role of vegetation in the hydrological cycle must be identified and a quantitative understanding of the interaction between vegetation, the hydrological cycle, and climate, needs to be developed.

Contents


1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
IGAC
STIB
JGOFS
GOEZS
LOICZ
BAHC
GCTE
GCEC
PAGES
GAIM
DIS
RRC

5.1 Biospheric Aspects of the Hydrological Cycle (BAHC)

An Established Core Project

Introduction

The terrestrial hydrological cycle is an integral component of the climate system and is strongly modulated by the atmosphere and the biogeophysical characteristics of the landscape. It supplies the necessary water resource for sustaining life on Earth and also is a major medium for the biogeochemical cycles.

Associated with the terrestrial water cycle there is a continuous exchange of energy, water and other substances through the atmosphere, the landscape, and inland aquatic systems. Vegetation cover is influenced by the climate. Conversely, vegetation plays an important role in determining the partitioning of the energy and water inputs at the lower boundary of the land-atmosphere system thus influencing the surface hydrological processes and, consequently, the climate. The dynamics of the hydrological processes and linkages between soils, vegetation and atmosphere along with their integrated global effects are only poorly understood. A thorough understanding of key biological-hydrological interactions of the soil-vegetation-atmosphere system is a prerequisite to predicting impacts of climate change on unmanaged and managed vegetation.

During the last two decades there has been a growing awareness of the importance of land-surface processes in global climate models. Model simulations are very sensitive to changes in surface albedo, moisture availability and surface roughness. In particular, the importance of evapotranspiration over land as a moisture source for the atmosphere and subsequent precipitation has been clearly demonstrated in several GCM experiments. Nevertheless, the representation of hydrological processes is one of the weakest and most challenging aspects of the present climate models.

The WCRP has responded to this challenge by establishing the Global Energy and Water Cycle Experiment (GEWEX) Programme, which is dedicated to understanding the role of physical-hydrological processes in the climate system. The IGBP Core Project on Biospheric Aspects of the Hydrological Cycle (BAHC) will deal with the complementary problem of resolving the role of the biosphere and land surface processes in this context. The BAHC project addresses the following question: how do plant communities and ecosystems function in combination with the topographic structure of the land-surface affect the cycle of water on Earth? These investigations must resolve not only the "scaling-up" problem of extending vegetation patch-scale information to larger meso- and GCM grid-scales, but also the basic question of how the impact of the biosphere on the water cycle will change as vegetation itself responds to changes in the physical climate system or is modified through human activities. The elucidation of these phenomena will provide a fundamental input to the IGBP core project dealing with ecosystems response to a changing environment (GCTE; Chapter 6.1).

The BAHC project will also complement the WCRP's GEWEX programme by gaining an understanding of the interactions between vegetation, land cover and the hydrological cycle. The strategy for achieving this includes field studies from small scale (patch, small catchment, landscape) up to the mesoscale and river-basin scale using *in situ* and remote observations to develop Soil-Vegetation-Atmosphere Transfer (SVAT) models that can be incorporated into complex GCMs and GHMs (Global Hydrological Models).

To achieve these goals, it will be necessary to work together with GEWEX programme to:

- determine the biospheric controls of the hydrologic cycle through field measurements for the purpose of developing models of the energy and water fluxes in the soil-vegetation-atmosphere system at temporal and spatial scales ranging from vegetation patches to GCM grid cells;
- develop appropriate data bases that can be used to describe the interactions

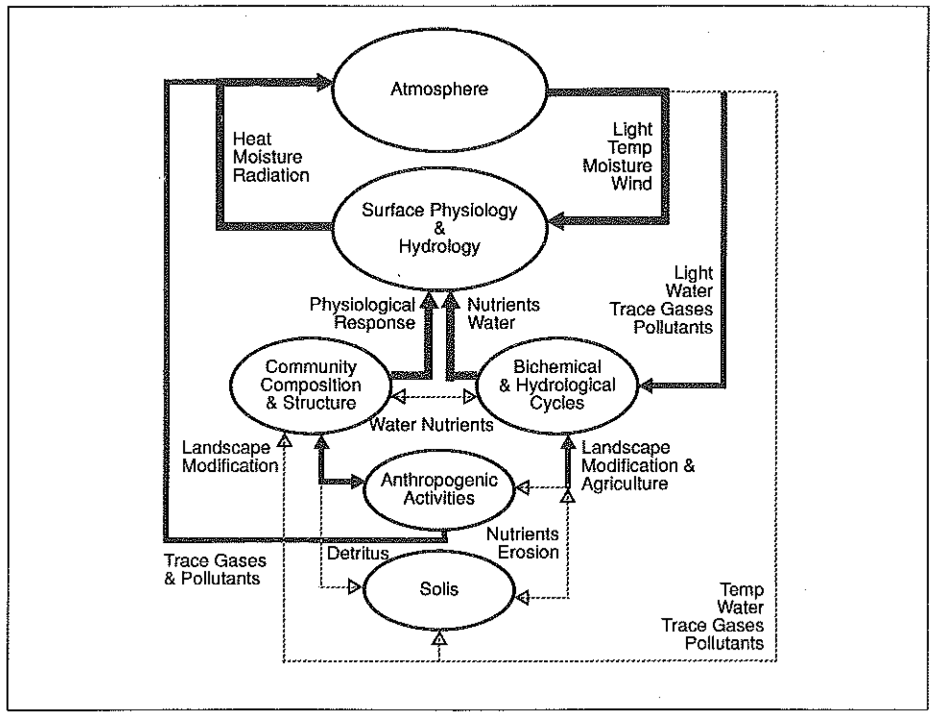


Figure 1a. Major elements in the coupling among the atmosphere and the terrestrial ecosystems. This simplified diagram emphasizes the time scales involved in the various couplings. The lower atmosphere and surface vegetation are coupled with a fast-response loop through the partitioning of incident solar radiation at the land surface and subsequent circulation of moisture and heat in the lower atmosphere which affects the physiology of the surface vegetation. The atmosphere is also coupled through weaker responses at longer time scales by climate modifications due to biogeochemical and hydrological cycles, soils and community composition and structure (Hall et al, 1988).

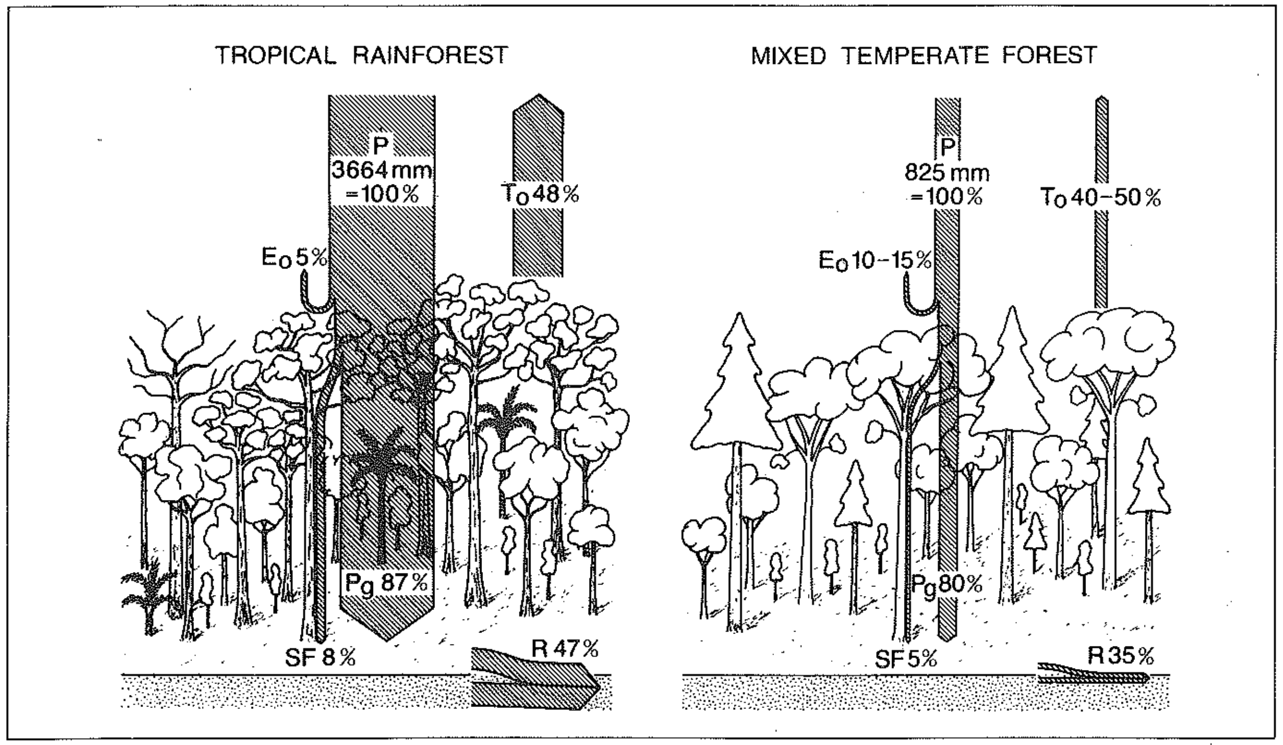


Figure 1b. Major components of the water cycle in pristine humid tropical predominantly evergreen forest in a weakly seasonal equatorial climate and in a mature and complex humid cool temperate deciduous beech-evergreen spruce (Douglas, silver fir) forest in central Europe. P = precipitation, T0 = actual transpiration, E0 = actual evaporation, SF = stem flow, Pg = precipitation to the ground, R = runoff (overland and subsurface) (Bruenig 1987).

between the biosphere and the physical Earth system and to test/validate model simulations of such interactions.

Vegetation influences the hydrological regime in several important ways (Fig. 1). First, vegetation canopy and litter surfaces are partitioning points for the physical inputs (energy and water) into the system. Here, the relevant processes are surface reflection, absorption and emission for radiation, sensible and latent heat fluxes, interception, through-flow and water-holding capacity. The canopy also determines aerodynamic roughness. Second, stomata-controlled leaf transpiration regulates the water flux from the soil to the atmosphere in response to the balance between water availability and evapotranspiration demand. Third, root systems (i) increase soil porosity and vertical hydraulic conductivity; (ii) enhance infiltration and percolation; (iii) augment the soil water-holding capacity; and most importantly, (iv) provide transport of water back to the canopy. Fourth, the biomass and its root system enhance lateral hydraulic resistance to surface runoff and subsurface flows, protecting the soil against erosion.

In contrast, the effect of the ambient hydrological regime on the vegetation cover depends upon the time scales under consideration. For the IGBP time scale (decades-to-centuries), the main issues are changes in leaf area index (LAI), primary productivity, and species adaptation or replacement. However, in order to understand these long-term effects, it is necessary to consider the shorter-term effects of component processes amenable to observation. Specifically, on intermediate time scales (months-to-few years), phenology, rooting density and distribution, possible stomatal adjustment, etc., and at short time scales, changes in stomatal control in response to water availability are of importance. Additionally, extreme events, such as fire, storms and floods, and their frequencies, often determine vegetative cover.

The role of seasonal snowcover and snowpack dynamics in temperature and boreal systems is profound. The partitioning of precipitation into snow versus rain often determines whether that precipitation is stored in the system for many months, or leaves the system within hours to days as evaporation, transpiration or streamflow. During snowmelt, watershed hydrograph peaks are dampened substantially because of the moderating pace of snowmelt compared to the instantaneous peaks of rainfall runoff. Hence, the initial time constant of the entire hydrologic cycle is controlled by snowpack processes. Meteorologically, snowcover produces an instantaneous shift in surface albedo and influences latent energy exchange, radically changing energy budgets. Ecologically, snowpack stores seasonal precipitation in arid areas, and snowmelt then may produce the only time of the growing season that soil profiles are water saturated. In these areas, there is a high correlation between spring snowpack water equivalence and ecosystem primary production. Protection of vegetation during harsh winters by snow influences timberline vegetation survival. In mesic climates, heavy snowpack may impede vegetation development. The snowmelt period is the trigger for a short, intense period of annual nutrient mobilization and transport in snow dominated ecosystems. This nutrient flush and warming spring temperatures can be the most active time of the entire year for ecosystem trace gas fluxes and photosynthetic activity. Finally, changes in the areal coverage and seasonal timing of continental snowpack may be an early and important signal of progressive climatic warming.

For study of the above biological processes, a thorough understanding of certain physical processes is required, which necessitates cooperation between BAHC and GEWEX. The physical processes that will be addressed in GEWEX, especially at the spatial scales of GCMs, are: (i) exchange of radiant energy at canopy level, as it determines the partitioning of net radiation between latent and sensible heat fluxes; and (ii) soil processes, especially the partitioning of water into surface runoff, infiltration and percolation below the root zone, and direct evaporation associated with upward capillary movement of water. In contrast, the processes that will be addressed in the BAHC project are: (i) evaporation of intercepted precipitation by the major functional vegetation types; and (ii) transpiration depending upon the atmospheric demand, availability of water in the soil, LAI and phenology, root-system state and functional vegetation type. In addition, groundwater transfer under humid and arid conditions, long distance transport through preferred pathways and storage for continental scales associated with climate and land-cover changes, will be an associated topic to be jointly dealt with by BAHC and GEWEX. It is emphasized that in keeping with the IGBP's defined objectives, the time scales of interest in BAHC would be the processes that affect the hydrological cycle on the decadal-to-century time scale.

Interactions, Variables and Data

Quantitative knowledge of the volume and dynamics of the major terrestrial water reservoirs and of the main processes of the local, regional and global hydrological cycle is incomplete. Precipitation, evaporation and water transport are very poorly documented on the global scale. Information from a variety of sources needs to be integrated into a common data base. The data vary in type from continuous temporal measurements of a few selected locations to geographically referenced maps of various surface properties and other information.

For BAHC, a Geographic Information System (GIS) is needed which includes the following attributes of the surface and subsurface: (i) climate data such as precipitation, humidity, radiation, temperature, wind speed, soil moisture, snowcover, etc.; (ii) river discharge and runoff data; (iii) functional vegetation and soil-types data; (iv) topographic, catchment boundary and land-use data; and (v) regolith, bedrock, and groundwater system data.

The issues related to climate, river discharge and runoff data both by conventional and remote-sensing methods are described in detail in WMO/ICSU (1989a, 1989b). In addition, issues relating to palaeohydrological data needs are discussed in Chapter 7.1 on PAGES.

Vegetation and Soil Attributes

Vegetation cover

Vegetation or land cover is a fundamental property of the land surface with respect to hydrological processes. In this regard, the most important attributes of plant cover are: (i) extension, density, height and permanence (portion of time the land remains covered) and phenology of vegetation; (ii) the structure of the canopy, especially leaf area and leaf distribution profile; and (iii) mean stomatal response of functional vegetation types.

Currently available global land-surface data, such as vegetative cover (Matthews 1983, 1984), land-use and soils (Wilson and Henderson-Sellers 1985) as well as remotely-sensed information, such as the normalized vegetation greenness index (NDVI), do not cover all the parameters mentioned above. Therefore, the determination of these parameters should be given a high priority. In particular, a more complete understanding of the cycling of water requires information on the interactive effects of climate-induced feedbacks within and between the biosphere and the atmosphere, and reliable global estimates of land cover and land-cover change. For this purpose, IGBP has initiated a Land-Cover Change Pilot Study (see Chapter 9) that has as a core objective to develop, validate and demonstrate a methodology capable of monitoring global land cover and its changes. GCTE (Chapter 6.1) has proposed a complementary activity that focuses on gaining predictive capacity for future land-cover change.

Soil attributes

The partitioning of water at the land surface, between surface runoff and infiltration, is determined by the state of the vegetation and soil as well as by the nature of precipitation events. The overall water-holding capacity of the soil is determined by soil texture, fabric and structure, which determine total pore space, and by the presence of roots and organic material. The global storage of water in the land surface layer (soil moisture) is not well defined over large scales. Soil infiltration rates during a given precipitation event are determined by precipitation intensity, hydraulic conductivity and water-holding capacity. The rates are also influenced by the slope of the terrain and antecedent climatic conditions, which determine the amount of water still within the soil, and by the

physical characteristics of the surface, such as the degree of crusting or compaction which, in turn, is influenced by litter and root systems. Water movement within the soil may be hampered by compacted layers (e.g., iron or carbonate pans, clay-enriched horizons).

The following soil processes are important to understanding the biospheric aspects of hydrology: (i) infiltration into the soil layer, particularly in relation to soil horizons and permafrost; (ii) soil water retention, especially in the rooting zone, which limits plant function at high or low water content; (iii) percolation below the root zone; (iv) subsurface runoff within the soil (interflow), along surfaces of less permeable horizons and lithic contacts; and (v) upward capillary movement due to withdrawal of water by roots or direct evaporation from the soil surface.

These aspects of soil attributes are also important to GCTE (Chapter 6.1).

Landscape and Subsurface Attributes

Changes in landscape properties, as a result of either climate changes or Man's activities, affect the hydrological cycle. Changes due to climate proceed at relatively slow rates. Human activities, however, may cause rapid modification of the characteristics of the landscape. Changes of land use (e.g., agriculture, urbanization, deforestation and drainage of swamps), changes of topography and drainage systems (e.g., construction of hydraulic structures, terraces and contour ploughing) all influence the hydrological cycle locally. The following attributes are of importance to the present project.

Surface topography

The realistic estimation of surface-water transfers and storages requires information on surface topography. This is of fundamental importance in determining plant communities, species location, growth and phenological behaviour. Topographic data exist as digital elevation grids at a global scale (e.g., U.S. Navy topographic data base). The spatial resolution varies from continent to continent, from 1.5' by 1.5' at best (for Australia) to 10' by 10' for most other continents. Further details on existing topographic data archiving efforts are discussed in the Chapter on IGBP-DIS (Chapter 9).

Aquatic system topology

An accurate description of the physiography of river drainage basins and lakes, such as length, width, slope gradients, floodplains, geomorphology of the bottom and meandering, is important for global change studies at the local to continental scales. Rivers, such as the Amazon or the Mississippi, that have a very gentle gradient, may be altered significantly by, for example, sea-level rise. The physiography of a river will determine certain characteristics of the riverine vegetation (LOICZ, Chapter 4.1).

The present state-of-the-art in river network topology documentation for South America is characterized by manually determined data (Vörösmarty et al. 1989) from a series of 1:1 M Operational Navigation Charts. For some countries more detail exists, for instance, for the UK at the Institute of Hydrology, with the 1:250,000 scale digitized river pattern already supplemented with a 1:50,000 scale set for most of the country.

Slope and aspect

Slope and aspect are important for runoff and for computing radiation input, snowmelt and evapotranspiration. A high resolution (100 m or less) digital elevation grid is required to generate realistic values of slope and aspect. For many regions of the world, such resolution is unattainable continentally in the foreseeable future, unless there are new developments in remote-sensing radar and major international survey programmes. The distribution of different slopes and aspects within a grid must therefore be generated statistically.

In view of this, a global topographic data base that includes local base-level information and river network topology should be developed. A standard global data set being developed under the World Digital Database for Environmental Sciences (WDDES) is of great importance for BAHC (Bickmore 1988).

Attributes of the subsurface systems

Subsurface water movement is governed by fundamental properties such as porosity, permeability, transmissivity, strata-depth and structure. These properties vary non-systematically between subsurface strata. Data on these properties are available at local scales in some continents but not on continental to global scales. Only some fundamental hydrological properties (e.g., porosity, transmissivity, erodibility) can be estimated from sources such as geological and soil maps, but a substantial part of the regolith remains undescribed because it falls outside traditional classifications of the subsurface. From the biospheric standpoint, the following classification of subsurface regions is of importance: (i) groundwater recharge areas, where the groundwater recharge rate is controlled by vegetation and soil, but the groundwater does not exert control on vegetation if it is too deep to be accessible to the vegetation; (ii) groundwater discharge areas, where vegetation controls the groundwater table via transpiration and, in turn, the water table controls vegetation in a closed loop (for example, in arid zones, groundwater discharge areas can be located by presence of vegetation); and (iii) wetlands, where probably the most complex interactions of groundwater with vegetation exist. Unfortunately, this information cannot be derived from simple landscape attributes, as it is also influenced by the subsurface properties.

The source data of the soil at global scales are maps at 1:5 million (FAO-UNESCO World Soil Map), a scale vastly inferior to that at which topographic data are available. A global terrain and soils data base is currently being developed by ISRIC (SOTER) at a scale of 1:1 million. Delineating groundwater basins is a difficult task. Hydrogeological maps and groundwater observation series with sufficient detail are not available for a number of regions. Information on the storage capacity and the time (storage) constants can be obtained from long-term analyses of historical hydrographs, using conceptual hydrological models combined with water-balance calculations.

For a hydrological model, the horizontal stratification of the component of the hydrological system below surface must be based on functional properties. The need for a total regolith survey is critical and is without active leadership from an appropriate international organization. The UNEP GRID system, or a similar organization, should be encouraged to initiate such a study.

Field Experiments

Recently land-surface experiments to provide data at proper spatial and temporal scales for validating soil-vegetation-atmosphere transfer (SVAT) schemes have been proposed for: (i) implementation within atmospheric general circulation and climate models; and (ii) interpretation of land-surface characteristics derived from space-based radiation measurements (WMO/ICSU 1990).

The concept of Hydrologic-Atmospheric Pilot Experiments (HAPEX) was introduced by the WCRP to provide the basis for improving and validating the parameterization of land-surface processes in climate models (André et al. 1987), where both atmospheric water demand and the moisture availability are simultaneously measured over at least one year, with intensive study periods of a few months. The representative regimes proposed for this purpose were: (i) temperate climate conditions with variable vegetative and agricultural cover; (ii) semi-arid zone with rapid soil water depletion following rainy periods; (iii) high-latitude forest with an extensive period of snow cover; and (iv) tropical rain forest. The major land-surface field experiments either undertaken during the recent decade or planned for the future are summarized in Table 1 and a schematic representation of some of the field measurements obtained during one field experiment (FIFE) is shown in Figure 2.

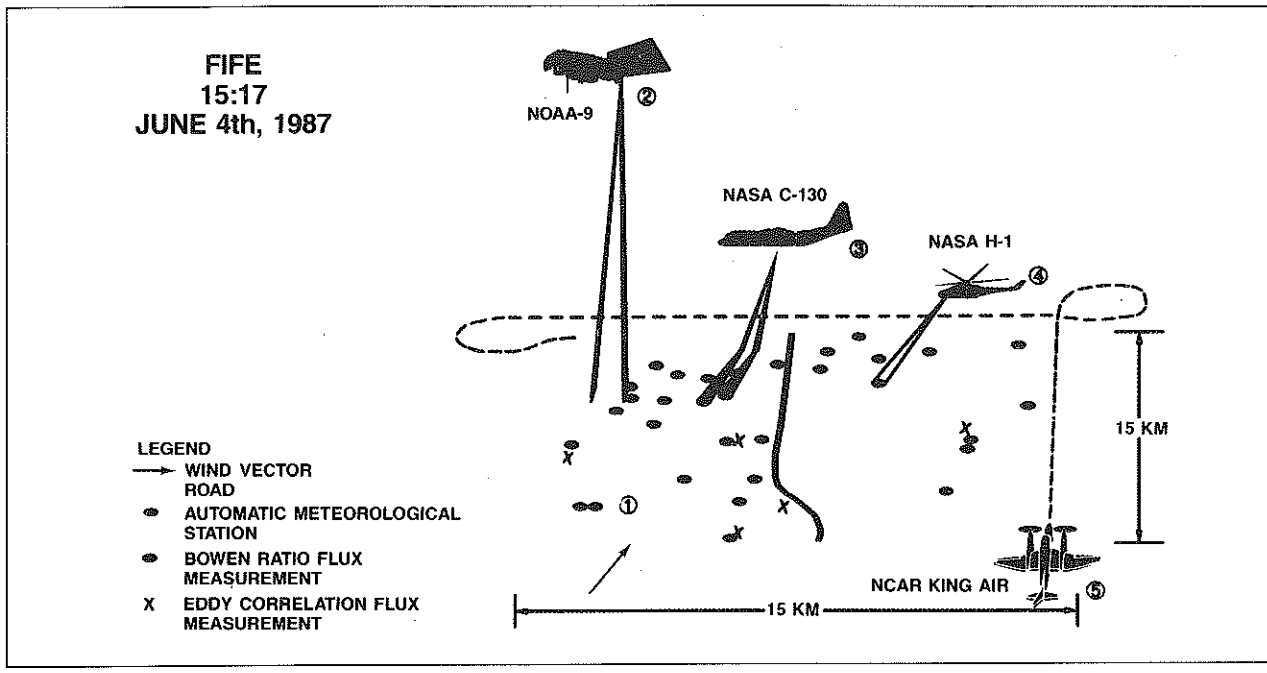


Figure 2. A schematic representation of some of the measurements at the FIFE site. Flux aircraft overfly the 15-km square site, and the NASA C-130 and the NASA helicopter obtain high spatial resolution remote-sensing measurements while one of the current operational remote-sensing satellites images the area. Airborne sensors duplicate the off-nadir geometry of the satellite imaging system as appropriate. Ground-based sensors also duplicate the viewing geometry, and upwards of 25 flux measurement stations are operating at the same time (NASA, 1988).

Spatial Scale of Experiment	Name of Experiment	Study Area	Period	Host Organization Sponsors, Advocates	Status
1 - 10 km²	Joint European Experiment	La Crau (France), Greenland Ibecetere (Niger)	1987-1988	CEC	C
	ABRACOS	Brazilian Amazonas	1990-1994	IH (UK) and INPE (Brazil)	P
100 km²	FIFE	USA Konza Prairie Long Term Ecological Research (LTER), site near Manhattan, Kansas 15 km X 15 km	1987-1989	USA Agencies, UK, Canada	C
	KUREX 88	USSR, Kursk, semi-arid, forest-steppe zone	1988-1989 Repetition	USSR Academy of Sciences	O
	HEIFE	PRC, Heihe River Basin, West China, arid, semi-arid fringe between a major desert and a vegetational area	1990-1994	PRC, Japan	O
	HIBE	Hildesheimer Börde, FRG	1988-1989	FRG	C
	EFEDA	Castillo-La Mancha, Central Spain, semi-arid desertification threatened steppe, marginal land use	1991	CEC, Spain	P
	SIFE, 20 km X 20 km	USA/Canada, Boreal forest Expmt.	1994	US, Canada	P
10,000 km²	HAPEX-MOBILHY	SW France, humid forest and agriculture	1985-1986	France, USA, UK	P
	VALDAI	USSR, experimental area of the State Hydrological Institute	1992-1995	USSR	
	HAPEX-SAHEL	Niger-Sahel, desertification threatened semiarid savanna	1992-1994	France, CEC, UK, USA	
	EFEDA-HAPEX	Castillo-La Mancha, Central Spain, semi-arid desertification threatened steppe, marginal land use	1991-1994	CEC, Spain	P
	Boreal Forest	USA, Canada, including 2 x SIFE	1995	USA, Canada	X
	Tropical Rain Forest	Brazil, Amazon Basin	1993-on	UK, Brazil, others ?	X
	Tundra/Taiga	USSR, Siberia	1995-on	USSR, IIASA	X
Continental Scale	AMAHSE	Brasilian Amazonas Basin	1992- ?	ISY, INPE, NASA, ESA	P
C=completed; P=planned; O=on-going; X=high priority for future research					

Table 1. A summary of major land-surface field experiments.

The first generation of experiments such as HAPEX I, FIFE, etc., (WMO/ICSU 1990) were targeted to improve the representation and accuracy of parameterization schemes implemented within climate models for some biomes and geographical/climatological conditions, and to develop methods to infer key parameters for the calculation of fluxes from satellite data.

These goals are complementary in that they allow a means of observing and modelling the Earth system at mutually consistent scales. Future experiments are needed to continue this work within different biomes of the world, so as to construct a comprehensive data set for use within global climate models and satellite data sets. Such experiments are being developed under the guidance of the Joint IGBP/WCRP Working Group on Land Surface Experiments (WMO/ICSU 1990). Specifically, the next generation of land-surface field experiments must be targeted to at least the following two specific issues of great importance as regards the response of the biota to global changes: (i) the impact of continued large-scale tropical deforestation on regional and global climate; and (ii) the links between surface hydrological and biophysical processes and drought in the semi-arid lands and desert margins.

In this regard, the following specific recommendations made by the Joint IGBP/WCRP Working Group on Land Surface Experiments (WMO/ICSU 1990) are pertinent:

(i) Future land-surface experiments should maintain long-term monitoring over several years of selected sub-areas nested within experiment sites, including biogeochemical measurements as well as further calibration data for remote-sensing in different biomes.

(ii) Series of land-surface experiments should be implemented for critical biomes and biome interfaces, as a matter of urgency, preferably before 1997. This recommendation is based on the increasing pace of human intervention in natural ecosystems and the need to provide calibration data for new remote-sensing instruments prior to the development of the polar-orbiting platforms.

(iii) Among the priority issues to be addressed should be desertification and tropical deforestation. Multidisciplinary experiments are already planned to address desertification-threatened areas in Niger and Spain. It is recommended that similar experiments be implemented in the tropical rain-forest regime in the near future.

The prioritized set of field experiments required to address these issues as recommended by the Joint IGBP/WCRP Working Group are summarized in Table 2.

Table 2. Recommended schedule for future land surface experiments (Source: WMO/ICSU 1990). For explanation of acronyms, see Appendix 7.

.... : monitoring effort
—— : small-scale (single site) experiment
++++ :large-scale (multiple site) experiment

Year	1991	1992	1993	1994	1995	1996
Experiment						
EFEDA	——	....	....	++++	....	....
HAPEX-Sahel	++++	....	....	....		....
SIFE			——	++++	....	....
Tropical Forest	....	....	——	....	....	++++

Modelling

The energy and water-exchange mechanisms between the surface and the atmosphere involving vegetation and land surface are extremely complex, essentially because they are highly non-linear processes. Developing models of such processes is an urgent but difficult task. A significant problem in the reliable coupling of land-surface models to atmospheric models is the difference in temporal and spatial scales, which characterize the two components of the coupled system. While the atmospheric part typically has a characteristic length scale of the order of 100 km, the biological part has to represent processes that go down to much finer scale. The scaling-up problem is a major modelling issue for the IGBP core projects involving land-surface processes (i.e., BAHC and GCTE). Typically, the scaling problem is resolved through use of soil-vegetation-atmosphere (SVAT) models. A conceptual depiction of scales of surface and atmospheric models as well as a schematic diagram of the hierarchy of models from patch-to-mesoscales to be developed under BAHC are shown in Figures 3 and 4, respectively.

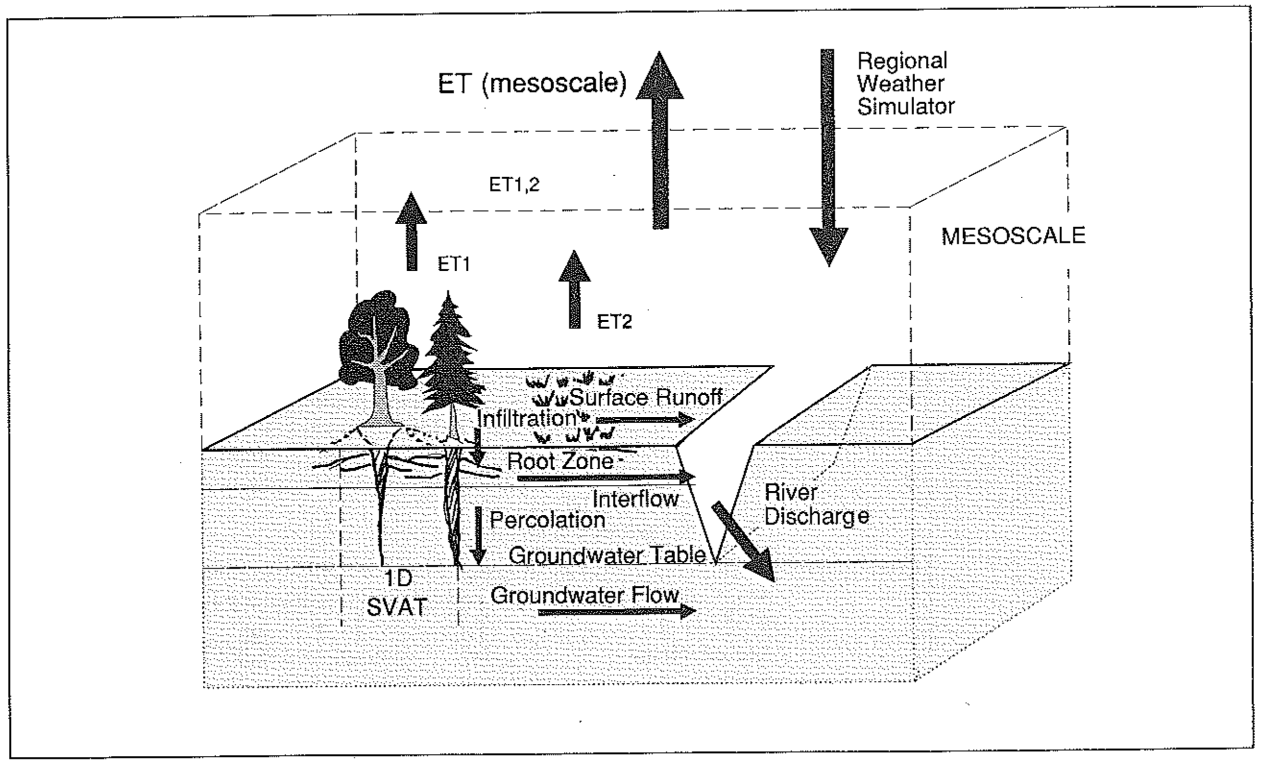


Figure 3. Scales of surface and atmospheric models (IGBP 1990).

The recent decade has seen a significant advance in the formulation of SVAT models for use in GCMs. Some of the more advanced models are the Biosphere-Atmosphere Transfer Scheme (BATS: Dickinson 1986) and the Simple Biosphere scheme (SiB: Sellers et al. 1986). These numerical schemes vary widely in their complexity and realism and require calibration. All SVAT models attempt to improve vegetation-dependent description of the energy, water and momentum interaction over land surfaces. The number of land-cover types considered is typically limited to between 10 and 20. Some models assume uniform coverage of a single vegetation type in distinct regions (biomes), while others allow fractional cover selected from the land-cover subset and seek to define average parameters at each grid point for the assigned vegetation mix.

The minimum requirement all SVAT models attempt to meet is to introduce land-cover dependency into key parameters such as albedo, aerodynamic roughness, the 'surface resistance' exerted by vegetation on transpiration in dry conditions, the amount of rain or snow held in an interception storage following precipitation, and the size of the accessible moisture store in the rooting zone. The latter parameter is influenced not only by rooting depth, but also by infiltration rate and deep drainage. The range of complexity for models meeting these requirements is currently very large, and model sensitivity studies to define the minimum complexity required are a high priority.

All the biosphere models currently used in GCMs are, in essence, one-dimensional SVAT models, as that is the format most compatible with the GCM,

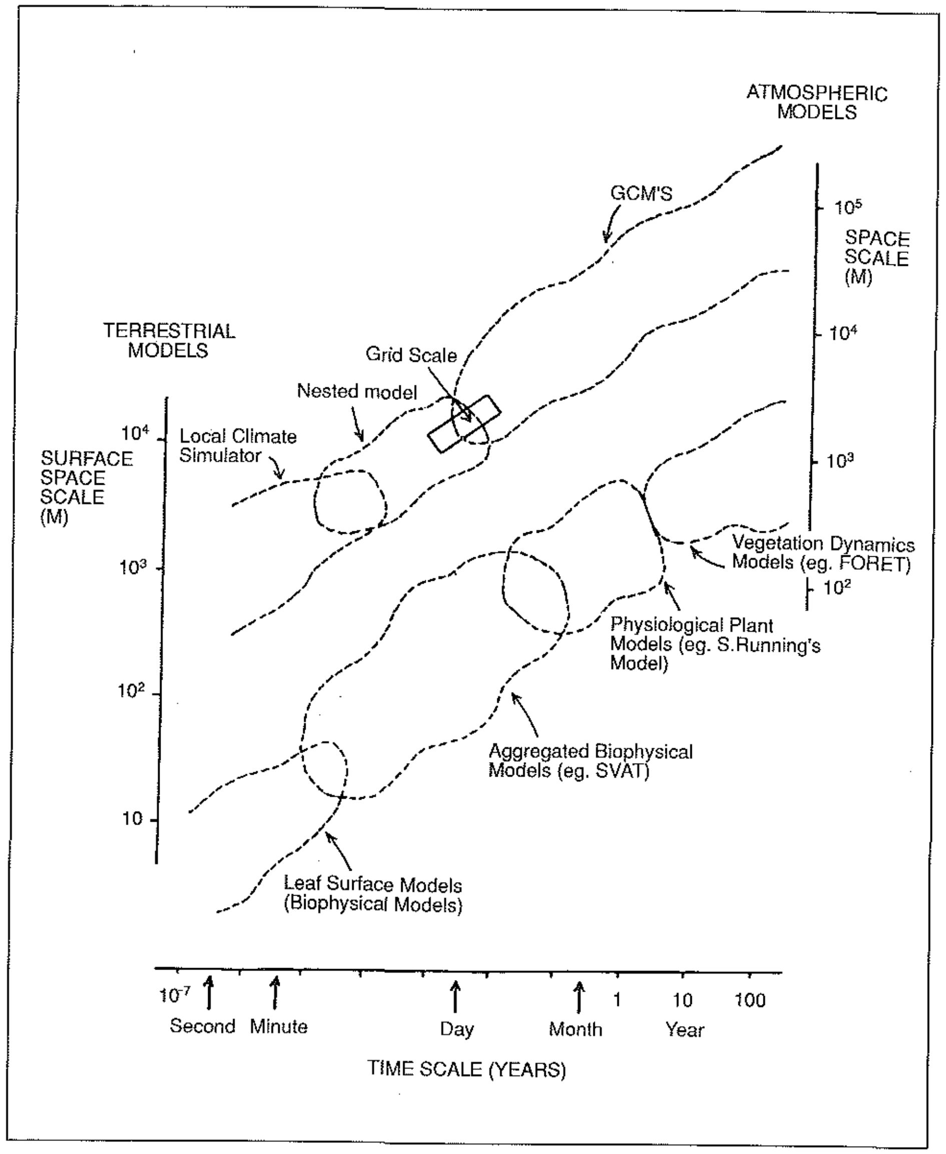


Figure 4. A schematic diagram of the hierarchy of models from patch-to-mesoscales to be developed under BAHC.

and retains the correct asymptotic limit as grid-mesh size decreases. But, for larger areas of GCM grid cell size, this means that the parameters used in the one-dimensional model loose their local physical and physiological significance. One possible solution to this problem is that the effective values of the parameters may be a non-linear combination between locally relevant values and the statistics involved in surface cover and mesoscale meteorological processes, particularly rainfall. Analytic and digital modelling, involving coupled hydro-meteorological-biospheric models operating at mesoscale and microscale, is required to discriminate between hypothetical aggregation schemes for scaling-up the effective values of the parameters for SVATs.

One of the main shortcomings of SVAT models in current use in GCMs is that they are static, that is, they assume a particular vegetation structure for a grid point. It is reasonable to expect that as climate or land-use changes affect ecosystem structure, at least some of the parameters will change as well. However, the current models do not have a dynamically changing structure as they do not incorporate rules for changing canopy structure (see GCTE, Chapter 6.1). Direct or indirect measurements by satellite-based sensors fed into models of land surface, containing both direct and feedback processes, is the only feasible means of coping with diverse land-use types. Joint effort of BAHC and GCTE will be necessary to resolve the issues related to coupling the dynamics of changing ecosystem structure and fluxes of energy and water from the land surface.

Ongoing research of the type currently being carried out under ISLSCP and proposed for the Earth Observation System (EOS) is required to facilitate this.

Another essential requirement for biospheric and ecological studies related to global change is the GCM-based simulation of precipitation in terms of frequency and intensity of events, typical rainfall-event totals, and distribution patterns. The crude representation of the essential physics due to necessities of parameterization for large spatial scales and our lack of full understanding of the processes make it difficult, if not impossible, to provide such information for the present day climate simulations. Clearly, close collaboration between the IGBP core projects dealing with land-surface processes (BAHC and GCTE) and the WCRP's GEWEX project is needed to fulfil this requirement.

Further discussion of IGBP-related land-surface modelling needs and recommendations for global change studies is given in the IGBP Report No. 10 (IGBP 1990)

Science Components

The non-linearities of the biospheric interactions with the hydrological cycle and the specific needs of numerical modelling and predictions require the integration of state variables from point and patch scales, where data are collected, up to model grid sizes (the scaling problem). Interacting processes and ecosystem attributes at a wide range of spatial and temporal scales need to be understood and modelled. Most of the biological processes related to hydrology respond slowly to changes in the environment. Changes in structure and function occur at time scales of weeks to decades. In contrast, the atmosphere has a much faster response time, with dynamic processes spanning from seconds to years. Considering that the time-scale of processes to be studied covers a broad range in both components of the system, with an intrinsic phase lag between the responses, the recommended core activities are divided into categories selected according to an appropriate space scale.

Objective

- *How do plant communities and ecosystems in combination with the topographic structure of the land surface affect the cycle of water on Earth.*

Two sub-objectives are:

- *To determine the biospheric controls of the hydrologic cycle through field measurements for the purpose of developing models of the energy and water fluxes in the soil-vegetation-atmosphere system at temporal and spatial scales ranging from vegetation patches to GCM grid cells;*
- *To develop and implement a long-term commitment to observations designed to test the results of global change modelling of the interactions between the biosphere and the physical Earth system in relation to the hydrological cycle.*

Specific core activities to achieve the goals of the core project are described below. These follow the spatial-scale categories defined in Table 3.

There is a need for development within WCRP of a "climate simulator/weather generator" that provides information on precipitation in terms of frequency and intensity of events, typical rainfall event totals and distribution pattern. Within the IGBP (BAHC and GCTE) and in close cooperation with WCRP's GEWEX project, the need to develop soil vegetation-atmosphere transfer models from patch to large river basin and continental scales is emphasized. To achieve these goals, the Core Project has to improve the knowledge of the soil-plant-atmosphere processes through field studies from site to GCM grid-size scales. The project has to develop a data baseline which includes long time series of hydroclimatological variables, in situ and remote-sensed data sets of special field experiments (FIFE, HAPEX-MOBILHY) and surface-attribute data, such as vegetation cover, soil and landscape type.

Considering the large diversity of temporal and spatial scales involved, the core activities are arranged in hierarchical spatial setting to highlight the following different conditions: (i) on the local patch scale of SVATs for single vegetation patches, vegetation, soil, geology and topography are considered to be homogeneous in the study area; (ii) on the scale of a really integrated SVATs or small catchment and landscape scale, vegetation and soil are "patchy" but topography is uniform; (iii) on the mesoscale or river basin and regional scale, vegetation and soil are "patchy", the topography and microclimate are non-uniform.

The field experiments for this purpose should be nested, i.e., patch-scale experiments should be integrated into SVAT experiments, which then serve as components of larger GCM grid size (mesoscale) as well as continental and global scale studies.

Table 3. Integrative process studies from patch to global scales

Scale km²	Modelling	Field Experiments	Research Thrusts
1 x 1 Local/Patch	1D SVAT Models for homogeneous units (patch), including vertical water movement in the soil; sub-basin scale	Single or few parameter studies, ISLSCP type, e.g., La Crau, France	Validation and calibration of single parameter satellite data (albedo, temperature, NDVI)
10 x 10 Area Integrated SVAT	Integrated SVAT model arrays in non-homogeneous areas (landscape) including hydrological models of small drainage systems	Complex experiments at pixel array scale, ISLSCP type, e.g., FIFE	Validation of algorithms to derive complex parameters from satellite data (fluxes)
100 x 100 Meso-scale	Mesoscale models for complex terrains, including soil hydrology models with lateral exchanges and ecosystems models	HAPEX and ISLSCP type experiments, e.g., HAPEX MOBILHY	Algorithm validation at grid scale by intercomparison with experimental results; application to ecosystem interactions
Continental	Coupled 3D Hydrological, Ecosystem and General Circulation Models		Production of global data sets on decadal time scales
Global	Coupling of Atmosphere, Ocean and Complex Land Surface Models (including Biosphere and Continental Hydrology Models)		Interactive global data analysis and 4D Assimilation Models of Global

Activity 1

Local (Patch) Scale Process Studies and Development of SVAT Models

Objective

- *To explain and model the partitioning of evapotranspiration into plant and non-plant processes in key vegetation types and its role in the energy and moisture exchange at the land surface, particularly the significance of canopy structure for exchange processes with the atmosphere.*

The typical scale of these studies is 1 x 1 km; this is the size of ISLSCP scale 1a and of the pixel size for certain satellite data (e.g., AVHRR). It can also be determined by the height-to-fetch requirements for measuring certain atmospheric variables, i.e., at a ratio 1:100, measurements at a height of 10 m require a horizontal fetch of 1 km. The physical and biospheric aspects of the main processes necessary for construction of SVAT models are discussed above. This scale is also of relevance to GCTE (see Chapter 6.1).

During its initial phase 1990-1997, the Core Project will develop, test and validate SVAT models using data collected in the patch-scale field experiments. At this scale, numerous plot experiments, mainly agricultural fields, are conducted by various research institutions around the world. It is necessary that such plot experiments are fully interpreted, their outcomes be made available to the scientific community and that as much as possible, they be nested in larger field studies recommended by the Joint IGBP/WCRP Working Group on Land Surface Experiments (WMO, 1990). In order to obtain maximum benefit from these experiments, a unified methodology for field experiments has been recommended (WMO, 1990). The status of such field experiments, over different functional vegetation types is summarized in Tables 1 and 2. In such experiments, the specific biospheric aspects that must be measured or evaluated are: (i) partitioning of net radiation into latent and sensible heat fluxes and precipitation into interception and throughfall; (ii) canopy and litter water-holding capacities (storages) and evaporation of intercepted precipitation; (iii) plant control of evapotranspiration: its dependence upon leaf-area index and phenology, state of the root system, water supply and meteorological variables; (iv) surface, canopy and aerodynamic resistances to evapotranspiration; resistance of water paths through vegetation; and (v) overall water-holding capacity of soils, infiltration, percolation below the root zone and upward capillary movement. In addition, effects of climate change on plant response, especially on stomatal behaviour; changes in photosynthetically active radiation (PAR), photon flux density, leaf temperature, water vapour saturation deficit of the air, CO_2 concentration and water supply should also be determined.

At this spatial scale, modelling activity essentially consists of developing soil-vegetation-atmosphere transfer schemes ranging from simple algorithms to parameterized functional relations. The specific tasks in this regard are: (i) intercomparison of appropriate SVAT models with respect to the corresponding model of higher generality by means of numerical simulation experiments; (ii) development of appropriate SVAT models to fit available data sets of small-scale experiments such as listed in Table 1; and (iii) sensitivity tests of SVAT models with respect to water stress and inhomogeneities in vegetation cover nutrient supply and against CO_2 fertilization effects, with special emphasis on a corresponding shift in water-use efficiency (see also Chapter 6.1).

For natural vegetation, the following important modelling hypotheses with respect to the auto-regulation of vegetation density, structure, and diversity should be investigated.

- A water-limited vegetation functional-type controls the canopy density in a way that controls the moisture stress at the roots to physiologically tolerable limits with respect to the local climate and soil conditions.
- An energy-limited vegetation functional-type would maximize leaf area and/or photosynthetic efficiency. The response would be affected by nutrient availability.

Areal Integrated SVAT Studies

Activity 2

Objective

- *To quantify and model areal evapotranspiration (ET) over heterogeneously vegetated andtopographically uniform areas, e.g., small catchments with mixes of two or more vegetation classes that can be integrated in a manner analogous to that in Activity 1.*

The atmospheric variables that force ET, such as net radiation, water vapour saturation deficit of the air, and wind speed, are spatially integrated results of the direct and feedback interactions between the atmosphere and the underlying heterogeneous surface.

To accomplish the main goal at this scale, point or site measurements have to be translated into areally integrated properties and the simple mechanistic SVAT models reparameterized and simplified to produce more aggregate and complex, but still one-dimensional models. For example, mixing ratios appropriate to heterogeneous vegetation types may be used as parameters to describe the state of overall vegetation in the whole space as basis for an areally integrated SVAT model.

There are two main approaches to the scaling-up procedure. One is the statistical treatment of the heterogeneities that formulates the probability density functions of measurements and surface attributes made at different sampling points within the scale. Another approach is to use remote sensing, aircraft and spaceborne, since the pixel is already an integrating entity in itself. Care must be taken, because averaged spectral radiances are different for sensors with different aperture angle and spatial resolution. Thus, the averaging procedures have to be standardized to give comparable results. These techniques are described in more detail by Becker et al. (1988). The scale selected for these studies is in the order of 10 x 10 km. This corresponds to the ISLSCP scale 1b, and is useful for representing averages of several pixels for most existing satellite sensors. Whenever possible, it is recommended that a small watershed be used, because this allows the closure of the water balance, and thus the cross-checking of the areal ET resulting from the energy and water balance schemes. The specific tasks at this scale are: (i) development of formulae that can represent average stomatal resistance and average surface resistance for areal combination of functional plant types; (ii) studies of the effects of spatial variability of litter production on interception of throughfall, infiltration and other soil-water relations; (iii) studies of the effects of spatial variability of soil hydraulic properties and of changes in root density profile and effect on evapotranspiration; (iv) development of estimates of areal precipitation interception as a function of remotely-sensed vegetation indices; (v) development of relationship of canopy surface conductance to remotely-sensed vegetation indices; and (vi) monitoring of the seasonal and interannual changes that occur in vegetation cover, using remotely-sensed vegetation indices.

For the period 1990-1997, the BAHC activities will focus on the field experiments shown in Table 2, with special emphasis on those vegetation types which have not yet been studied, i.e., tropical forests, boreal forest and tundra/taiga. Following the recommendation of the IGBP/WCRP Working Group on Land Surface Experiments, an IGBP field project in Amazonia should be given high priority.

Activity 3

Mesoscale Studies

Objective

- *To develop relationships of vegetation-atmosphere interactions from smaller scales to GCM scales via field studies and development of an advanced atmospheric mesoscale model.*

Previous research under various programmes has shown that such mesoscale atmospheric and hydrological models are powerful tools to achieve the required spatial integration of land-surface processes. For this purpose, field studies and modelling of the role of the heterogeneities of land-surface attributes and their influence on the hydrological mesoscale processes, with associated feedbacks, have to be carried out. The land-surface attributes are taken from existing information and statistical summaries of satellite-based data. The typical scale for these studies is 100 x 100 km, i.e., the size of WCRP's HAPEX studies and current typical climate model resolution. The important characteristics of this scale are horizontal transport and flux divergence of water and heat. The unit study area should be a hydrological basin whose surface and subsurface basin divides are as close to identical as possible so that full accounting of the water budget can be assured. At this scale, the lower atmosphere is modulated both by large and mesoscale atmospheric dynamic forcings and by surface aerodynamic roughness and topography.

During the period 1990-1997, BAHC activities should include field experiments of the HAPEX type, especially for the Amazon Basin. These field experiments should be used for the comparison of different approaches to large-scale ET modelling (e.g., resistance models, complementary relationship ET model, coupling satellite data with ecosystem simulation), and the development of a coupled vegetation-atmosphere mesoscale boundary-layer model. This model should be used as a "translator" for the continental-scale hydrological model. The requirement that the unit study area be a hydrological basin should be stressed. Land-surface attribute data necessary to perform these tasks will require remote sensing, by both aircraft and satellite. For details, see WMO (1990)

Activity 4

Continental-Scale Studies

Objective

- *In cooperation with GEWEX, to improve upon the inadequate representation of land surface hydrology and mesoscale atmospheric phenomena (weaknesses in present GCMs), mainly by improvements in the treatment of topographic representation evapotranspiration, and to distinguish between the natural and man-induced changes in the hydrological cycle for selected continental basins.*

Initial priority must be to participate in the GEWEX Continental Scale Project on the Mississippi River Basin. However, in view of the convergent interest of several IGBP Core Projects (IGAC, LOICZ, BAHC and GCTE) in the coupling between hydrology, vegetative cover and biogeochemical cycles in the Amazon River Basin and its influences on the global earth System, BAHC should endeavour to develop a long-term strategy for studying the biospheric aspects of the hydrological cycle over Amazonia. Thus, BAHC activities at the continental scale should develop in not only concert with the GEWEX continental study of the Mississippi River Basin, but in addition, a study of the Amazon Basin should be initiated in collaboration with other IGBP projects (LOICZ, GCTE), engaging appropriate IGBP Regional Research Centres.

In this regard, an essential requirement is the development of vegetation-atmosphere process models for inclusion in global or continental-scale climate models. For this activity, a high resolution coupled vegetation-atmosphere model is necessary. A fine mesh of 0.5^0 x 0.5^0 (55 x 55 km at the equator) grid size, or even smaller, should be nested into an existing GCM. In addition, SVAT models for different functional vegetation types of the basin should be used as "translators" of surface variables and attributes. While current land-surface parameterization in GCM models can crudely resolve changes that occur in the regional climate and hydrological cycle due to modifications in surface properties, ecosystem dynamics models are required which represent vegetation behaviour in response to climate changes (see Chapter 6.1).

Critical data for this effort will be produced by the IGBP-DIS. Specifically, the land cover study initiated by IGBP-DIS (see Chapter 9) will provide monthly mean, or more frequent, global maps of LAI and other vegetation parameters based on remote sensing products and complementary *in situ* information.

Core Project Implementation

An IGBP Scientific Steering Committee (SSC) on Biospheric Aspects of the Hydrological Cycle (BAHC) will be established during 1990. In addition, establishment of an IGBP-BAHC Core Project Office (CPO) is planned for the later part of 1990. Under the supervision of the Chairperson of the BAHC Scientific Steering Committee, the CPO will serve as the central office for coordination, communication, etc., between the core project activities, interested research institutions and groups. Ongoing tasks of the CPO will include developing implementation plans for core activities under the direction of the BAHC-SSC, holding necessary meetings, workshops, etc., maintaining an information bulletin on the project activities and research results, data, etc.

An offer to host the IGBP-BAHC CPO at the Freie Universität Berlin under the joint sponsorship of the Federal Republic of Germany and the German Democratic Republic is currently being finalized.

In the implementation of BAHC, close cooperation with the WCRP's GEWEX project is a must. Additionally, it should be noted that the International Association of Hydrological Sciences (IAHS) has set up three Working Groups in support of BAHC activities. Thus, close cooperation with IAHS should also be maintained. Activities within IHP (Unesco) and WCP-Water (WMO) are also relevant to BAHC.

During the period 1991-1997, the following Core Activities discussed above will be carried out in cooperation with the WCRP/GEWEX project:

- observational studies and field experiments in the priority regions as recommended by the Joint IGBP/WCRP Working Group on Land Surface Experiments to better understand the direct and feedback processes within the soil-vegetation-atmosphere system in relation to the hydrological cycle;
- validation and calibration of existing SVAT models, with available data sets (FIFE, HAPEX, Amazonas) and in close cooperation with the IHP of Unesco, WCRP/GEWEX, IAHS activities and various national groups;
- development of simple and areally integrated SVAT models for different plant functional types;
- development of a coupled SVAT model for studying the hydrological cycle of large river basins as a first step toward a global hydrological model;
- development and practical investigation of algorithms to solve the scaling problems;
- participation in the construction of a complete hydroclimatological data base, and GIS for surface and subsurface attributes, including remote-sensing data.

Around 1998, new orbiting sensors will be launched and provide better data of the land-surface characteristics and measurements of the atmosphere variables. New generation computers and climate models with higher resolution, improved data assimilation schemes, biogeophysical and hydrological processes and boundary conditions, will permit the testing of more complicated hypotheses relating to future climate scenarios.

In order to develop detailed research implementation plans and coordinate the research effort discussed above, the following meetings and workshops are proposed for the 1990-1994 time frame:

(i) an Open Meeting of scientists from the IGBP National Committees, ICSU bodies, and other international organizations to agree on the detailed science plan and to develop an outline of the implementation strategy (early 1991);
(ii) a focused topical workshop for each core activity organized and run by the core activity leaders (i.e., three workshops during 1991-1993);
(iii) a workshop on intercomparison of modelling results from the various scales (1994).

References

André, J.-C., Goutorbe, J.-P., Perrier, A. et al. 1987. Evaporation over land-surfaces: First results from HAPEX-MOBILHY special observing period. Annales Geophysicae 6:477-492.

Becker, F., Bolle, H. J. and Rowntree, P. R. 1988. The International Satellite Land-Surface Climatology Project. ISLSCP Report No. 10. UNEP-ISLSCP Secretariat, Berlin.

Bickmore, D. P. 1988. World Digital Database for Environment Sciences (WDDES). In: Mounsly, H. and Tomlinson, R. F. (eds). Building Databases for Global Sciences. Taylor and Francis, London.

Bruenig, E. 1987. The forest ecosystem: tropical and boreal. Ambio XIV(2-3):68.79.

Dickinson, R. E., Henderson-Sellers, A., Kennedy, P. J. and Wilson, M. F. 1986. Biosphere-Atmosphere Transfer Scheme (BATS) for the NCAR Community Climate Model. NCAR Technical Note 275+STR. National Centre for Atmospheric Research, Boulder, CO. 69 pp.

IGBP 1990. Land-atmosphere interface. Report on a combined modelling workshop of IGBP Coordinating Panels 3, 4, and 5, Brussels, Belgium, June 8-11, 1989. Turner, S. J. and Walker, B. H. (eds) IGBP, Stockholm. (IGBP Report No. 10).

Matthews, E. 1983. Global vegetation and land-use: New high resolution data bases for climate studies. J. Clim. Appl. Meteor. 22:474-487.

Matthews, E. 1984. Prescription of land-surface boundary conditions in GISS GCM II and vegetation, land-use and seasonal albedo data sets: documentation of archived data tape. NASA Technical Memos 86046 and 86107. NASA, Goddard Institute for Space Studies, New York, NY.

NASA 1988. NASA Earth Science and Applications Division - Program Plans for 1988-89-90. NASA, Washington, DC. 133 pp.

Sellers, P. J., Mintz, Y., Sud, Y. C. and Dalcher, A. 1986. A Simple Biosphere Model (SiB) for use within general circulation models. J. Atm. Sciences 43(6):505-531.

Vörösmarty, C. J., Moore III, B., Grace, A. L. and Gildea, M. P. 1989. Continental-scale models of water balance and fluvial transport: An application to South America. Global Biogeochemical Cycles, 3(3):241-265.

Wilson, M. F. and Henderson-Sellers, A. 1985. A global archive of land cover and soils data for use in general circulation climate models. J. Climatology 5:119-143.

WMO/ICSU. 1989a. The Global Water Runoff Data Project. WCRP 22, WMO/TD No. 302. WMO/ICSU 1989b. Global Energy and Water Cycle Experiment (GEWEX). Report of the First Session of the JSC Scientific Steering Group for GEWEX. WCRP 25, WMO/TD No. 321.

WMO/ICSU. 1990. Report of the first meeting of the Joint IGBP/WCRP Working Group on Land-Surface Processes (in preparation).

Suggested Reading

André, J. C., Bougeault, P. and Goutorbe, J. P. 1990. Regional estimates of heat and evaporation fluxes over non-homogenous terrain. Examples from the HAPEX-MOBILHY programmes.

Dickinson, R. E. 1984. Modelling evapotranspiration for three-dimensional global climate models. In: Climate Processes and Climate Sensitivity. Geophysical Monogr. 29, Maurice Ewing Vol 5:58-72, AGU, Washington DC.

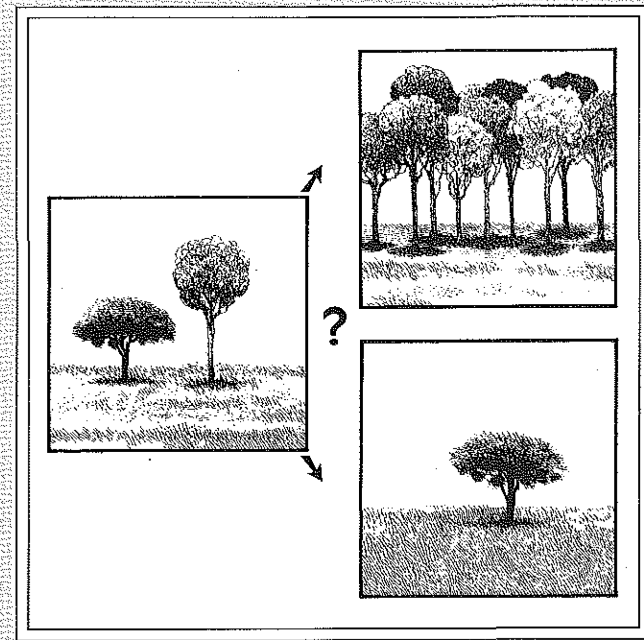
Jarvis, P. G. and McNaughton, K. G. 1986. Stomatal control of transpiration. Scaling up from leaf to region. Adv. Ecol. Res. 15:1-49.

Monteith, J. L. 1988. Does transpiration limit the growth of vegetation or vice-versa? J. Hydrology 100:57-68.

Sellers, P. J. et al. 1989. First ISLSCP field experiment. Experimental execution and preliminary analysis. In: Remote Sensing and Large-Scale Global Processes. IAHS Publ. 186.

Shuttleworth, W. J. 1988. Macrohydrology, the new challenge for process hydrology. J. Hydrology 100:31-56.

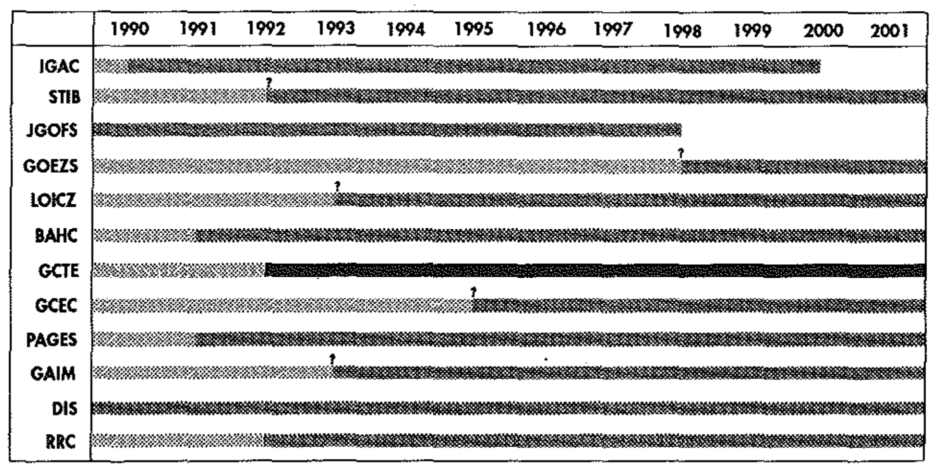
GLOBAL IGBP CHANGE



How Will Global Change Affect Terrestrial Ecosystems?

Climate change and increased nutrient deposition from the atmosphere will affect oils, plant productivity, biogeochemical cycles, vegetation structure, and species composition. Temporal and spatial patterns for temperature, precipitation, and the occurrence of extreme weather events influence not only natural ecosystems, but also impose regional constraints on agriculture and forestry. Major changes in ecosystem extents will have important feedback effects on physical aspects of the climate system through associated changes in roughness and reflectivity of the Earth's surface and altered fluxes of H_2O, CO_2, and trace gases. Global change may also affect ecological complexity with possible important feedbacks to ecosystem functioning.

Contents



1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
IGAC
STIB
JGOFS
GOEZS
LOICZ
BAHC
GCTE
GCEC
PAGES
GAIM
DIS
RRC

6.1 Global Change and Terrestrial Ecosystems (GCTE)

An Established Core Project

Introduction

The Response of Terrestrial Ecosystems to Global Change

The elements of global change included in this project concern changes in climate, atmospheric carbon dioxide and land use. The potential increase in UV-B and its effects on biological processes are not included at this stage. They may develop as part of STIB (Chapter 2.2) in a later phase, following the present SCOPE analysis of the topic. Air pollution effects are also excluded, but they may be taken into account in a later phase of the proposed work on the impacts on agriculture and forestry.

Global climate and land-use changes will have direct effects on terrestrial ecosystems, such as alteration of water-use efficiency by plants, increased carbon (C) storage caused by elevated CO_2, or the net release of soil C caused by elevated temperatures. These direct effects will induce changes in structure and function of ecosystems that are expected to feedback to the atmosphere, soils, and the geosphere. For example, changes in energy partitioning in deforested regions may reduce evapotranspiration, and this in turn may have a positive feedback on the greenhouse effect through reduction of cloudiness.

Developing the means to predict and monitor changes in terrestrial ecosystems is needed to provide the necessary inputs to global models of climate and biogeochemistry. In addition, these investigations will lead to the capability of predicting changes for regional and local situations. The development of a capability to predict responses by terrestrial ecosystems will involve combinations of efforts including synthesis of literature, experiments and observations at a number of scales, and modelling. The goals of this Core Project involve development of a predictive capacity by all useful means. Models are one of the means to that end, and the project is intended to lead to the development of a range of models, using a generic model structure.

Definitions

Throughout this document the term *ecosystem* is used as a general term for any interactive, ecological unit, generally involving a set of functionally different biological entities and a dynamic abiotic component. This term by itself does not connote any specific dimensions. The term *patch* indicates a land unit treated as internally homogeneous for the purpose at hand, and integrated for the ecological property in question.

The term *landscape* indicates a unit of terrain consisting of more than one contiguous patch. The dimensions of patches and landscapes are also non-specific, in general becoming specified by the property addressed. Patches and landscapes, and indeed the world, can all be viewed as ecosystems.

There is a need for a single term to cover the non-demographic, functional attributes of ecosystems; the processes involving exchanges of energy and matter with the atmosphere, nutrient cycling and storage, biomass accumulation, etc. Following much debate about ambiguity in use of the words "function", and "metabolism", the term *ecosystem physiology* was adopted.

Objective

- *To develop the capability to predict the effects of changes in climate, atmospheric CO_2 and land use on terrestrial ecosystems, and how these effects can lead to feedbacks to the physical climate system.*

This capability is required for two reasons. The primary reason is to predict the consequences of global change for ecosystem structure and physiology, since these ecosystem attributes have direct effects on issues important to humans including productivity, future land use, and biotic diversity. The second reason is to estimate the potential feedbacks of the changes on further atmospheric and climate change.

Figure 1 represents the structure of this Core Project in terms of issues of global change, the linkages between activities of this and other Core Projects of IGBP, and the general products of these activities.

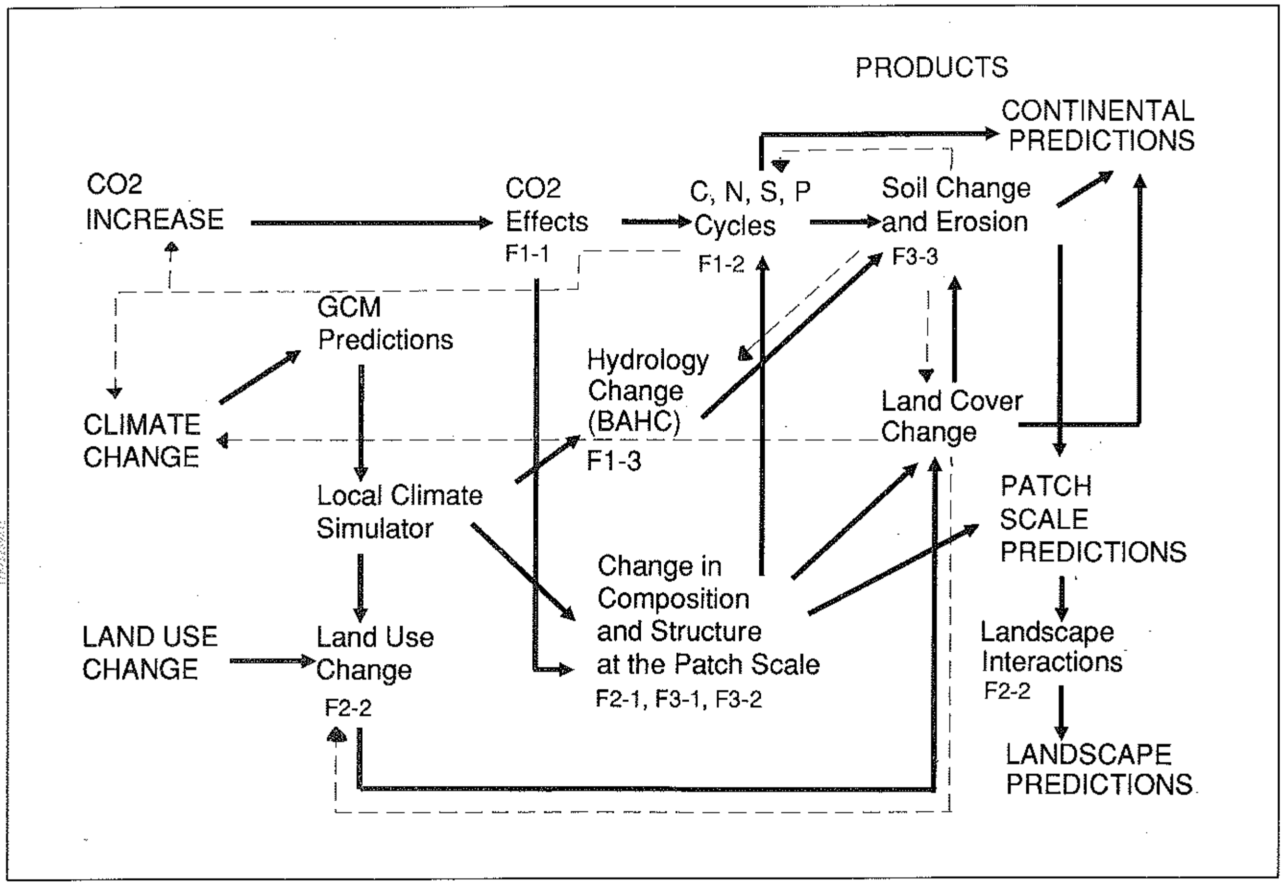


Figure 1. Structure of the Global Change and Terrestrial Ecosystems (GCTE) Core Project in terms of issues, linkages between activities of GCTE and other Core Projects of IGBP, and the general products of these activities.

Science Components

General Design of the Core Project

This project has three main Foci:

(1) The physiology of ecosystems that relates to the ways in which ecosystems exchange energy and materials and the processes through which they change biomass and storage of elements.
(2) The dynamics of ecosystem as a function of changes in the composition, and the physiognomic structure of ecosystems and their spatial distributions.
(3) The impacts on agriculture and forestry concerned with effects on the major crop, forest and livestock species in terms of the yield of harvestable products.

In regard to the first two Foci, the interactions of structure and function are at the heart of understanding how ecosystems will respond to global change (Fig. 2). The interactions are specifically addressed in two of the core activities (Focus 1, Activity 3, Changes in Water and Energy Fluxes and Focus 2, Activity 1, Changes in Biological composition and Ecosystem Structure at the Patch Scale), which link Focus 1 and 2. Thee six activities of Foci 1 and 2 constitute a

progression leading to the capability to predict the distributions, composition and physiology of ecosystems on a regional scale. Focus 3 on agriculture and forestry represents the first phase of what is intended to be developed into a separate Core Project. Additional issues which should be studied include mixed farming systems and socio-economic interactions and controls on managed systems, and a wide variety of disturbance regimes specifically important in agroecosystems. Ultimately, GCTE must make continental scale predictions for several properties, such as albedo, evapotranspiration, carbon storage, etc. This means that some research tasks must be directed toward the continental-scale issues. These include development of necessary geographic data bases for application of smaller scale predictions, and coarse resolution, land cover predictive modelling.

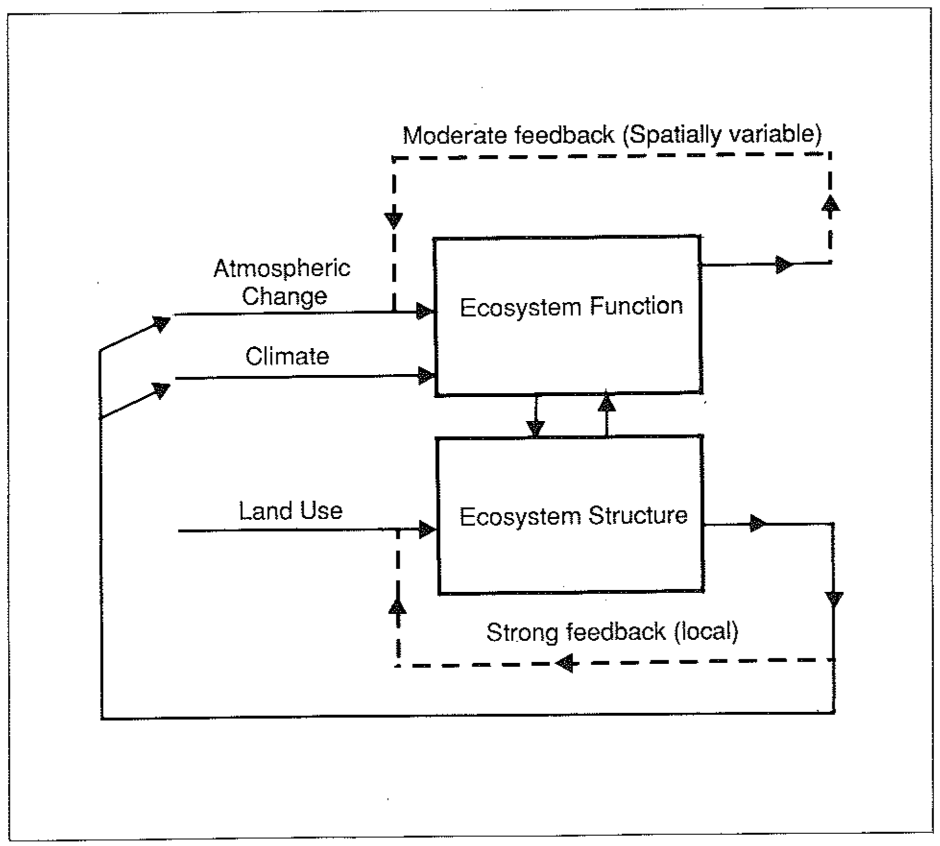


Figure 2. Global change effects of ecosystems, considered in terms of structure and function. Structure includes spatial (vertical structure, horizontal (including patchiness)) and biological diversity (functional types and species). Function includes material fluxes and production processes (IGBP 1990b).

The central problem is developing an understanding of regional and global systems. The general strategy for achieving this is essentially one of stratified sampling (Table 1). The world can be viewed as composed of biomes, the largest class of ecosystem type. These biomes may change character in a changed world, but also, the borders or transitions between these biomes are likely to be highly sensitive to the rates of global change. In particular, the tundra-boreal forest, the temperate grassland-shrubland-forest, the subtropical-tropical woodland-savanna, and the wet tropical-seasonal forest transition zones have been identified as sensitive transition zones of global relevance (IGBP, 1990b). A model-based predictive capacity developed for the range of such sensitive areas over time will be most useful in extrapolation to the continental scale. In addition, studies conducted in sites of representative conditions of a biome-type are also needed.

Four kinds of activities are envisaged (Table 1). One is the execution of field experiments within representative ecosystems and associated transition zones. Another is the development of land-cover change models, themselves entailing

Table 1. Table of area of study, relevant operations and corresponding GCTE activity (Focus number, followed by Activity number)

Scale	Operations	Activity No.
Continental/ Regional	Low resolution data-base development. Low resolution land-cover modelling. Low resolution soil-change modelling. Pest and disease modelling.	F2-3 F2-3 F3-3 F3-2
Transition zone and landscape scale	Medium-fine resolution data base. Landscape analysis. Mechanistic modelling for land cover and species changes. Soil-vegetation-atmosphere analyses of water and energy fluxes. Pest and disease analysis of changing distributions.	F2-2, F2-3 F2-2 F2-1, F3-1, F3-2 F1-4 F3-2
Patch-scale experimentation	CO_2 and climate experiments. Biogeochemical experiments. Soil experiments. Landscape manipulation. Soil-vegetation-atmosphere analyses of water and energy fluxes. Agricultural species experiments and models.	F1-1, F1-4 F1-2 F3-3 F2-1 F1-4 F3-1
Controlled experimental facilities	CO_2 and detailed laboratory experiments.	F1-1, F1-2, F3-1

identification of functional biotic groups, etc. A third is landscape analysis for application of experimental and modelling results at the landscape scale. The fourth is development of an adequate geographic data base for a region so that observations and model output can be applied to real terrain.

The field experiments will need to be reinforced with controlled-environment experiments such as CO_2 incubations within phytotrons and greenhouses. The location of experiments within the representative ecosystems will provide the context of which functional type or species and which conditions are chosen for experimentation in the controlled environments. Thus, as the focus moves from large scale to smaller, the large-scale sets the context upon which smaller scale operations should take place. On the other hand, results of smaller-scale research are scaled up to the larger-scale systems through appropriate modelling and methodological techniques, including data-base extrapolation and integration of observations.

All of the core activities involve development of predictive capacity so that responses of terrestrial ecosystems can be derived from scenarios of change in CO_2, climate and land use. The activities are organized so that some provide predictions at the continental (and thus global) scale, whereas others deal with the regional, landscape or patch scales. The global and regional scale knowledge is needed primarily to estimate feedback to the climate system, with the regional information being of particular importance for analyzing transition zones likely to show greatest change. The landscape and patch predictions are needed to provide greater realism at the local level, both for incorporation into the larger-scale estimates, and because of their importance to humans.

The Problems of Space and Time Scales and Variability

The proposed research strategy involves the parallel development of measurements and computer-based, mechanistic models. For example, we propose well-focused physiological measurements of the effects of CO_2 and climatic variables on selected plant functional types at the scale of individual plants, and also large-scale field experiments on the effects of altered CO_2 on ecosystems. The results of the large-scale experiments will likely not be obviously predictable from the results of the small-scale experiments, because of the complex interactions among plants and between plants and soils. These large-scale experiments are expensive and only a limited number can be done. In order to develop a general predictive capability from these experiments, we need to build and test models that start from a simple representation of the plant-level effects and also include representations of our current understanding of interactions among plants. The great value of the large-scale experiments is in providing data on parameters for models and in validating the models. They will provide data that the models must be shown to reproduce, at least approximately.

The integration of experiments and modelling also provides a way to address the time-scale problems. Owing to the decadal to century focus of IGBP, mechanistic models are a necessary tool for looking forward and extrapolating beyond present conditions. The problems of variability, including changes in the nature and frequencies of extreme events, and possible unrecognized feedbacks, may lead to "surprises" (Holling 1978) that our models cannot predict. In this sense, models developed in the IGBP must be regarded as benchmarks reflecting the current state of knowledge, and they must be designed to allow incorporation of new insights that arise when monitoring of global systems produces qualitatively unexpected results.

A final problem concerns the large numbers of species that occur in ecosystems. Species differ greatly in their physiology and responses to changing environment, but we cannot expect to characterize them all. How, then, do we choose the basic taxonomic entities in our models? We propose the use of "functional types" (IGBP 1989, 1990a; Smith and Huston 1989, Prentice et al. 1989). For each specific research problem and modelling effort, the task is to identify the smallest appropriate number of distinct, functionally different types of organisms and to focus experimental study on examples of each. The functional types will be the basic biological entities in experiments and the models, making the modelling problems tractable.

Thus, although we refer for example to predicting the dynamics of species composition as an important goal, we do not, however, expect to be able to work at the species level everywhere. Studies must be clearly directed towards the project's overall objective to develop a predictive capacity for ecosystem dynamics over a significant portion of the Earth's surface.

Project Organization

The Core Activities are highly interlinked with each other and with other IGBP effort and, to a certain extent, hierarchical in terms of information flow between them and to products of the Core Activity. These relationships are illustrated in Figure 1.

Eight of the Core Activities must be administered as an integrated set of activities within this Core Project and two should preferably be administered by, or at least shared with, other IGBP Core Projects and Activities. All ten are required to achieve the Core Project objective.

Typically, the Core Activities combine monitoring, experiments, modelling at various scales, and inputs from other sources. Some of the larger field experiments will contribute to several Core Activities and will jointly serve other Core Projects, e.g., BAHC (Chapter 5.1) and IGAC (Chapter 2.1). Because of their cost and complexity, they will be located in a limited number of regions and the proposed IGBP Regional Research Centres (Chapter 11) may play a role in their implementation.

Ecosystem Physiology *Focus 1*

Of the many functional attributes of ecosystems that may be influenced by global changes, those which are of primary interest to IGBP can be grouped into four main areas of research activity.

Activity 1

Effects of Elevated CO_2

Two major questions underlie the need for this activity:

(1) How will increases in atmospheric CO_2 influence plant physiology?

Carbon dioxide is a limiting substrate for photosynthesis in C_3 species but less so in C_4 species, which are CO_2 saturated (Björkman and Pearcy 1983). Photosynthetic rates of C_3 species are therefore expected to rise with CO_2, when other resources for photosynthesis, such as nitrogen and phosphorus, are not limiting (Acock and Allen 1985). Increased photosynthetic capacity or decreased respiration at elevated CO_2 leads to an increase in carbon compounds relative to tissue protein (Lincoln et al. 1986, Gifford et al. 1985). This change can cause increased or decreased rates of herbivore (Lincoln et al. 1986) and decreased rates of litter decomposition (Melillo et al. 1984). The increased supply of carbohydrates increases the capacity of plants to support mycorrhizae and nitrogen fixing associations, enhancing the capacity of these species to grow on nutrient-poor soil (Norby 1987, O'Neill et al. 1987). The occurrence of sinks for photosynthetic assimilates, such as mycorrhizae and fruits, enhances the CO_2 stimulation of photosynthesis (Clough et al. 1981).

Increased CO_2 causes stomatal conductance to decrease and as a consequence water use efficiency increases (Warrick et al. 1986a), enhancing the capacity of plants to grow in water-limited environments (Morison and Gifford 1984).

(2) How will the known plant physiological response to CO_2 influence ecosystem processes and net vegetation function at the patch scale?

Species differ in their photosynthetic and stomatal responses to CO_2. These physiological differences may lead to changes in patch structure by changing competitive interactions (Drake et al. 1989, Reekie and Bazzaz 1989). Enhanced water-use efficiency at elevated CO_2 will allow increased leaf area index (LAI) in water-limited environments (Woodward 1987). An increase in LAI will change light levels within a patch, influencing the capacity of light-limited species to survive. Other changes will be induced by differential responses to herbivore (Lincoln et al. 1986, Fajer 1989) and by influencing soil processes. Soil processes may be influenced by changes in C/element ratios, which will alter nutrient availability, through stimulation of nitrogen fixation (Masterson and Sherwood 1978, Norby 1987) and through increased carbon sequestration in the soil (Overdieck and Reining 1986).

Objective

- *To determine and predict the effects of elevated CO_2 on ecosystems, at the patch scale.*

Achieving this objective requires the parallel development of experiments and modelling, over a wide range of scales of time and structures of interest. These include an integrated set of experiments, ranging in spatial scale from the level of the single-leaf to the patch, with temporal scales from minutes at the single-leaf level to at least ten years for tree-patch experiments (IGBP 1990b).

The top priority is for large-scale experiments involving free air CO_2 enrichment studies (FACE), in which water regime and temperature are also varied. They will need to run for more than one growing season for perennial communities, in order to establish the most likely pattern of patch adjustment to CO_2 change. The period of adjustment covers the time taken for the responses of all plants, soil organisms and patch cycling to adjust to the elevated CO_2 concentration. This adjustment period is expected to take at least 3 to 5 years for perennial grassland; it is likely to be at least 10 to 15 years or longer for forest. The current SCOPE project on modelling production and decomposition in coniferous forests and grasslands will provide an assessment of adjustment periods and will also identify the priority research requirements.

The large-scale experiments will have limited capacity to study interactions between CO_2 and temperature, but studying the interactions between CO_2 and water supply is an important requirement. The highest priority is for measurements of ecosystem properties at the patch scale, including net primary and ecosystem productivity; the flows of water, nutrients and energy (in particular water-use efficiency, carbon allocation and decomposition); and the responses of overlapping phenologies (IGBP 1990b).

There will be few large-scale experiments because of their expense and the heavy requirement for trained personnel. As a consequence, there should be an agreement on the ecosystems most suitable for study. These will be communities expected to differ in their sensitivity to CO_2 increase, such as those in which temperature and water are limited in different combinations. Experiments should be given high priority in the following areas: currently cold and wet and where significant changes in temperature are expected (e.g., tundra), cold (or cool) and dry (temperate, semi-arid grasslands or shrublands), hot and dry (subtropical or tropical arid savannas), and hot and wet (tropical rain forest).

As stated earlier, achieving the objectives of this activity will require an integrated set of experiments, across a range of scales. The fine scale (i.e., leaf to plant and hours to a season) experiments are most likely to be run in a controlled environment at the plant level, and need to focus on the interactions between changes in CO_2 concentration and temperature, humidity, water supply and soil nutrient status. In addition, controlled environment experiments are also required for investigating the effects of CO_2 on plant competition, on herbivore and pathogen effects, on plant symbionts, and decomposition.

Medium-scale experiments (in the order of a growing season in duration and small patch size) should be attempted in the field to complement the controlled environment. The focus of these experiments will be on plant-plant and plant-soil interactions, and they will facilitate scaling-up predictions from the controlled environment to the large-scale patch experiments.

The experimental and modelling aspects of the CO_2 studies must develop in parallel. Model development needs to focus on transient changes in CO_2 concentration and the corresponding impact on ecosystem processes. Patch models of vegetation dynamics (Activity 5) are needed in order to incorporate the direct effects of CO_2 on patch processes. In addition, atmospheric measurements of CO_2 over certain regions will be needed to better quantify the influence of the patch scale CO_2 fluxes on the atmosphere. These measurements could be made through an expansion of the on-going CO_2 monitoring network as described in Focus 1, Activity 2.

Activity 2

Changes in the Biogeochemistry of Carbon, Nitrogen, Phosphorus and Sulphur

In the past decade, substantial progress has been made in understanding the biogeochemical cycles of carbon, nitrogen, phosphorus, and sulphur, in describing their interactions, and in determining the direct effects of climate and land-use change in regulating these cycles. Research is not so far advanced on the effects of an altered atmospheric composition in controlling terrestrial biogeochemistry, but Activity 1 (above) and a number of ongoing studies are beginning to address that deficiency (see IGAC Chapter 2.1). On the other hand, we have very little information on the interactive effects of an altered atmosphere (especially elevated carbon dioxide), climate change, and land-use change on terrestrial biogeochemistry. Understanding these interactive effects is crucial, because the changes are occurring together, and because there is every reason to believe that they will interact in their biogeochemical consequences. In particular, it will not be possible to estimate the changes in terrestrial carbon storage without taking these biogeochemical interactions into account.

Research at a number of scales is needed to address these concerns, including:

i) Studies of the interactions of climatic, atmospheric, and land-use change, with special attention to land clearing and to changes in fire regimes, on biogeochemistry on components of ecosystems. These studies can best be carried out in conjunction with the experiments with elevated carbon dioxide described in the previous section.
ii) Continued development of generic models based on interactions of the biogeochemical cycles.
iii) In addition, some carefully focused field-based experimental studies are needed. These should be carried out in regions where: (i) ecosystems are

likely to change substantially as a consequence of global change; (ii) interactions among the driving variables are likely; and (iii) feedbacks from ecosystem level alterations to regional and global changes are plausible. We suggest three ecological regions for initial focus: tropical regions that are undergoing intensive agricultural or pastoral development; semi-arid regions on ecotones between woody and grassland vegetation; and high latitude regions with substantial soil carbon storage.

(iv) Ongoing syntheses of information on the global biogeochemical cycles, their interactions, and their controls. (See Chapter 8.1, 1, GAIM).

These three regions, described above in point iii), define the locations for initial tasks of this activity. For each task, field measurements and experimentation is emphasized. However, we recognize that for the experimental designs to be meaningful and the measurements to be broadly used, they need to be based on ecosystem models, and that the results of measurements and experiments will be synthesized with the aid of models. Extension of the results to unstudied or newly developed land-use practices will similarly require a substantial modelling effort. Finally, extrapolation of results in space and time will require a substantial investment in remote sensing as well as modelling - particularly in models that can be driven by remotely-derived inputs.

Four tasks are outlined for this activity. The first task is designed to reduce the uncertainty in the carbon fluxes and the magnitude of storage pools of terrestrial ecosystems. The next three tasks outline regional priorities for focused studies on a suite of biogeochemical elements (C, N, P, and S) and their interactive behaviour.

Objectives

- *To develop the capacity to predict how fluxes and pools of carbon, nitrogen, phosphorus and sulphur change in ecosystems in response to changes in CO_2, climate and land use (including fire regimes).*
- *To estimate the distribution of terrestrial carbon pools within continents and, to predict how they might change under given scenarios of global change.*

Task 1. Estimating terrestrial C pools and fluxes.

One of the major uncertainties regrading the global C cycle relates to the importance of terrestrial ecosystems as sources and sinks (Bolin 1986, Tans et al. 1990). After a number of years in which calculations of the global carbon budget appeared to be converging on a small net flux from terrestrial ecosystems to the atmosphere, a recent paper by Tans et al. (1990) made a strong case that terrestrial ecosystems, in particular north temperate systems, are significant net sinks of CO_2. If this atmospherically-based analysis is correct, previous analyses must have erred in their treatment of land-use change and its consequences (Bolin 1986), the effect of elevated CO_2 on carbon storage, or other processes subject to human modification (such as the effects of enhanced nitrogen deposition on carbon storage).

The objective of this task is to establish quantitatively the terrestrial ecosystems as sources and sinks for atmospheric CO_2. This objective will be addressed in several ways. First, the CO_2 enrichment experiments (Focus 1, Activity 1) will determine the overall effects of elevated CO_2 on carbon storage. Second, the precision of atmospherically-based analyses (such as Tans et al. 1990) can be increased substantially if a more detailed spatial and temporal monitoring network for CO_2 concentrations over continental areas can be established. Current measurements of the atmospheric CO_2 are made in remote areas and are highly associated with maritime regions so that continental measurements are relatively sparse. The established Background Air Pollution Monitoring Network (WMO-BAPMoN) and the NOAA Geophysical Monitoring for Climate Change (GMCC) network partially meets the needs, but an expansion of the flask sampling network would greatly assist in resolving the issue of identifying the source and sink regions of the terrestrial biosphere. At the same time, an effort should be made to improve our knowledge of sources and sinks of carbon associated with land clearing. The approximate storage and net turnover of C from various ecosystem types are generally known (although these studies are

relatively few in number; see Bolin 1986). However, the areal extent of the major ecosystem types and the distribution and dynamics of their successional stages are poorly known relative to the global carbon storage. This study should be conducted jointly with the IGBP-DIS, as part of the Land Cover Study (Chapter 9).

Task 2. Tropical areas undergoing human development

Land-use change is currently most rapid, and its consequences most evident, in tropical regions, in part because of the disproportionate share of human population growth that is taking place in the tropics. Land clearing and conversion causes substantial losses of carbon and nitrogen, lesser losses of sulphur and of phosphorus from cleared sites in most regions, but the rate at which this aterial is lost is much faster in the tropics. Accordingly, a number of the IGBP Core Projects, including IGAC (Chapter 2.1), LOICZ (Chapter 4.1) and BAHC (Chapter 5.1), emphasize tropical systems.

To evaluate the consequences of environmental change in tropical regions that are under development, we need to:

i) Determine the fate of the carbon, nitrogen, phosphorus, and sulphur lost during, and in the few years following, land clearing. How much is: volatilized in fires or afterwards in cleared sites, and in what forms (e.g., carbon dioxide or methane, nitrogen gas, ammonia, nitric oxide, nitrous oxide)? Leached to streamwater and groundwater? Eroded?

ii) Determine the regional consequences of land-use change through watershed studies, a gas-flux measurement studies, and regional climatic measurements in relatively large cleared areas (several to tens of kilometers).

iii) Determine interactions of land-use change with increasing carbon dioxide concentrations and other atmospheric changes such as elevated oxidant concentrations (many of the latter themselves driven by land-use changes) in a few experimental sites. Temperature change is likely to be less significant in the tropics than in higher latitude systems.

Often we know the amount of material lost but not its pathway or fate, and these are critical on local, regional, and global scales. Nitrogen would probably reward particular effort in tropical systems, because tropical forests are relatively nitrogen-rich by global standards. The rapid rate of change in element pools following land clearing in tropical areas is likely to be an advantage in these studies; massive amounts of material are moving in a short period of time, and hence fluxes are more readily detectable than in other regions.

To meet these goals, a coordinated regional watershed study of the effects of land conversion should be undertaken on large watersheds in tropical forest and savanna regions nested within large river basin measurement programmes like those now underway in the Amazon and Orinoco Basins, and proposed in BAHC (Chapter 5.1) and LOICZ (Chapter 4.1). Losses of elements in solution, erosion, and gaseous emissions should be carried out. The experimental program should interact with the "tropical land use change" activity of IGAC (Chapter 2.1) which is proposing ground- and aircraft-based measurements of trace-gas fluxes over tropical forest and savanna areas. In addition to these intensive sites, plot-level measurements of the fate of elements in different land use systems should be undertaken on a number of sites, and interactions of land use change with atmospheric change should be pursued at a few well-equipped sites. Close coordination of among other IGBP Core Projects (i.e., IGAC, LOICZ, and BAHC) and with other ongoing studies must be maintained during the development and implementation of the study.

Task 3. Semi-arid ecosystems

Semi-arid areas at or near a transition zone (ecotone) between woody and grassland vegetation are widespread globally. They are also particularly interesting due to the proximity of ecosystems dominated by contrasting life forms (e.g., forests compared to grasslands or shrublands) and often contrasting photosynthetic pathways (C_3 versus C_4). There is therefore a substantial likelihood that changes in atmospheric chemistry, climate or land use will result in radical alteration of biogeochemical dynamics due to physiognomic shifts in this region, which will feedback, positively or negatively, to future climate and atmospheric composition conditions. For example, increasing CO_2 concentrations should favour woody C_3 vegetation over C_4 grasses, thereby increasing carbon storage. However, increasing temperatures should favour C_4 grasses. Human activity can also have opposing effects. Increases in fire frequency may favour grasses; intensified grazing may increase the patchy distribution of certain soil and set in motion a positive feedback towards shrub invasion. Land cleared in dry-forest areas is often converted to self-maintaining grassland, with potential climatological and biogeochemical consequences. All of these are likely to be strong effects, and the net effects of all of them together are not clear and not likely to be clarified without experimentation. Accordingly, a detailed study of the interactive effects of atmospheric chemistry, climatic, and land-use change in semi-arid areas is proposed. Such a study should include demographic measurements of the major woody and graminoid species as well as carbon, nitrogen, sulphur, and phosphorus dynamics. There is evidence that limitations to plant or animal mobility or establishment govern the rate of response of woody vegetation to land changes, and the same could be true of responses to global change. Moreover, demographic processes are unusually amenable to systematic study at grassland/woody vegetation transition zones.

It would be most logical to establish an intensive site in the tropics (savanna-forest boundary) and in the temperate zone (prairie-shrubland or -forest boundary) in which a full range of measurements would be undertaken. Many of the issues in Tasks 2 and 3 would be best addressed in a study which cuts across a rainfall gradient in the tropics, which ranged from humid tropical forests to semi-arid savannas. Such studies have already been proposed in West Africa and northern Australia, and comparable studies in other tropical and sub-tropical regions are required.

Task 4. High-latitude ecosystems

Predicted temperature increases are greatest in high-latitude areas, and direct effects of elevated CO_2 on terrestrial ecosystems are also likely, because high latitude ecosystems are already relatively carbon-rich and nutrient-poor. All else being equal, increases in temperature alone are expected to lead to increases in decomposition greater than any increases in net primary production, and therefore to increases in CO_2 flux from soils. Depending on changes in precipitation, which cannot yet be predicted with confidence, methane fluxes might increase as well. These effects do not occur independently, but interact intimately with other ecosystem processes, so that an increase in decomposition will lead to increased mineralization of nitrogen and to a lesser extent sulphur and phosphorus. These could cause an increase in productivity that could temporarily (decades to centuries) override any increase in decomposition and cause increased carbon storage on land (Pastor and Post 1988). Elevated CO_2 could also cause increased carbon fixation, but that in turn might widen carbon-nutrient ratios to the point that immobilization by microorganisms was substantially increased. That in turn would decrease nutrient availability, increasing plant carbon-nutrient ratios still further, and hence decreasing productivity. The net results of these interactive effects are fundamental and very poorly known.

An intensive effort to determine the effects of atmospheric chemistry and climatic change should be carried out in high-latitude ecosystems. Some experimental work along these lines has been carried out. This should be extended to other sites, and with a strong emphasis on interactions among the biogeochemical cycles. An intensive experimental site should be established in both tundra and boreal-forest ecosystems. The intensive measurements at these sites should be complemented with extensive measurements of soil heating, moisture conditions, and other environmental variables for mechanistic models at various complementary sites. These should be selected along gradients of the major ecological factors controlling high-latitude ecosystems.

Measurements at these intensive sites should be undertaken under elevated CO_2, elevated temperature, and both reduced and elevated precipitation. Measurements of plant properties (carbon storage, production, water and nutrient-use-efficiency) must be complemented with measurements of nitrogen and other nutrient pools and transformations. These experiments could be conducted in conjunction with the high latitude ecosystems component of IGAC (Chapter 2.1)

Core Project that will emphasize CO_2, CH_4, and N_2O under altered conditions.

Completion of these three tasks will not yield an overall understanding of global change in the biogeochemical cycles, but it will provide substantial progress in the most critical areas in the next five to ten years.

Changes in Water and Energy Fluxes

Activity 3

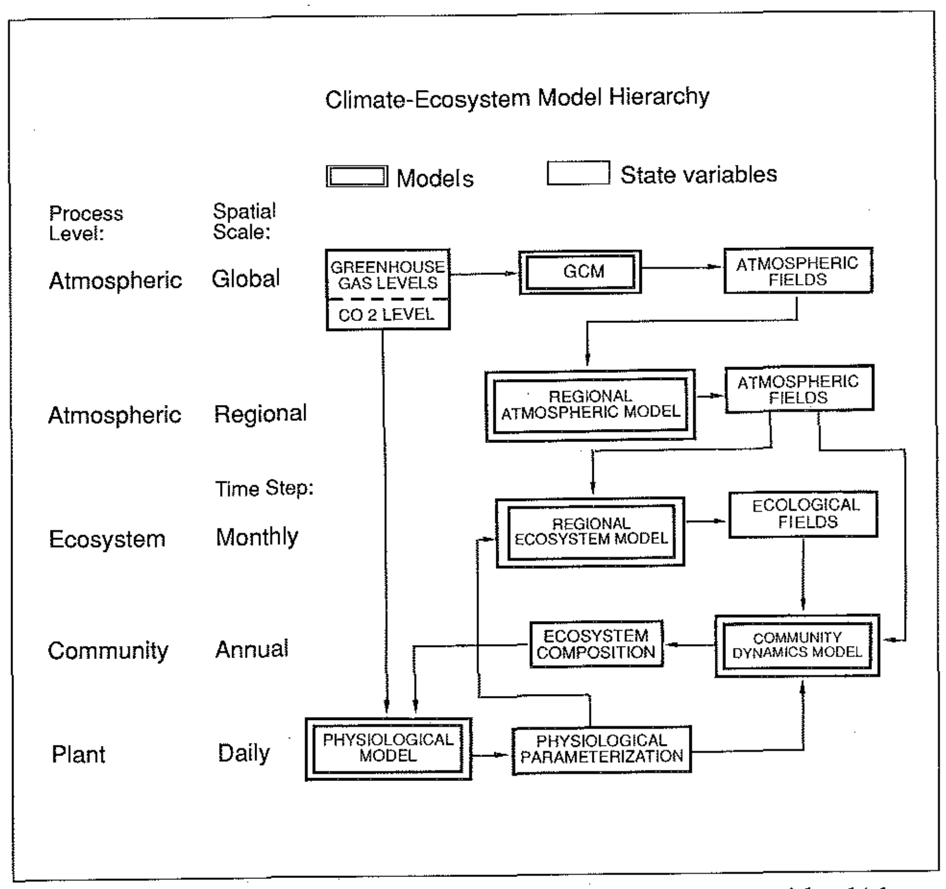
The studies discussed here will be conducted jointly with BAHC (Chapter 5.1). Close collaboration is necessary for achievement of the specific goals set down below.

The main question which needs to be addressed is: As climate and land-use changes, how will the biotic response affect the exchange of energy and water between land ecosystems and the atmosphere, thus affecting the feedback to further climate change?

Land surfaces interact with the atmosphere through exchanges of energy, water, gases and particulates. As land surfaces are modified by global change, these exchanges will be altered. Changes in the distribution of incoming energy in terms of reflectance, long-wave radiation, and conversions to latent heat will represent a feedback to climate.

A suite of SVAT models to be developed by BAHC (Chapter 6.1) will link ecosystem properties with the various fluxes of energy including evaporated water. Surface properties critical to these fluxes are albedo, long-wave emissivity, roughness length and biophysical and hydrological controls on water flux. These properties are prone to changes in diurnal cycles, seasonal cycles, disturbance-succession cycles, and, of course, with land-use and land-cover changes generated by climate change. Linking changes in terrestrial ecosystems relative to SVAT models will comprise the main tasks of this Core Activity and define the joint activity between BAHC and GCTE.

There must be a strong linkage between predictions of change in structure and function of terrestrial ecosystems and general circulation models (GCMs).



Hierarchical levels and spatial regions of atmospheric and ecological models which can be interlinked to provide a method of cross-translating information between scales.

A generalized SVAT model will provide this linkage (see BAHC, Chapter 5.1). The following two tasks are to be jointly developed and implemented with BAHC. Details of these tasks are presented in BAHC (Chapter 5.1).

Task 1. Vertical partitioning of water and energy by the biota.
Task 2. Three-dimensional movement and storage of water in terrestrial ecosystems.

Focus 2

Change in Ecosystem Structure

The three activities in this section constitute the progressive development of a model for predicting the dynamics of composition and structure at the patch, landscape and, finally, regional levels. The relationships between the various models at each scale are illustrated in Figure 3. Emphasis is given eventually to predicting change at the scale of a GCM grid cell. The landscape level fits between the patch and this grid-cell scale (which is equivalent to the regional scale).

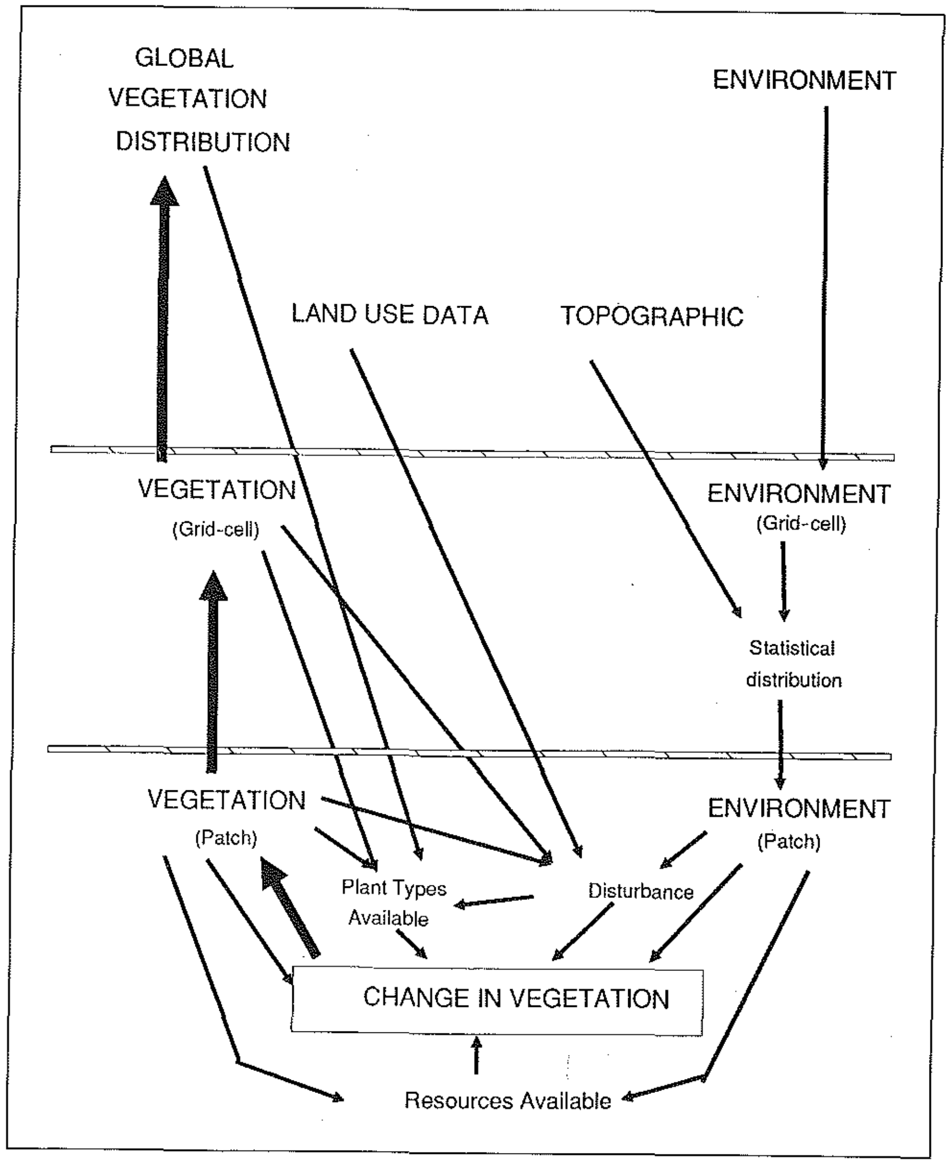


Figure 3. Relationship between models of ecosystem change at different scales. Grid-cell size is approximately 100 by 100 km. The patch scale is considered less than 10 km and is usually much less than 100 m. Development of models to translate between these scales will be a major consideration in GCTE in collaboration with IGAC, LOICZ, BAHC, and IGBP-DIS (IGBP 1990b)

Changes in Biological Composition of Species Functional Types and Ecosystem Structure at the Patch Scale.

Activity 1

Changes in climate and atmospheric CO_2 will influence the interactions among functional types of organisms, and hence lead to changes in the biological composition of ecosystems. The manner in which these changes take place is the main research focus of this activity.

Because temperature change will alter global atmospheric circulation patterns, many climatic variables other than temperature will be influenced. From the perspective of ecosystems, changes in temperature seasonality and the seasonal distribution of precipitation, its year to year variability, annual total and the sequences of "year types" may be more important than average annual changes in temperature or rainfall. Changes in the extreme values of temperature, or any other environmental factor, are likely to have major effects on ecosystem components and their functioning. Climatic changes will force plant and animal species to respond by genetic adaptation, migration, or extinction (Prentice 1986, Woodward 1987). Changes in the distribution of different functional groups of plant and animal species will confer changes in ecosystem structure (or physiognomy), in the habitat for animal species, and in aspects of ecosystem physiology such as evapotranspiration and nutrient cycling, that are partly determined by vegetation physiognomy and composition. The species (or more practically, functional groups) interact in complex ways to determine the relative abundances of taxa and the consequent structure and function of an ecosystem. Many interactions occur at a fine spatial scale, including resource competition between individual plants on a patch, and succession and gap-phase dynamics (Shugart 1984). Other interactions occur at a somewhat larger scale, through secondary effects of climate-induced changes in herbivores and pathogens or changes in fire or hurricane frequency (Prentice et al. 1989). Changes in episodic events of all types are likely consequences of climate change, both as a direct effect of changes in temperature and humidity, and indirectly through changes in primary productivity, plant physiognomy or tissue chemistry. Any such changes in disturbance will have significant effects on species composition and on structure.

Objectives

- *To predict the transient dynamics of change in biological composition, in terms of the relative importance of different functional types of organisms, in response to environmental changes at the patch scale including what is commonly known as community dynamics".*
- *To determine the effects of changes in occurrence and abundance of functional types on ecosystem physiology and possible feedbacks.*

This dual focus will be on broad functional types of species identifiable within evolutionarily distinct biotas, and on limited number of species that are particularly important in their own right, e.g., dominant species in species-poor communities, or economically important pests (IGBP 1990b).

Task 1. Classification of functional type

Species functional type classifications will be developed, with the help of guild analyses for major groups of organisms, leading to selection of species for intensive study. Sets of properties must be defined that can indicate functional-type responses to changes in key climate variables, e.g., growing-season temperature, winter minimum temperature, growing-season drought, ET, rooting depth, etc., and indicate the functional-type characteristics (IGBP 1989, 1990a).

Task 2. Characterization of functional type responses to key climate variables and CO_2

Laboratory and field measurements of growth, mortality and reproductive potential of functional types under altered climate and CO_2 conditions need to be conducted in conjunction with experiments in Activity 1. The intra-patch dynamics of individuals belonging to the major species functional types need to be characterized within a model framework. The sensitivity of these functional types to changes in meteorological, chemical, and pedological parameters will be tested with the model and field observations.

Task 3. Linkages between community dynamics and ecosystem processes

The interactions between ecosystem structure and ecosystem physiology must be determined to achieve the ability to predict ecosystem response to global change. This determination will involve developing the capacity to predict interactions among individuals of similar and different functional types and, consequently, the dynamics of community composition. In turn, this will require field observations and experiments to quantify the effects of organisms on their local environment and on each other (IGBP 1990b); controlled environment and field experiments to quantify the effects of depletion of specific resources on the growth of different types of organisms, and parallel with these experimental efforts, the development of mechanistic models. These will be generalized patch-scale models for vegetation dynamics (IGBP 1990b, Prentice et al. 1989) that can predict such interactions from basic physiological and life-history attributes and physical representations of resource competition. They may involve detailed simulation models based on individual organisms as well as state-and-transition models.

Task 4. Climate-induced changes by fire (in particular) and other disturbance regimes that affect community composition and ecosystem physiology.

Changes in the frequency and intensity of pest outbreaks, herbivore, storms, droughts and fire resulting from climate change can dramatically alter the community composition under certain conditions. Change in fire regimes is a prime example of the climate-induced impacts and ecologically significant phenomena.

Fire is of such importance in determining ecosystem structure and function in many regions that it requires particular attention. The aim here is to develop a generic model of fire effects, with specific attention being paid to changes in fire regimes (i.e., frequency, seasonality, intensity). An associated requirement will be to define and collect appropriate data. Much will come from synthesis of existing information, but new observations and some experiments will also be required. These should be developed jointly with the requirements for Activities of Focus 1, Activity 1 and Focus 2, Activity 2.

Activity 2

Ecosystem Dynamics at the Landscape Level

A landscape is composed of an interacting set of contiguous patches. At this level, structural and functional elements of biotic and abiotic systems combine to create the landscape pattern of interactions. The nature of these interactions at the landscape level includes soil and water movement, biological dispersion/invasions, gaseous transfers, and disturbances (e.g., fire or wind-storms). These processes are typically a function of topography, land cover, the prevailing climatic regime and land use.

Objectives

- *To identify and quantify the landscape-level processes that will change in response to changes in CO_2, climate and land-use.*
- *To incorporate these into a generic model of landscape dynamics.*

Task 1. Development of a generic model of landscape dynamics

This task will combine experimental results and model products from activities on CO_2 effects, biogeochemistry, soil movement, ecosystem structure, and water and energy fluxes. Model output from individual activities will be linked as a series of modules into a model of the system. Ecosystem physiology (Focus 1, Activities 1-3) needs to be linked across patch boundaries via simulation models, which take spatial interactions into account. Disturbance is a critical landscape level phenomenon (IGBP 1989, 1990b), and the effects of fires, droughts, frosts, wind storms, and particular combinations of such events need to be explicitly included (Focus 2, Activity 1, Task 4). The outcome for the landscape model will be dynamically changing spatial patterns driven by combinations of smaller scale functional and structural attributes that specifically are susceptible to global change phenomena.

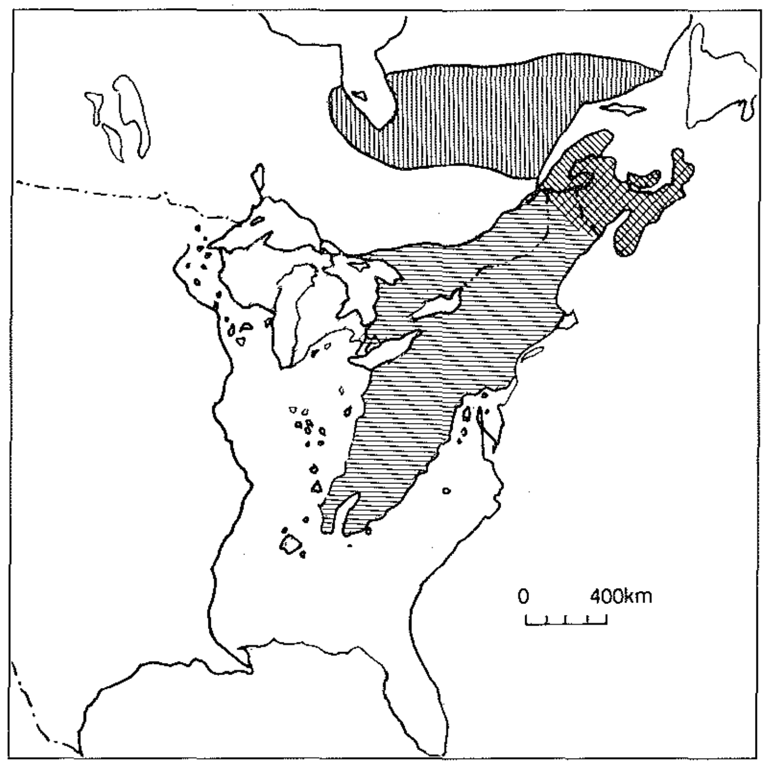
Task 2. Monitoring and observation

Landscape-level changes in patch relationships will be identified, and quantified as a function of their determinants, by a combination of ground-based measurements and fine-grain spatial and spectral resolution remote sensing by either aircraft or satellite. Landscape attributes should be monitored to include areal extent of ecosystem patches, demographic development of specific patch types, and disturbance incidents in the landscape. This monitoring effort will best be accomplished by using the same representative landscapes from around the globe that are to be used for the experimental areas of the preceding Core Activities (see Focus 1, Activities 1 and 2).

Activity 3

Change in the Distribution of Biota and Regional and Continental Land Cover and Land Use

The main issue to be studied at the regional and continental scale is the consideration of transient dynamics. It cannot be assumed that propagules of adapted species will be available, and that the biota will be able to move (migrate) as dictated by changes in climate. Given the anticipated rates of climate change, it is highly likely that for many species the rate of climate change will exceed their



Present and future range for a common forest tree, eastern hemlock (Tsuga canadensis), under a doubling CO_2 climate scenario. Horizontal shading is the present range, and vertical shading the potential range with CO_2 doubling. Cross-hatched area of overlap is where the trees are likely to be found 100 years from now. Relict colonies may persist to the south in pockets of favourable environments. Significant advances to the north is unlikely due to the slower dispersal rate (NRC 1986).

maximum rates of dispersal. At this level predictions about change in ecosystem composition must take into account the interactive effects of changes in climate and CO_2, changes in the nature, frequencies and sequences of extreme and rare events, and the rates of change in climatic variables relative to the potential rates of species dispersal. Models will play a fundamental role in studying these transient phenomena relative to changes in community composition. In addition, these effects will be modified by the effects due to past and current land-use patterns and management.

Objectives

- *To develop predictive models of change in the distribution of biota, and of land-cover types.*
- *To monitor the changes in land cover, based on a classification of land-use categories and vegetation functional types.*
- *To develop scenarios of future changes in land-use, based on integrating the effects of future climate change scenarios and scenarios of changes in human demography, economics and technology.*

The first objective will be specifically addressed in this Core Project. The second will be addressed by the IGBP-DIS study on Land-Cover Change (Chapter 9). The third lies outside the expertise of the IGBP, and it is hoped that this requirement will be taken up by IGBP's counterpart programme on Human Dimensions of Global Change, in close collaboration with IGBP scientists. In Focus 3 of this Core Project, the agricultural issues are dealt with, and special attention is given to the global effects on yield and management practices of agroecosystems. The additional technological developments and commodity/supply issues go beyond the scope of this Core Project. Therefore, scientific issues underlying these will be treated in the later development of the Core Project proposed for agroecosystem research.

Task 1. Develop a functional classification of global vegetation types

This task must be developed in conjunction with the IGBP-DIS study on Land-Cover Change (Chapter 9). The prime need is to define the vegetation attributes (e.g., albedo, evapotranspiration, surface roughness, biomass/primary productivity, seasonal CO_2 uptake and decomposition) that indicate functional change in vegetation in terms of global change objectives. A classification scheme needs to be developed on the basis of these attributes. An early requirement will be to decide on the degree of difference that is considered significant. Development of this classification scheme will be developed in concert with IGAC (Chapter 2.1) and BAHC (Chapter 5.1).

Task 2. Predicting changes in functional type distributions at the regional or continental scale

Since this task addresses issues related to understanding the causes of the distributions of animals and plants on regional or even continental scales, the first step is to develop correlations between the distributions of species and various limiting environmental factors. Fundamental to understanding the current and future distribution of the biota is the assessment of the dispersal abilities of species (or functional types of species) of interest. These analyses are profitably done on the edges of a species' range or in transition zones. Once correlations are established, experimental studies to determine the cause-effect nature of the correlations should be undertaken.

The variety of experiments that are necessary is extensive and cannot be discussed here. However, the simplest studies are likely to involve elucidation of abiotic relations to key processes of the organism's life cycle such as mortality or reproductive capacity. Determining the limiting effects of species interactions such as pollination, parasitism, or predator-prey relations is more difficult but no less important.

Development of predictive, correlative models will be an important component of this activity. Modelling work should aim towards a scaling-up from the

mechanistic landscape-scale models developed under Focus 2, Activity 1 to the scale of regions and continents. Just as the scaling up from patch-scale models (Focus 2, Activity 1) to the landscape (Focus 2, Activity 2) involves incorporating new processes (spatial interactions between patches), so scaling up to regions means including other processes (e.g., long-distance dispersal of organisms between landscapes). Information on the dispersal capacity of organisms must be reduced to the basic minimum in this level of models (IGBP 1990b, Prentice 1986), but the representation of dispersal is crucial. It seems likely that rare, long-distance events are important in the climatically induced migration of taxa (Prentice 1986), so these must be considered in the model design.

There are three basic approaches to achieving the modelling of this task:

(1) Correlative models. The approaches of Box (1981), Emmanuel et al. (1985), and others need to be developed further and used to obtain rapid, first-cut, continental-scale predictions of change. For vegetation, many models exist that purport to predict the distribution of vegetation types by using simple climatic variables as model inputs. These extant models need to be assessed to determine whether or not the vegetation types that are predicted are useful for inferring a variety of ecological processes, such as net annual primary production, or presence or absence of an animal species. The major disadvantages (e.g., lack of transients) are dealt with in detail in IGBP (1989, 1990b) but the models will be of value in indicating areas of likely major change.

(2) Mechanistic, plant-by-plant replacement models, of the FORET type (Shugart 1984) expanded to be spatially explicit and to include spatial dynamics. These are powerful models and could meet the objectives of the project. Their major disadvantage is the amount of information required to run them. It will take a long time before they can be applied to all regions of the world to produce satisfactory coverage at the level of resolution at which they operate. A variation of this approach is the use of matrix transition models, such as the FATE (Functional Attributes in Terrestrial Ecosystems) model of Moore and Noble (1990), which is an extension of Noble and Slatyer's (1980) vital attributes model of change, involving many spatial units (see IGBP 1990b).

3) State-and-transition models. These are essentially rule-based models, using existing knowledge and understanding of vegetation dynamics. For the purposes of this project, they would require a classification of the present land cover into a number of essentially different vegetation types, or vegetation mosaics, each of which is then further defined in terms of a limited number of possible states in which they can exist. These states are defined in terms of the project objectives, on the basis of what is currently known about vegetation dynamics. The conditions which give rise to a change from one state to another are then cast in the form of rules, in a state-and-transition model.

The disadvantage of this approach is that it is imprecise and non-quantitative. However, it will allow for a rapid assessment of regional vegetation change, based on mechanisms that are known to be important in regard to global change phenomena. In addition, ecosystem attributes that can be remotely sensed will be especially useful for addressing this activity. Without remotely sensed data the regional and continental scales of resolution cannot be adequately addressed. While remote sensing is by far the most time and cost effective way to obtain data relative to this activity, there is considerable need to develop new ways to analyze images and to produce different kinds of images so that relevant ecological data can be obtained. The current "state of the art" in remote sensing leaves much to be desired from the perspective of estimating ecosystem structure and functioning and determination of species' distributions. Investigations are underway to overcome these deficiencies through the IGBP Land-Cover Study (see Chapter 9).

Task 3. Testing models against historical data

The palaeoecological record provides a means to test models that predict vegetation cover or taxon distributions at a broad spatial scale. Global changes during the Holocene (c. 20,000 years) have included the appearance and disappearance of large-scale assemblages of plants and animals that have no modern counterpart (e.g., open forests with certain boreal trees and steppe elements in the eastern USA, Webb 1987, "disharmonious assemblages" of animals in North America), which can be explained by prevalence of climatic conditions with no exact modern equivalent. "No-analogue" biotic assemblages are just as likely to occur in the "greenhouse" world. Models should be able to predict their occurrence; palaeoecological data provide a best test of whether they can.

Simulations of climate during the Holocene can be compared with the distribution of terrestrial communities (e.g., COHMAP Members 1988) and, unlike the future case, these scenarios can be checked and improved against independent palaeoenvironmental evidence. Past climate scenarios can then be used as input to the models, the predictions of which can be compared with the continental record of past vegetation that can be pieced together from pollen and macrofossil analysis (COHMAP Members 1988). The Core Project on Past Global Changes (PAGES, Chapter 7.1) builds on the work of COHMAP by providing improved palaeoclimatic scenarios and continental-scale syntheses of data on vegetation and plant and animal taxon distributions at key times during the Holocene, for use in testing and improving large-scale models.

The palaeoecological record will also be crucial in developing large-scale, mechanical models incorporating dispersal. Past migration rates can be inferred (e.g., Davis 1981). These rarely represent maximum rates (Prentice 1986), because climate has rarely changed as fast as it is expected to during the next 200 years, but nevertheless any model must be able to produce migration rates at least as fast as those seen in the past. Further, when supplied with scenarios of past climate change, models should be able to simulate the actually observed migration patterns of taxa across continents.

Focus 3

Global Change Impact on Agriculture and Forestry

The world's ecosystems constitute a continuum from virtually pristine to intensively managed and highly modified systems devoted to some form of production. Agroecosystems represent the latter end of this continuum. The risk imposed by human-induced global change presents us with both the most urgent requirement for understanding its likely impact on agroecosystems and our greatest chance of mitigating the effects or adapting to the changes based on proper scientific understanding and evaluation. Such scientific knowledge is essential in any attempt to develop proper management schemes and a socio-economic evaluation of the consequences. Although many ecosystem processes operate over the entire continuum, the IGBP needs to provide a focus on the study of agroecosystems. The research priorities identified in this focus concentrate on yield of the major crop, forest and livestock species, and key factors which affect harvestable products.

Agroecosystems around the world share a number of common characteristics, which make practical an integrated research focus to study the impact of global change on agroecosystems. It is recognized that the intensity of environmental change is contingent on the way climate and land use affect various ecosystem and landscape characteristics. Thus, some of the tasks outlined for each activity may have to be adapted to specific agroecosystems, while maintaining the ability to integrate information across systems. Other national and international organizations are addressing similar questions (IBSNAT, CGIAR, FAO, and others). This focus must complement these programmes while attaining specific IGBP research goals for agroecosystems.

It is necessary to identify those key elements of agroecosystems for which understanding is paramount. The Core Activities required involve monitoring, experimental research, and modelling. Monitoring is required for direct assessment of change, in order to test hypotheses about change and to obtain information in order to generate new hypotheses. Modelling will allow prediction of the net effect of several concurrent changes, and allow understanding to be integrated across levels and between sub-systems. The model structure should offer the means for integrating the various impacts of climate change and will be an important guide in the development of research and data needs. Models developed for this focus will differ from those in the other Foci, because of the inclusion of management and the importance of production and yield of harvestable products.

Each of the Core Activities addresses some aspect of developing the capacity to predict the outcome of global changes on agroecosystems in terms of production of food and fibre, quality of the land resource, or the distribution of species. Many of the issues important for agroecosystems are addressed by the other Foci. Soil related activities are important in all three Foci, but because of their overriding importance to agroecosystems, they are most fully developed in this focus.

In this initial phase of research, the focus is on monoculture agricultural crops, livestock and forests. As the IGBP develops this focus, further planning will be carried out to specify research needs for additional aspects of pastoral systems and for mixed crop/forest/livestock systems and the possible advantages of a separate Core Project on "Global Change Impacts on Agriculture and Forestry" will be evaluated.

Activity 1

Effects of Climate and Atmospheric Change on Key Agronomic Species

The primary question is what will be the direct and interactive effects of changes in climate and atmospheric composition on selected agronomic plants and animals, and on the yield of harvested products.

Changes in climate and atmospheric concentration of CO_2 and pollutants acting singly or interactively can influence production of crop, forest and livestock species (IGBP 1990b). It is necessary to identify the impact of changes in temperature, humidity and rainfall and atmospheric composition on growth and yield of crop and forest species and on the growth, fitness and reproductive capacity of livestock.

Given this information, base-management options, such as selection of more adapted species, may be implemented. Implementation must incorporate an understanding of the interactions across the plant-soil-atmosphere continuum. For instance, selection of plant species is based on above-ground yield, which in turn is related to water-use efficiency. Change in the concentration of CO_2 and climate may change root/shoot and carbon/nitrogen ratios, which will affect yield and has implications for decomposition processes and the long-term quality of the land resource.

The key issue is the effect on yield and sustainability rather than on biomass or primary productivity of plants. A slowing in the rate of flower development in sorghum with CO_2 enrichment (Marc and Gifford 1983) may impact yield if combined with a changing abiotic environment. Understanding temperature effects on crop plants is also critical. Corn yield for instance, may be impaired by high temperatures during the brief period of pollination (Walker et al. 1989). It has been shown that climate and atmospheric changes each separately will have an effect on species (Warrick et al. 1986b), but we know little about their potential interactive effects. Experimental research consistently demonstrates that elevated CO_2 may, with optimal abiotic conditions, act as a fertilizer for crop and forest species (Shugart et al. 1986). However, changed climatic conditions will modify the effects of enhanced CO_2 on plants (Warrick et al. 1986b). Increasing temperature, for example, will generally increase respiration more than photosynthesis and may counteract higher CO_2 uptake due to CO_2 increase. Furthermore, an increase in atmospheric CO_2 interacting with climate will have an effect on the yield of crop plants, which may be different to the overall effect on primary production. In the case of forests, it is the effect on timber yield which is of prime concern. Interactive effects of water and temperature are primary determinants of regeneration processes of trees, and of production in commercial forestry.

With regard to livestock, temperature change may have the greatest direct effect on animal net production, mortality, fecundity and milk production. Higher temperatures could reduce fertility in sheep in some areas while an increase in summer rainfall could promote the incidence of footrot and fleece rot in other areas (Walker et al. 1989).

Objective

- *To understand the effects of climatic and atmospheric changes, singly and interactively, on major crop, forest and livestock species.*

There are three main tasks related to species which have been or will be targeted as critical agroecosystem species (IGBP 1990b).

Task 1. Develop an understanding of the effects of climate change on crop and livestock species.

The effects of climate change will include single and combined effects of changes in temperature, precipitation, soil moisture regimes, and solar radiation. This task involves identification of those species which are critical and which may be seriously impacted by the direct effects of climate change. The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT 1989) has identified eleven such species or groups of crop plants (aroids, barley, cassava, dry bean, maize, peanut, potato, rice, sorghum, soybean and wheat). Additional crops have been identified as important and are suggested for inclusion within this activity (IGBP 1990b). These include: bananas/plantains, sugar cane, grain legumes, oil seeds, root crops, vegetable and fruit crops, fibre crops, and industrial crops. An equivalent list of tree species needs to be developed for the major, commercially important forest production regions in the world. The list of livestock species that will be influenced by climate change is quite long. Priority attention should be focused on the major breeds of cattle and sheep. A survey of species production at their biological limits for each of these abiotic parameters must be conducted to provide information about changes which might be expected.

Modelling of plant and animal species at the climate imposed physiological limits of spatial distribution will be required to integrate information, develop a classification of the types of responses which might be expected for extension to species not investigated, and to link information to the full agroecosystem. IBSNAT models of key species provide the basic format for crop plant species. Appropriate models for tree and animal species must be developed. Such models should be linked to GIS systems to evaluate their future potential distributions in relation to climate and soils.

While the direct effects of climate change on livestock may be significant, the greatest changes in livestock production from the extensive pastoral regions of the world will more likely be a result of changes in rangeland production and composition. Much of the basic understanding required for predicting these changes will come from the research in Focus 1 and 2. However, there is an additional need, to meet the requirements of this task, to specifically address the changes in productivity or grazed rangelands, and the dynamics of the functional composition of rangelands. This work needs to be closely integrated with that proposed under Focus 2. It should be focused on sites representative of selected, major rangeland types (see IGBP 1990b).

Task 2. Determine the impact of climate change on the physiology of plant development

With regard to agricultural plants this task requires a basic understanding of the environmental and genetic control of plant development. The primary impact of climate change on a crop will depend on the stage of plant development and the rate of change from one life stage to the next. The environmental and genetic control of development is not understood for most grain and fruit crops (IGBP 1990b). This understanding of the relationship between the genetic control of development and environment is necessary to determine the flexibility of species to continue production under changed conditions, and to determine the modified conditions or areas which are required for continued production.

The main requirement is for controlled experiments under field conditions. Selection of plant species for inclusion in the experiments should be drawn first from those grain and fruit crops identified as critical for world food production. (IGBP 1990b).

Task 3. Determine the effects of elevated CO_2 on major crop and forest species in terms of harvested products.

The effects of elevated CO_2 levels and the interaction of CO_2 with climate on plant production will in large part be met by the work proposed in Focus 1. However, additional research is required here to determine how increased CO_2 will affect plant growth in crops and how this will influence soils and harvestable products. Change in the atmospheric concentration of CO_2 may have con-sequences for the partitioning of biomass to or away from harvestable products and may change competitive relationships among species. The additional work must be closely integrated with the experimental approach in Focus 1.

Changes in Pests and Diseases of Crops and Livestock — *Activity 2*

The primary question to be addressed in this activity is: Will crop and livestock species and the sustainability of agroecosystem production be affected by changes in the incidence of pests and pathogens resulting from global change?

Changes in the frequency of pest and disease outbreaks and in their distribution will affect all agroecosystems to varying degrees. Small changes in temperature (in particular) or other climate variables may dramatically change the distribution and severity of pests and diseases (see discussions in Mooney and Drake 1986), as illustrated by the projected increase in the Screw Worm fly distribution. Such changes could alter the management requirements for producing, harvesting, and storing agricultural crops and forest products, and could have a severe impact on livestock. Plague locusts, rusts, Scot's Pine beetles, sawflies, tsetse fly, cattle tick, etc., are all strongly influenced by temperature and moisture regimes. Insect pests and vectors, which do not have a diapause state, may become more widespread as temperatures increase and the frequency of frost is lowered. Land-use changes could likewise change pest and pathogen regimes when hosts and vectors are moved into areas previously unaffected.

Because these pests have substantial economic significance, some have been well studied and modelled. A reorientation of this information to the specific questions of climate change is needed followed by the identification of organisms which have predisposing life-history features which may cause future problems but have not yet been studied in appropriate depth.

Objective

- *To understand how pests and diseases will change in impact and spatial and temporal distribution and variability, and to model these changes so that they may be incorporated into change and management scenarios.*

Task 1. Analysis of the dynamics of pests and disease in relation to climatic gradients.

Information on the current distributions, and on the changes (fluctuations) in these distributions of pests and diseases affecting important plant and animal species, must be obtained together with the concurrent climatic conditions and land-use management. The interactive effect of changing climate, land use and distributions must be analysed. This information should be developed for different biogeographic regions of the world. In particular, the relationships of disease vectors to climatic events need to be assessed.

Task 2. Develop predictive models for pests and disease.

Model development is essential if we are to predict the changes in distribution of pests and diseases. Although the control of pests and diseases in agricultural systems is often very strong, empirical data about many problem species is not available. Current and future agricultural-production management systems require effective methods of pest and disease control and the need for these may be identified through modelling change scenarios.

Both of these tasks should begin with well-studied organisms. An effort should be made to identify the pre-disposing functional characteristics, which promote pest and disease outbreak under climatic change for each category of pest or disease vector. These functional characters should be applied to other less-studied organisms in each category to determine which organisms should receive the highest priority for research.

Activity 3

Change in in situ *Properties, Redistribution and Net Loss of Soil*

In common with other ecosystem components, soils have variables that operate at slow, intermediate and fast rates. It is important to recognize this, and the fact that these variables may not always move soil properties or development in the same direction. Many soil properties are highly dynamic, whereas others are relatively static. Soluble salts are examples of highly dynamic variables, changing over a season and capable of approaching equilibrium in a few years. Organic matter levels have a time dimension of decades to centuries, while carbonate and (particularly) clay weathering have a scale of millennia in semiarid climates (Anderson 1977). Despite a medium time-scale for organic matter build up in soils, at another level of detail one can differentiate fast (mainly microbial processes), intermediate (where turnover is dampened by physical sorption to clay), and slow (or chemically-stabilized) changes in humus components in soils (Anderson 1979, Jenkinson and Rayner 1977). Episodic events that initiate a threshold response in soils result in considerable change in properties over short time spans. In this respect, soils must be considered as being highly dynamic, and land use and climatic changes may significantly modify the rates of these processes.

Consequences of changes in climate and land use on soil processes and properties include:

- Carbon accumulation and distribution in the soil. Most of the changes associated with a change in atmospheric CO_2 concentration and climate will impact on soils through the amount, distribution and composition of plant biomass above- and below-ground. These changes will alter the rates of plant decomposition and in combination with any observed moisture effects will alter the distribution of organic C, N, P, and S in soils. It also can alter the availability of organically held nutrients that are normally released over a season by nutrient cycling processes.
- Soil water supply and the ability of the soil to sustain the growth of crops. These will involve changes organic matter content, water holding capacity, and changes is soil surface characteristics such as compaction, which will affect permeability and water infiltration.
- The distribution of salts, other soluble components and nutrients. These will result mainly from changes in the hydrological cycle (e.g., accumulation of salts, leaching of nutrients, leaching of soluble organic components, clay migration and other pedogenic processes). The consequences of changes in these highly dynamic processes can become evident in a few years.
- Soil erosion, which includes accelerated wind and water erosion of croplands. Managed areas are particularly susceptible because changes in land use cause changes in canopy cover and surface soil protection, and in carbon inputs and distribution. In general, these changes make soils more vulnerable to erosion.

Objective

- *To develop the capacity to predict the effects of changes in climate and atmospheric composition on the quality of land through changes of* in situ *soil processes and in soil erosion.*

Task 1. Changes in soil processes resulting from climate and land-management changes.

Soil modifications resulting from climatic and land-use changes in non-agricultural as well as agricultural and forestry systems will require: (i) comparative analyses of soils along existing temperature and rainfall gradients (longer term effects); and (ii) manipulative experiments in which chemical, physical and biological processes are measured under different temperature (if possible) and water regimes. These studies should complement those outlined in the previous Foci.

The soil changes which need to be examined (as based on the UNEP/ISSS workshop, February 1990) include: (i) amount and quality of organic C, N, P, and S; (ii) structural stability and moisture characteristics; (iii) nutrient status, acidity and redox regime; (iv) salinity and alkalinity; (v) soil meso- and macro-fauna; and (vi) iron and aluminum amorphous minerals.

Task 2. Soil erosion and redistribution of soil in response to changes in climate and land management.

The work required for this task involves specific attention to the interactive effects of changes in rainfall regime and land-cover characteristics, including changes in vegetation cover resulting from climatic changes or agricultural-management activities. Erosion rates are far higher where the original vegetation cover has been modified or removed and where the soil surface has been disturbed.

This task requires the development of a geomorphological, mechanistic model based, in turn, on a GIS for intensive study areas and, in coarser detail, continents. Information required includes: (i) climate-change scenarios and local climate/weather simulator from WCRP and others; (ii) land-cover change predictions from Focus 2, Activities 1-3; (iii) land-use change predictions from Focus 2, Activity 3; and (iv) hydrologic change predictions from BAHC and Focus 1, Activity 3 (Fig. 1). Remote-sensing will be necessary in this task, firstly to provide information to develop and test erosion models (e.g., Pickup and Chewings 1986), and secondly to initiate a monitoring system designed to detect trends in the selected regions.

The information produced in Tasks 1 and 2 can be integrated by means of generalized agroecosystem models, which include information on driving variables, processes and properties (e.g., Parton et al. 1987, 1989). Processes already studied and integrated into models include above- and below-ground primary production, decomposition and nutrient cycling. Major driving variables include climate (temperature and water), parent material (soil texture), base status, total S and P, topography and management. The effects of these controlling factors are expressed over a broad spatial scale from the globe down to regional, landscape or field plot levels.

Two main approaches are available for this purpose: (i) analogue studies using soil chronosequences or using situations where (e.g., due to deforestation, mine reclamation studies, volcanic areas, etc.), local soil climate has changed, and (ii) manipulation studies (e.g., elevated CO_2) in the field (small chamber, small watershed), greenhouse or laboratory.

Other approaches are given in: "Methods of Soil Analysis", American Society of Agric., v. 1 & 2, Tropical Soil Biology and Fertility Programme of IUBS (Ingram and Swift 1989). Processes which are important in elemental interactions and which are important for soil quality have recently been reviewed (Anderson 1988, Stewart and Cole 1989).

The work on processes needs to be developed in conjunction with soil process models. Models have been developed to understand the functioning of agroecosystems in relatively young unweathered soils. These models can be used to simulate the effects of a range of climatic conditions on crop productivity and soil quality. Extrapolation of this approach to more weathered soils will depend on a better understanding of several major processes, including the effect of soil inorganic constituents and selected minerals on abiotic and biotic formation and stabilization of organic matter.

Implementation

General

The implementation of the Core Activities will be phased according to the logical sequence of information transfers between tasks and activities, and (pragmatically) on gaining support from the scientific community, national and regional support for the specific tasks and the establishment of cross-activity linkages. Monitoring progress of the Core Project must be explicitly built into the implementation plans of each task.

The Scientific Steering Committee (SSC) will facilitate coordination of tasks among the activity or focus of responsibility (e.g., ensuring that variables being measured, time intervals, levels of accuracy, etc., are compatible between tasks and allow for the activity as a whole to come together). Occasionally, a task working group may be formed to work on a specific topic or methodology for the Core Project. These task working groups will have defined life times and will be disbanded once the objective is achieved.

Core Project Office

The CPO will serve as the base of communication between activities and other projects, where this is needed. Activity offices will also be identified, and much of the coordination of the research would be conducted at this level. The core activities are the operational units of the project, and as such are the most important.

Meetings and Initiating Workshops

The initiation of the Core Project depends on its acceptance by the scientific community and the IGBP member nations. An Open Meeting of scientists from the member nations, ICSU bodies, and other associated organizations will be arranged in March 1991 to formulate an implementation plan.

In addition to the Open Meeting, a series of regional and national presentations of the Core Projects and Activities will be conducted at pertinent scientific society meetings. These presentations, based on a package of visual aids, are necessary to ensure acceptance by the community of ecological scientists.

Following the Core Project Open Meeting, it is planned to hold an initiating workshop for each Core Activity, to which all National Committees of IGBP will be again invited. The workshops will be organized and run by the Core Activity leaders, in association with the Core Project Office, and will be aimed at refining priorities, setting targets, selecting areas, identifying research groups and agreeing on broad methodological approaches and research products.

Progress Assessment

A mid-term check of progress of this Core Project is proposed for April 1994. A workshop to make an intercomparison of modelling results from all scales of the project will be held. The workshop will enable participants from various research groups to compare field and model results through model validation and verification comparisons. Progress assessment and identification of gaps in the operational aspect of the Core Project will be made. Means for assessing progress of specific tasks will be developed at the initiating workshops, planned for each task.

Other Workshops

A number of developments will require specific workshops. One example is the need to bring together social scientists and IGBP scientists to plan and initiate a project on predicting changes in land-use.

References

Acock, B. and Allen, L. H. 1985. Crop responses to elevated carbon dioxide. In:Strain, B. R. and Cure, J. D. (eds) Direct Effects of Increasing Carbon Dioxide on Vegetation, pp. 53-97. DOE/ER-0238, US Department of Energy, Washington, DC, USA.

Anderson, D. W. 1977. Early stages of soil formation on glacial till mine spoils in a semi-arid climate. Geoderma 19:11-19.

Anderson, D. W. 1979. Processes of humus formation and transformations of soils of the Canadian Great Plains. J. Soil Sci. 30:77-84.

Anderson, D. W. 1988. The effect of parent material and soil development on nutrient cycling in temperate ecosystems. Biogeochem. 5, 71-79.

Björkman, O. and Pearcy, R. W. 1983. Physiological effects. In: Lemon, E. R. (ed) CO_2 and Plants - The Response of Plants to Rising Levels of Atmospheric Carbon Dioxide, pp. 65-105. Westview Press Inc., Boulder, USA.

Bolin, B. and Cook, R. B. (eds) 1983. The Major Biogeochemical Cycles and Their Interactions. SCOPE 21. John Wiley & Sons, Chichester.

Bolin, B. 1986. The carbon cycle and projections for the future. In: Bolin, B., Döös, B. R., Jäger, J. and Warrick, R. A. (eds). The Greenhouse Effect, Climatic Change, and Ecosystems. SCOPE 29:93-156. John Wiley & Sons, Chichester.

Box, E. O. 1981. Microclimate and plant forms: an introduction to predictive modelling in phytogeography. In: Leith, H. (ed). Tasks in Vegetation Science Vol. 1. Junk, The Hague.

Clough, J. M., Peet, M. M. and Kramer, P. J. 1981. Effects of high atmospheric CO_2 and sink size on rates of photosynthesis of a soybean cultivar. Plant Physiology 67:1007-1010.

COHMAP Members 1988. Anderson, P. M., Barnosky, C. W., Bartlein, P. J., Behling, P. J., Brubaker, L., Cushing, E. J., Dodson, J., Dworetsky, B., Guetter, P. J., Harrison, S. P., Huntly, B., Kutzbach, J. E., Markgraf, V., Marvel, R., McGlone, M. S., Mix, A., Moar, N. T., Morley, J., Perrott, R. A., Peterson, G. M., Prell, W. L., Prentice, I. C., Ritchie, J. C., Roberts, N., Ruddiman, W. F., Salinger, M. J., Spaulding, W. G., Street-Perrott, F. A., Thompson, R. S., Wang, P. K., Webb III, T., Winkler, M. G., and Wright Jr., H. E.

Davis, M. B. 1981. Quarternary history and the stability of forest communities. In: West, D. C., Shugart, H. H. and Botkin D. B. (eds). Forest Succession: Concepts and Application, pp. 132-153. Springer-Verlag, New York.

Drake, B. G., Leadley, P. W., Arp, W. J., Nassiry, D. and Curtis, P. S. 1989. An open top chamber for field studies of elevated atmospheric CO_2 concentration on saltmarsh vegetation. Functional Ecology 3:363-371.

Emmanuel, W. R., Shugart, H. H. and Stevenson, M. P. 1985. Climatic change and the broad-scale distribution of terrestrial ecosystem complexes. Climatic Change 7:29-43.

Fajer, E. D. 1989. The effects of enriched CO_2 atmospheres on plant-insect herbivore interactions and growth responses of larvae of the specialist butterfly, Junonia cochia (Lepidoptera: Nymphalidae). Oecologia 81:514-520.

Gifford, R. M., Landers, H. and Morison, J. J. L. 1985. Respiration of crop species under CO_2 enrichment. Physiologia Plantarum 63:351-356.

Holling, C. S. 1978. Adaptive Environmental Assessment and Management. John Wiley & Sons, Chichester. 377 pp.

BSNAT. 1989. International Benchmark Sites Network for Agrotechnology Transfer. University of Hawaii, 2500 Dole Street, Krauss 18, Honolulu, HI 96822, USA.

IGBP 1989. Effects of Atmospheric and Climate Change on Terrestrial Ecosystems. Report of a Workshop organized by the IGBP Co-ordinating Panel on Effects of Climate Change on Terrestrial Ecosystems at CSIRO, Division of Wildlife and Ecology, Canberra, Australia, 29 February - 2 March, 1988. Walker, B. H. and Graetz, R. D. (eds).

IGBP Report 5. IGBP Secretariat, Stockholm. IGBP 1990a. Land Atmosphere Interface. Report on a Combined Modelling Workshop of IGBP Coordinating Panels 3, 4, and 5. Turner, S. J. and Walker, B. H. (eds) IGBP Report 10. IGBP Secretariat, Stockholm.

IGBP 1990b. Proceedings of the Workshops of the Coordinating Panel on Effects of Global Change on Terrestrial Ecosystems. I. A Framework for Modelling the Effects of Climate and Atmospheric Change on Terrestrial Ecosystems, Woods Hole, USA, 15-17 April, 1989. II. Non-Modelling Research Requirements for Understanding, Predicting, and Monitoring Global Change, Canberra, 29-31 August 1989. III. The Impact of Global Change on Agriculture and Forestry, Yaoundé, 27 November-1 December, 1989. Edited by Walker, B. H., Turner, S. J., Prinsley, R. T., Smith, D. M. S., and Nix, H. A. (1990) (IGBP Report 11) .

Ingram, J. S. I. and Swift, M. J. (eds) 1989. Tropical Soil Biology and Fertility (TSBF) Programme. Report of the Fourth TSBF Interregional Workshop. IUBS 20. 64 pp.

Jenkinson, D. S. and Rayner, J. H. 1977. The turnover of soil organic matter in some Rothamsted classical experiments. Soil Sci. 123:298-305.

Lincoln, D. E., Couvet, D. and Sionit, N. 1986. Response of an insect herbivore to host plants grown in carbon dioxide enriched atmospheres. Oecologia 69:556-560.

Marc, J. and Gifford, R. M. 1983. Floral initiation in wheat, sunflower, and sorghum under carbon dioxide enrichment. Can. J. Bot. 62:9-14.

Masterson, C. L. and Sherwood, M. T. 1978. Some effects of increased atmospheric carbon dioxide on white clover (Trifolium repens) and pea (Pisum sativum). Plant and Soil 49:421-426.

Melillo, J. M., Naiman, R. J., Aber, J. D. and Linkens, A. E. 1984. Factors controlling mass loss and nitrogen dynamics of plant litter decaying in northern streams. Bulletin of Marine Science 35:341-356.

Mooney, H. A. and Drake, J. A. 1986. Biological Invasions: a SCOPE Programme Overview. In: Drake, J. A., Mooney, H. A., di Castri, F., Groves, R. H., Kruger, F. J., Rejmtnek, M., and Williamson, M. (eds) Biological Invasions: A Global Perspective. SCOPE 37:491-509. John Wiley & Sons, Chichester.

Moore, A. D. and Noble, I. R. 1990. FATE: An individualistic model of vegetation stand dynamics. Environmental Mechanics. (In press).

Morison, J. I. L. and Gifford, R. M. 1984. Plant growth and water use with limited water supply in high CO_2 concentration. II. Plant dry weight, partitioning and water use efficiency. Australian Journal of Plant Physiology 11:375-384.

Noble, I. R. and Slatyer, R. O. 1980. Use of vital attributes to predict successional changes in plant communities subject to recurrent disturbance. Vegetatio 43:5-21.

Norby, R. J. 1987. Nodulation and nitrogenase activity in nitrogen-fixing woody plants stimulated by CO2 enrichment of the atmosphere. Physiologia Plantarum 71:77-82.

NRC. 1986. Global Change in the Geosphere-Biosphere Programme. Initial Priorities for an IGBP. National Academy Press, Washington, DC.

O'Neill, E. G., Luxmoore, R. J. and Norby, R. J. 1987. Increases in mycorrhizal colonization and seedling growth in Pinus echinata and Quercus alba in an enriched CO_2 atmosphere. Canadian Journal of Forest Research 17:878-883.

Overdieck, D. and Reining, F. 1986. Effect of atmospheric CO_2 enrichment on perennial ryegrass (*Lolium perenne* L.) and whiteclover (*Trifolium repens* L.) competing in managed model- ecosystems I. Phytomass production. Acta Oecologia 7:357- 366.

Parton, W. J., Schimel, D. S., Cole, C. V. and Ojima, D. S. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Sci. Soc. Am. J. 51: 1173-1179.

Parton, W. J., Cole, C. V., Stewart, J. W. B., Schimel, D. S. and Ojima, D. S. 1989. Simulating regional patterns of C, N, and P dynamics in the U.S. central grasslands region. In: Clarholm, M. and Bergström, L. (eds). Ecology of Arable Land - Perspectives and Challenges. Developments in Plant and Soil Sciences Vol. 39. Klüwer Academic Publishers.

Pastor, J. and Post, W. M. 1988. Response of northern forests to CO_2 induced climatic change. Nature 334:55-58.

Pickup, G. and Chewings, V. H. 1986. Mapping and forecasting soil erosion patterns from landsat on a microcomputer-based image processing facility. Australian Rangeland Journal 8(1):57-62.

Prentice, I. C. 1986. Vegetation response to past climatic variation. Vegetatio 67:131-141.

Prentice, I. C., Webb, R. S., Ter-Mikhaelian, M., Solomon, A. M., Smith, T. M,

Pitovranov, S. E., Nikolov, N., Minin, A. A., Leemans, R., Lavorel, S., Korzukhin, M. D, Hrabovszky, J. P, Helmisaari, H. O, Harrison, S. P., Emanuel, W. R., and Bonan, G. B. 1989. Developing a Global Vegetation Dynamics Model: Results of an IIASA Summer Workshop. International Institute of Applied Systems Analysis, Laxenburg, Austria.

Reekie, E. G. and Bazzaz, F. A. 1989. Competition and patterns of resource use among seedlings of five tropical trees grown at ambient and elevated CO_2. Oecologia 79:212-222.

Sellers, P. J., Mintz, Y., Sud, Y. C. and Dalcher, A. 1986. A simple biosphere (SIB) for use within general circulation models. Journal of Atmospheric Science 43:503-531.

Shugart, H. H. 1984. A Theory of Forest Dynamics. Springer-Verlag, New York. 278 pp.

Shugart, H. H. Antonovisky, M. J., Jarvis, P. G. and Sanford, A. P. 1986. CO_2, climatic change, and forest ecosystems. In: Bolin, B., Döös, B. R., Jäger, J. and Warrick, R. A. (eds). The Greenhouse Effect, Climatic Change, and Ecosystems. SCOPE 29:475-521. John Wiley & Sons, Chichester.

Smith, T. and Huston, M. 1989. A theory of the spatial and temporal dynamics of plant communities. Vegetatio.

Stewart, J. W. B. and Cole, C. V. 1989. Influences of elemental interactions and pedogenic processes in organic matter dynamics. In: Clarholm, M. and L. Bergstrîm (eds). Ecology of Arable Land - Perspectives and Challenges. Developments in Plant and Soil Sciences Vol. 39. Klüwer Academic Publishers.

Tans, P. P., Fung, I. Y., and Takahashi, T. 1990. Observational Constraints on the Global Atmospheric CO_2 Budget. Science 247:1431-1438.

Walker, B. H., Young, M. D., Parslow, J. S., Cocks, K. D., Fleming, P. M., Margules, C. R. and Landsberg, J. J. 1989. Effect on renewable natural resources. In: Global Climatic Change - Issues for Australia, pp. 31-76. Commonwealth of Australia.

Warrick, R. A., Shugart, H. H., Antonovsky, M. J. with Tarrant, J. R. and Tucker, C. J. 1986a. The effects of increased CO_2 and climatic change on terrestrial ecosystems. In: Bolin, B., Döös B. R., Jäger, J. and Warrick R. A. (eds). The Greenhouse Effect, Climatic Change, and Ecosystems. SCOPE 29:363-382. John Wiley and Sons, Chichester.

Warrick, R. A., Gifford, R. M. and Parry, M. L. 1986b. CO_2, climate change and agriculture. In: Bolin, B., Döös, B. R, Jäger, J., and Warrick R. A. (eds). The Greenhouse Effect, Climatic Change, and Ecosystems. SCOPE 29:393-473. John Wiley & Sons, Chichester.

Webb, S. L. 1987. The Holocene extension of range of American beech into Wisconsin: Paleoecological evidence for long-distance seed dispersal. Ecology 68:1993-2005.

Woodward, F. I. 1987. Climate and Plant Distribution. Cambridge University Press, Cambridge. 174 pp.

Suggested Reading

Bolin, B. and Cook, R. B. (eds). 1983. The Major Biogeochemical Cycles and their Interactions. SCOPE 21. John Wiley & Sons, Chichester.

Bolin, B., Döös, B. R., Jäger, J. and Warrick, R. A. (eds). 1988.The Greenhouse Effect, Climatic Change, and Ecosystems. SCOPE 29. John Wiley & Sons, Chichester.

Bouwman, A. F. (ed) 1990. Soils and the Greenhouse Effect. Proceedings of the International Conference Soils and the Greenhouse Effect. Wageningen, The Netherlands 1989. John Wiley & Sons, Chichester.

Drake, J. A., Mooney, H. A., di Castri, F., Groves, R. H., Kruger, F. J., Rejmanek, M., and Williamson, M. 1989. Biological Invasions: A Global Perspective. SCOPE 37. John Wiley & Sons, Chichester.

Prentice, I. C., Webb, R. S., Ter-Mikhaelian, M., Solomon, A. M., Smith, T. M, Pitovranov, S. E., Nikolov, N., Minin, A. A., Leemans, R., Lavorel, S., Korzukhin, M. D, Hrabovszky, J. P, Helmisaari, H. O, Harrison, S. P.,

Emanuel, W. R., and Bonan, G. B. 1989. Developing a global vegetation dynamics model: Results of an IIASA summer workshop. International Institute of Applied Systems Analysis, Laxenburg, Austria.
Rosswall, T. R., Woodmansee, R. G., and Risser, P. G. 1988. Scales and Global Change: Spatial and Temporal Variability in Biospheric and Geospheric Processes. SCOPE 35. John Wiley and Sons, Chichester.
West, D. C., Shugart, H. H. and Botkin, D. B. (eds). Forest Succession: Concepts and Application, pp. 132-153. Springer-Verlag, New York.

6.2 Global Change and Ecological Complexity (GCEC)

A Potential Core Project

Objective

- *To develop a capability to predict the relation between global change and ecological complexity. In this context, global change is defined as changes in land-use, atmospheric chemistry, and climate. Ecological complexity is understood to be a function of genetic, alpha, beta, and patch diversity ranging from genetic variation at the individual population level through diversity of functional types of species to regional community complexity.*

Introduction

There are two as yet untested hypotheses relating to the effects of global change on ecological complexity that are potentially very important.
- Changes in species diversity lead to a changes in ecosystem function, such as, productivity, nutrient cycling, and response to disturbance.
- Genetic variation is necessary for species survival in a variable environment; if variability drops below a certain threshold, species survival is endangered.

The question of the level of species redundancy in ecosystem species composition is at the core of the first hypothesis. However, some key species and habitats may regulate ecosystem function and dynamics, and already some such have been identified. If genetic variability does influence species vigour, a change in diversity involving such species and communities will have a significant effect on ecological complexity.

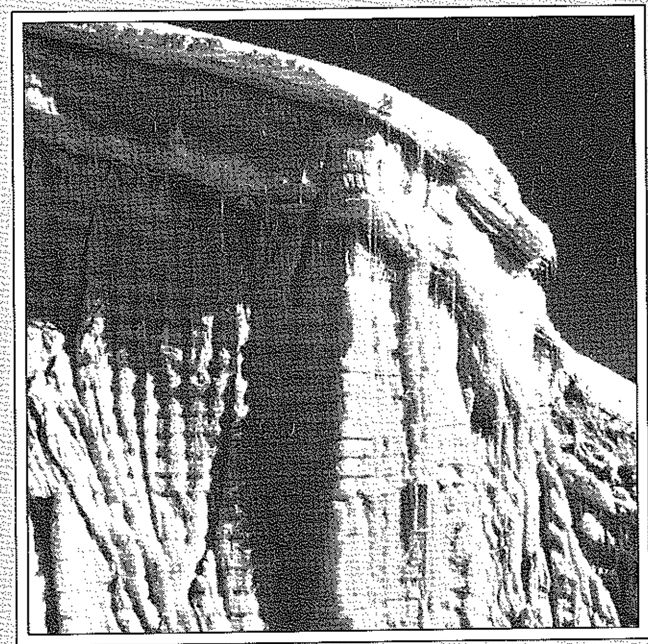
A significant change of biological/ecological diversity may have already occurred because of the fragmentation of habitats. This existing pressure in combination with the anticipated rapid climate changes constitute a potentially serious treat to ecosystems. For some systems, e.g., stranded mountain-top relics, the probable effects are obvious. However, for other systems the effects that may occur as a result of climatic changes are not so obvious.

Proposal

There are two important questions that need to be answered before the IGBP can proceed with an active research project.
- What kinds of diversity (genetic, populational, community), singly or in combination, in which kinds of ecosystems are ecologically important?
- What will the likely effects be of global change, land-use and climate, on the diversity of those ecosystems (genes, species, communities) if diversity is of vital importance?

An analysis of the existing data is needed to examine these questions in detail and to better define the research problem. It is proposed that SCOPE and IUBS undertake an initial analysis as a first phase of this potential IGBP project. Based on the outcome of this analysis, a science plan may be developed.

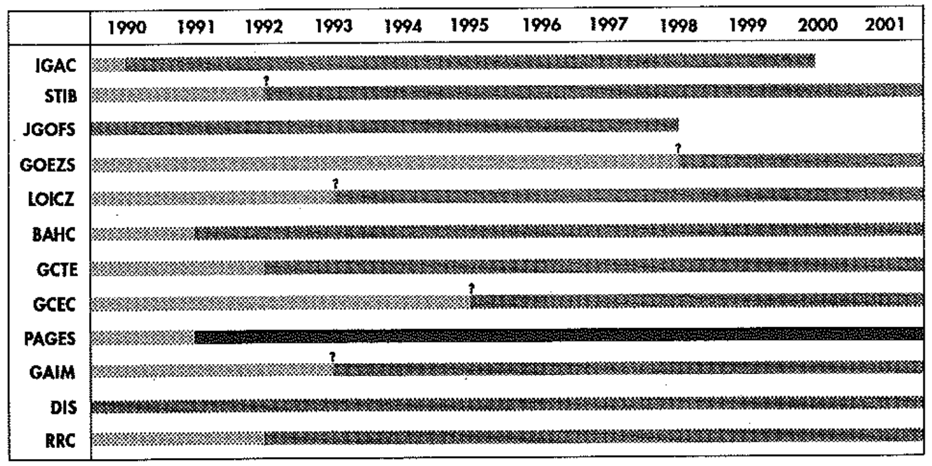
GLOBAL
IGBP
CHANGE



What Significant Climatic and Environmental Changes Have Occurred in the Past, and What Were Their Causes?

Changes in the past global environment are recorded in natural archives of many kinds: ice cores, ocean and lake sediments, tree rings, pollen and coral deposits. Analyses of such records have provided much of what we know of past climatic change and its effects. For example, pollen records have allowed us to deduce the effect of climate change on the distribution and composition of terrestrial ecosystems during a glacial cycle. Variations in concentration of gases trapped within polar ice cores provide evidence for change in atmospheric conditions through the last ice-age cycle of 160,000 years. This record indicates that variations in the atmospheric carbon dioxide content and average global temperature are linked, but in its present form cannot be used to infer cause and effect. It does, however, demonstrate the bounds for the extent and rate of such natural changes, and, importantly, it provides a context against which the measured record of carbon dioxide abundance over the last three decades can be interpreted. A continued and focussed effort in examining the information available in natural archives will provide us with a unique data base for the periods in the Earth's history when human influences were absent and will also highlight past periods when humans started to perturb the global system.

Contents



1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
IGAC
STIB
JGOFS
GOEZS
LOICZ
BAHC
GCTE
GCEC
PAGES
GAIM
DIS
RRC

7.1 Past Global Changes (PAGES)

An Established Core Project

Introduction

Background

In foretelling global changes of the future we are faced with questions which can be answered only through a better knowledge of the past. For this purpose we need to know not only the history of climate per se, but also the related changes, be they causes or effects, in the entire Earth system. These include the chemistry of the air and the water and the soils, the state and distribution of vegetation and marine biota, and the level of the oceans and their mode of circulation, to mention but a few.

In seeking and interpreting these data we must be aware that the Earth system is never in a state of absolute equilibrium. As an example, the last stages of transition from a glacial to the present interglacial state occurred only about 10,000 yr ago, a reach of time which is of the same order of magnitude as the mean residence time of ice in the Greenland and Antarctic ice sheets (even though the deepest ice is an order of magnitude older). The polar ice sheets may thus be yet approaching their interglacial state, such that rates of accumulation and ablation are not in balance, with resultant changes in world sea level.

Secondly, the Earth system is continually changing, due to natural processes. Global surface temperature, for example, varies considerably from year to year and from decade to decade, in reaction to external forcing or through internal oscillations of the atmosphere-ocean system. These natural changes are of both short- and long-term. Thus, the instrumental global temperature record of the last 100 yr must be interpreted in the perspective of the natural variations of a much longer span, which include, in the last 1000 yr, the probably global Little Ice Age (ca. AD 1500-1850) and the preceding Medieval Warm Interval (AD 1000-1200). It thus becomes a matter of some urgency to improve our knowledge of these past events, and to identify their causes. Similar natural variations may well be superposed on any current global warming trend; knowledge of these forcing mechanisms and their effects are necessary to quantify anticipated warming due to the enhanced greenhouse effect.

There are many lessons to be learned from the remarkably steady rise in CO_2 found in atmospheric samples taken from around the world. Each year about 1/3 of the CO_2 in the atmosphere is exchanged with the biosphere and with the oceans. A yearly imbalance of but 1% between the flux of CO_2 into and out of the atmosphere would fully account for the observed upward trend. Measurements of air drawn from polar ice cores show; (i) a relatively constant concentration of atmospheric CO_2 through the millennium that preceded the Industrial Age; (ii) an increase in the 19th century; and (iii) a steeper increase in the current century. Measurements of CO_2 taken from polar ice yield abundances for the period 1960-1970 that overlap with those from air samples taken during the same period. Hence, there can be little doubt that the ongoing increase in atmospheric CO_2 is due to anthropogenic emissions. The ice core studies also show that during certain periods the CO_2 exchange fluxes were not in balance, leading to changes in atmospheric concentration. The ice-core drawn from the Antarctic Vostok station, covering the period of the last 160,000 yr, demonstrated that both CO_2 and CH_4 varied in step with temperatures derived from isotopic ratios in the ice itself. This finding is important in several respects. It implies that changes in greenhouse forcing, associated with CO_2 and CH_4 fluctuations, played a critical role in the climate change of the last two glacial-interglacial cycles. It also raises fundamental questions as to how the atmospheric concentrations of these gases are controlled. The observed fluctuations in CO_2 are most likely due to changes in the vigor of the biological pump in parts of the surface ocean. The changes in

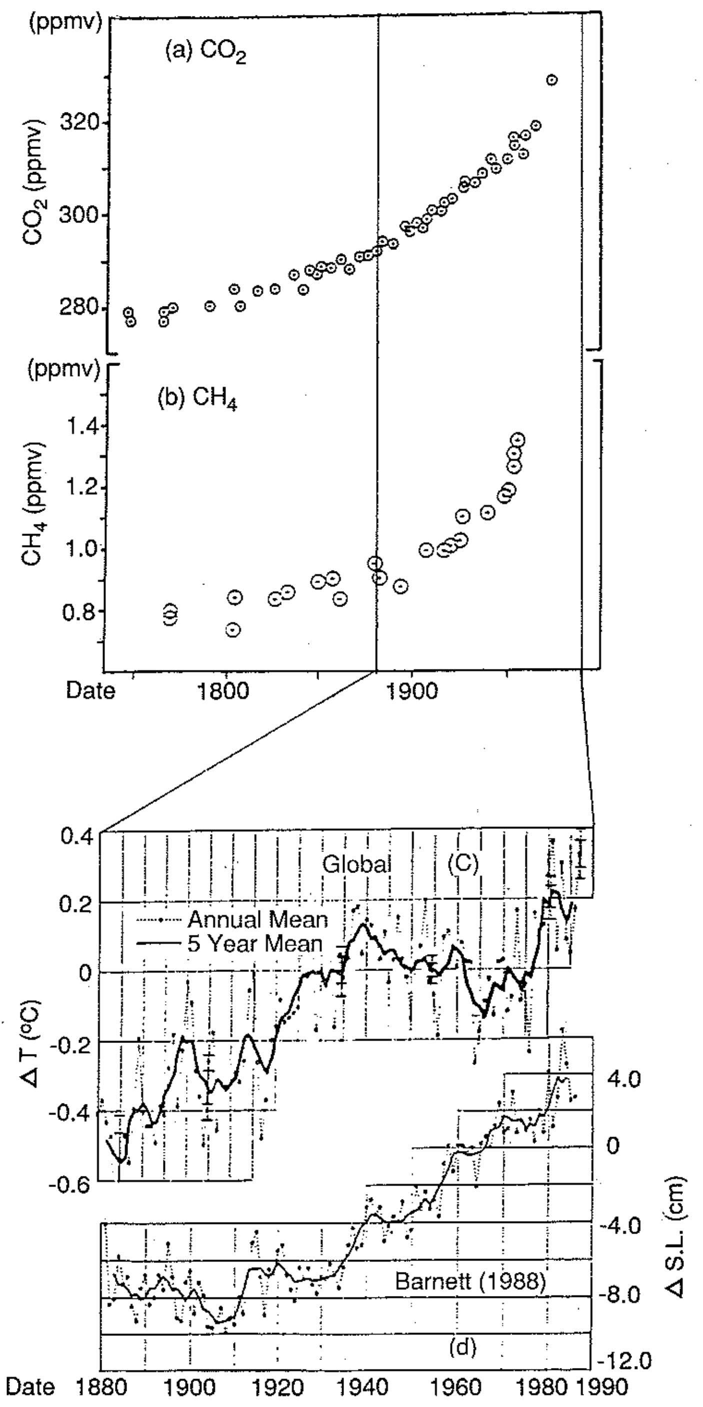


Figure 1. The record of global changes during the past 150 years. Curves a-b, reconstructions of atmospheric CO_2 and CH_4 concentrations based on the analysis of gas trapped in ice collected at Siple Station, West Antarctica (from Stauffer 1988). Present concentrations are 345 ppm(v) (CO_2) and 1.7 ppm(v) (CH_4). Curves c-d, records of global mean annual temperature (from Hanson 1989) and sea-level changes (from Barnett 1988). In both curves, the average value for the period 1951-1970 is set equal to zero, with data reported as deviations from zero; the dashed lines are annual mean values and the solid line, a 5-year running mean.

CH_4 are fundamentally different; they are probably the result of changes in source terms, as for example, from a change in the amount of wetlands, although changes in the oxidizing capacity of the atmosphere, which controls the natural destruction of CH_4, cannot be excluded. Furthermore, it reveals that with anticipated global warming, we can expect feedback effects involving processes similar to those which took place in the course of past climatic changes.

An unexpected finding from polar ice cores was that between 70,000 and 30,000 B.P., the climate of Greenland and probably of the entire North Atlantic region oscillated, back and forth, about a dozen times between colder and milder climate states. Not only $\partial^{18}O$, but all the parameters measured thus far, including airborne dust, appear to follow the same natural oscillation between two distinct climatic states. The last of these events occurred during the last glacial-interglacial transition and coincides with the Bolling-Allerod warm phase, determined by pollen studies in peat bogs. What followed was a rapid cooling, found in continental records, that is known as the Younger Dryas cold period. At about 10,000 B.P. the Younger Dryas drew to a sudden end, marking the final transition to the contemporary, warmer Holocene Period.

These climatic changes of the glacial-postglacial transition are related to changes in the extension of the cold region of the North Atlantic ocean, as derived from ocean sediment studies. This observation reveals the sensitivity of the North Atlantic region to ocean circulation changes. It has been speculated that the abrupt climatic changes during the glaciation and at its end are due to a switching on and off of deep water formation in the North Atlantic ocean (Broecker and Denton 1990). Regional and global responses of vegetation to these climatic changes can be readily identified in, for example, pollen information in peat bogs and in laminated lake sediments.

Rationale

Data concerning previous environmental conditions are available from instrumental records and documentary histories, as well as from the information preserved in natural archives of many types, including ice cores; marine, lacustrine and terrestrial sediments (loess deposits, in particular); tree rings; corals; and palaeosols. Studies of the physical, chemical and biological parameters recorded in such archives have provided a wealth of information on both the "natural" behaviour of the Earth system and on more recent human impacts. Quantitative information on global changes of the past can be used to document forcing factors and to understand the large-scale responses to such forcing mechanisms; to place observed trends in contemporary data into a broader context; to identify unknown and potentially important processes that link biological, physical and chemical components of the Earth system; to test hypotheses regarding these linkages; and to evaluate the validity of analytical Earth system models through sensitivity studies and detailed comparisons of simulated behaviour with changes reconstructed from palaeodata.

Insights from global changes of the past have already enhanced our understanding of changes in atmospheric composition, albedo, landscapes and land-use, global biomass and biogeochemical cycles, the mixing rate of the ocean, solar modulation of cosmic radiation, and the magnitudes and rates of environmental changes associated with glacial-interglacial climatic cycles (Bradley 1990). Much of the evidence for human-induced change and all of the evidence for past changes resulting from natural forcing are drawn from records of the past. Natural archives of past environmental conditions provide important clues about Earth system processes, and help focus research activity on key questions concerning forcing functions and system responses. Parameters such as albedo, atmospheric greenhouse gas and aerosol concentrations, and the distribution of types of vegetation derived from palaeodata are needed to fix the primary boundary conditions used in model simulations of climate and to perform model validation tests.

The recovery and interpretation of historical and proxy data, including the development of tools and techniques, have been traditionally done through individual or single-laboratory efforts, employing an often specialized technique to examine typically regional or continental records that cover an often limited temporal domain. The emergence of an integrated Earth system science calls for a much fuller knowledge of the past, in both space and time, and for data sets that are drawn as composites from different efforts and disparate techniques. Concerns of impending climate change impose a sense of urgency in this endeavour.

The PAGES Core Project has been developed to respond to these needs through a set of coordinated activities that address key scientific questions through specific research tasks. It will enlist the intellectual efforts of scientists and technicians of many nations, employing the full spectrum of techniques to recover and interpret the past record of global changes. It will also require a significant increase in the level of human resources that are now being applied to the problem.

Organization

Focused research will be carried out in four general activities. The first three address fundamental Earth system processes for which palaeodata are of particular value. The fourth is an all-pervasive effort in coordinated data collection that supports the other three. These activities are: (i) Solar and Orbital Forcing and Response, (ii) Fundamental Earth System Processes, (iii) Rapid and Abrupt Global Changes, and (iv) Multi-Proxy Mapping

As described below, specific research tasks within each activity are further divided into one of two streams of temporal emphasis: *Stream I* tasks will focus on the last 2000 yr of Earth history; *Stream II* tasks will address the general period encompassing the glacial-interglacial cycles of the late Quaternary.

Three cross-project needs are also identified which are common to each of the research activities. These are: (i) The development of analytical models of the palaeoenvironment, including climate, ocean circulation, ice flow, vegetation, hydrology, biogeochemical cycles, and of the coupled Earth system. (ii) The improvement and modernization of the technology that is employed in recovering and interpreting data from natural archives. (iii) The management and dissemination of palaeodata, including both existing information and the new data that will be obtained through activities of PAGES and other relevant efforts.

The organization of PAGES into four research activities, further divided into two streams of temporal emphasis, is shown in Figure 2. A fuller description of the specific research tasks that are included in the matrix, and more specific information on each of the cross-project needs, is given in the sections describing the Core Activities. Additional background regarding the needs and rationale of the PAGES project may be found in Eddy and Oeschger (1989).

The Two-Stream Approach

The two temporal streams of PAGES define periods of especial importance in understanding anticipated global climatic changes of the next 50-100 yr. The first will concentrate on shedding new light on the fixed period of most recent and most relevant change; the second will focus on the processes that have driven the glacial-interglacial cycles that have dominated Earth system history in the last several hundred thousand years. Although the two streams concentrate on periods of Earth history that are very recent in geologic terms, data and insights from the more remote past are also needed to define the background on which more recent changes are imposed, and to illuminate the more fundamental processes that link elements of the Earth system. Research elements of the project will specifically include the study of earlier Earth system history, as an additional source of information relevant to the study of more recent and more rapid changes.

Earth History During the Past 2000 Years (Stream I)

Stream I will endeavour to improve, significantly, our understanding of the history of the Earth system over the past 2000 yr, through the documentation of changes in the physical climate system, air and ocean chemistry, and conditions

PAGES Programme organization into two streams. In addition, the following cross project needs have been identified: (i) palaeoclimatic and palaeoenvironmental modelling; (ii) advances in technology: sampling and analytic methods; and (iii) methodology: dating and correlation, data sources.

Research Tasks		
ACTIVITY/TASK	STREAM 1	STREAM II
1. Solar and orbital forcing and response	- History of solar activity	- Sedimentary records - Deconvolution
2. Fundamental Earth system processes		
a. Trace-gas composition and climate	- Climate and trace gas records	- Improved temporal resolution - Northern and Southern Hemispheres - Carbon cycle - CO_2 and CH_4 in glacial/interglacial
b. Global impacts of volcanic activity	- Record of vulcanism - Critical periods - Volcanic records in ice	
c. Ice-sheet mass balance in global sea-level change	- Snow accumulation - Temperature-accumulation relationships - Monitoring current conditions - Ice-sheet modelling	
3. Rapid and abrupt global changes	- Record abrupt events - Identification of forcing mechanism - Role of preconditions	
4. Multi-Proxy Mapping	- Transfer funtions - Map of climatic anomalies - Climate Data in representative regions - Data from tropics - Response of climate to known events	- Definition of key sites - Glacial data set - Land/sea correlations - Palaeoenvironmental maps - Maps of vegetation change

Figure 2. Organization of the PAGES Project

in the biosphere. The chosen period is that of man's greatest impacts on the planet and the era of significant overlap between written records and the environmental information stored in natural archives. A better understanding of the climatic fluctuations that occurred during this period (such as the Little Ice Age and the preceding, Medieval Warm Interval) can be expected to provide important insights into the rates of regional- to global-scale changes that are expected to occur within the Earth system in the next 50-100 yr.

A clearer illumination of the global and regional changes that have occurred in the last 2000 yr has many potential pay-offs. The period of most reliable climate history, now limited to at most a few centuries, will be extended at least fivefold; a more extensive global record of land-use changes will allow us to begin to assess the effects of past human impacts on the Earth system; it may be possible to distinguish human-induced changes in this period from natural responses to external forcing mechanisms and internal system dynamics, allowing calibration and estimation of anticipated anthropogenic impacts; and, by focusing on the period of overlap between written history and natural records, Stream I research will provide a Rosetta stone which can be used to validate and interpret data obtained from natural archives of the much more distant past.

Objective

- *To reconstruct the detailed history of climatic and environmental change for the entire globe for the period since 2000 B.P., with temporal resolution that is at least decadal and, ideally, annual or seasonal.*

Individual tasks will concentrate initially on critical time periods, specific regions of interest, or parts of the globe for which multi-proxy data are particularly needed and presently inadequate. Results of Stream I research will provide the data necessary to establish a detailed baseline of natural change, to measure human impact, to calibrate and quantify environmental signals from the more distant past, to elucidate the connections and phase relationships between biogeochemical and climatic changes, and to validate numerical models of the Earth system and explain the primary forcing mechanisms for the various responses that are documented, using models to test hypotheses.

Key scientific questions

Research in the Stream I time domain will focus on a set of pressing unsolved questions, which include the following:

- What were the causes of decadal and interannual climatic variations of the past?
- Were the Medieval Warm Interval and Little Ice Age global events? Were the responses synchronous and the amplitudes comparable in the Northern and Southern Hemispheres? What were the relevant forcing mechanisms? Were these events accompanied by changes in atmospheric CO_2 and CH_4? If so, what were the causes of such trace gas changes? What were the phase relationships between these changes and surface temperature?
- How have landscapes changed during the past 2000 yr? What are the causes of such changes?
- How can responses to anthropogenic impacts on the Earth system be distinguished from those induced by natural forcing mechanisms? How can forced responses be distinguished from natural system variability or internal instability?
- How can we improve the record of human-induced vs. natural changes in atmospheric CO_2, CH_4 and other trace gases?
- What quantitative palaeoenvironmental information is recorded in the various natural proxy records?

Glacial-Interglacial Cycles in the Late Quaternary (Stream II)

The Stream II focus is on understanding the dynamics that cause glacial-interglacial variations, as well as the interactive feedbacks among various components of the Earth system that control the response of the system to climatic forcing.

Objective

- *To reconstruct a history of climatic and environmental change through a full glacial cycle, in order to improve our understanding of the natural processes that invoke global climatic changes.*

The purposes are to understand both the causes of change and the way the Earth system functions during times of glacial maximum and minimum conditions; to document the onset and nature of the transitions from warm to cold and

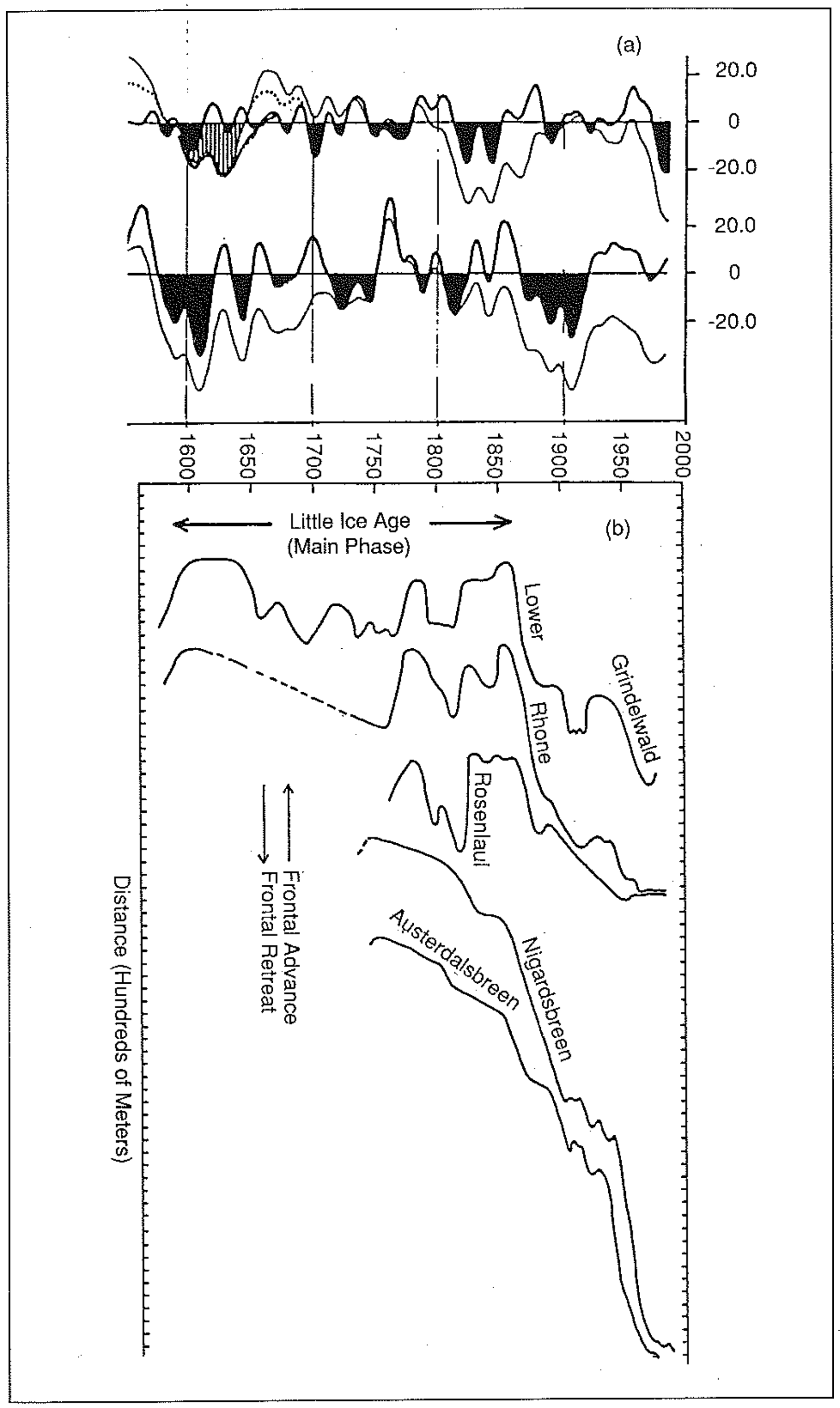


Figure 3. Examples of Stream I data records. Curve a, raw values (thick curves) and standardized indices (thin curves) of maximum wood density for spruce and fir trees from the Alps (top) and for pine trees from northern Scandinavia (bottom). Annual data have been smoothed with a low-pass filter; dotted and hatched portions have been corrected (from Schweingruber et al. 1988). Curve b, corresponding time-distance diagrams of glacier margin fluctuations based on historical and geological data for glaciers in the Swiss Alps (Lower Grindelwald Zumbuhl et al. 1981; Rhone and Rosenlaui, Zumbuhl and Holzhauser 1988) and in southwestern Norway (Nigards breen and Austerdalsbreen; Grove 1988). The termination of the Little Ice Age around 1860 A.D. is evident (from Broecker and Denton 1989).

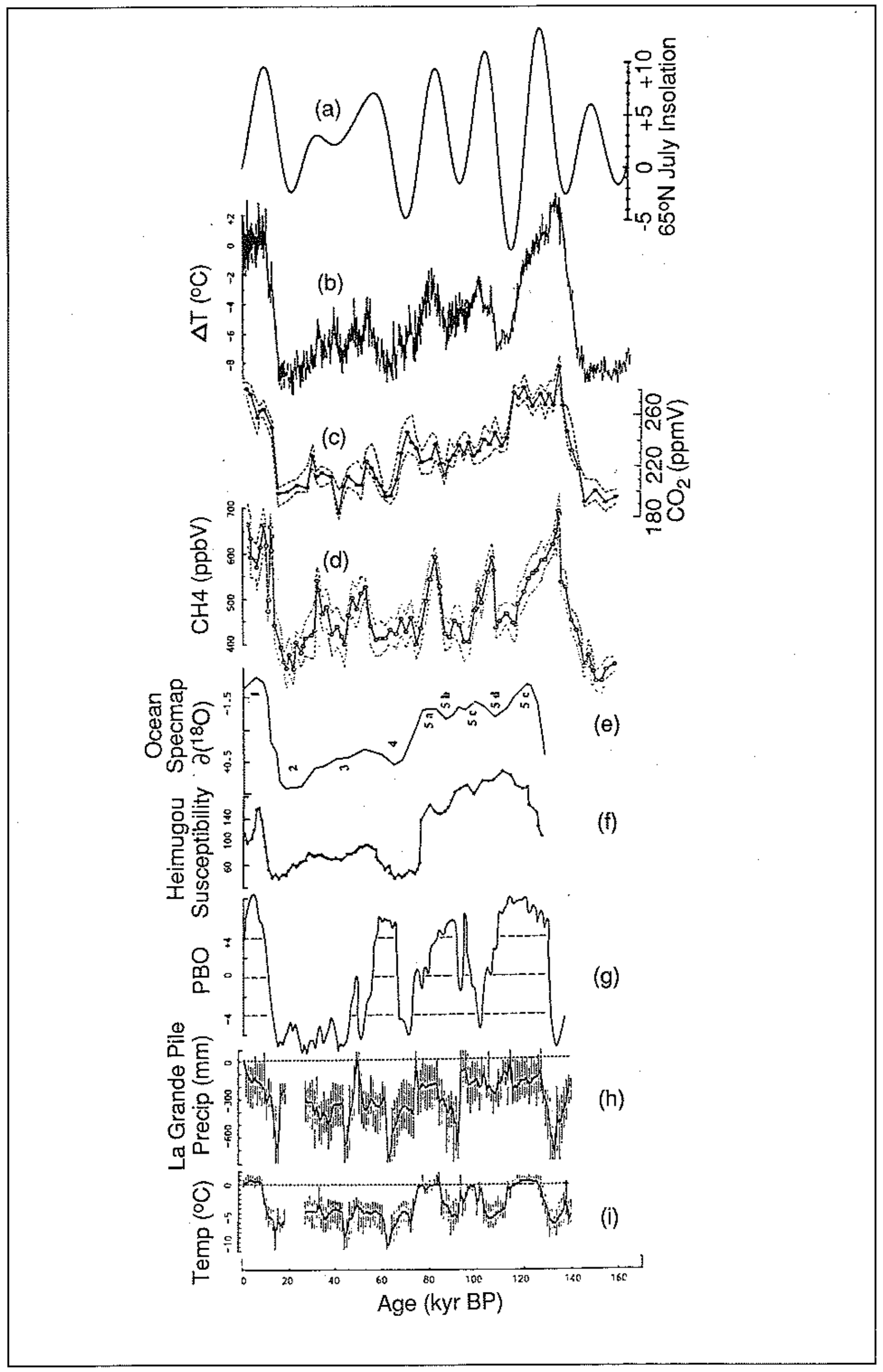


Figure 4. Examples of Stream II data on global forcings and earth system responses. Curve a, July insolation at 65 N (the Milankovitch forcing parameter) expressed as the percent deviation from the present value (from Berger 1978). Curves b-d, records of temperature deviations from present in C, based on oxygen isotope data (Jouzel et al. 1987); atmospheric CO_2 (Barnola et al. 1987); and atmospheric CH_4 (Barnola et al. 1987) determined on gas trapped in the Vostok (Antarctica) ice core (from IPCC Policymakers Summary). Curve e, SPECMAP O-isotopic record (Imbrie 1984), indicating major isotopic stages (from An et al. 1990). Curve f, magnetic susceptibility profile from Heimuguon loess section, Loess Plateau, central China (from An et al. 1990). Curve g, palaeobioclimatic operator (PBO, or best possible climate profile of fossil vegetation changes) time-series reconstructed from la Grande Pile pollen records (from Guiot et al. 1989). Curves h-i, annual total precipitation and mean temperature reconstructions (expressed as deviations from modern values) for la Grande Pile, based on determination of modern analogue for fossil pollen assemblages (from Guiot et al. 1989).

cold to warm periods; and to define the causes and characteristics of the more abrupt changes that punctuate these periods and the transitions between them. It is also critical to determine the present phase of the Earth's climate relative to the current glacial cycle. Information will be used, as it becomes available, from the full span of the late Quaternary Period.

Key scientific questions

- How did the chemical composition of the atmosphere change through the last glacial cycle?
- What are the causes of atmospheric CO_2 and CH_4 variations?
- What are the phase relationships between atmospheric CO_2, CH_4 and other radiatively active gases and climate change? Do CO_2 and CH_4 play a significant role in coupling the climate of the Northern and Southern Hemispheres?
- What processes in the geosphere-biosphere system have responded to the variations in insolation that have presumably triggered the onset and demise of the major ice ages?
- What feedbacks operated within the Earth system in connection with past changes in ocean and atmospheric circulation, atmospheric turbidity, the hydrological cycle, surface albedo, ice volume, and sea level?
- Are the high-frequency $\partial^{18}O$, CH_4 and, perhaps, CO_2 oscillations that have been observed in Greenland ice cores the result of internal forcing? Are these oscillations indicative of temperature fluctuations of global scale?
- How did vegetation and ocean productivity respond to climate changes of the past? How did vegetation and ocean productivity changes affect the abundance of atmospheric CO_2, CH_4 and other radiatively active trace gases?
- How can data from land and ocean records be integrated?

Science Components

Activity 1

Activity Descriptions

Solar and Orbital Forcing and Response

Solar luminosity and Earth orbital parameters are the primary external controls on the amount of solar energy received by the Earth system; the state of the atmosphere (e.g., trace-gas composition, turbidity, cloudiness), which is addressed by Activity 2, modifies the insolation received through processes internal to the Earth system. Here we consider the external forcing mechanisms.

Task 1. Intrinsic solar changes

What is known about intrinsic changes in solar behaviour in the past is now limited to the reconstruction of an index of solar activity for the past 7000 yr, which is based on the analysis of tree-rings ^{14}C (Stuiver and Braziunas, 1989). The index can be related to the more relevant parameter of insolation through modern, spaceborne measurements that have documented changes in solar energy flux, and related them to concurrent changes in solar activity. These relationships and the history of solar activity through both the recent and more remote past each need further clarification. The analysis of ^{10}Be in ice cores should provide the data to extend the proxy record of solar energy flux as much as several hundred thousand years into the past (Beer et al. 1988), despite complexities introduced in these data by variations in local precipitation and by changes in the Earth's magnetic moment. Developing a reliable means for deducing quantitative changes in solar luminosity from changes in the more easily recovered parameter of solar activity, which modulates the cosmogenic production of the radioisotopes that are sampled in tree-rings and ice cores, is at present our only hope for recovering a long-term record of past variations in solar output.

Task 2. Earth orbit changes

Parameters describing the Earth's orbit and axis of rotation determine the latitudinal and seasonal distribution of solar irradiation that is received at the top of the Earth's atmosphere. The Milankovitch or astronomical theory of periodic glaciation holds that long-term changes in these parameters are sufficient to explain the glacial-interglacial cycles of the last 2000-3000 yr, given the present proportion of land mass at high latitudes and assuming a roughly constant solar luminosity. Prominent periodicities of this forcing are 100,000 yr (eccentricity), 41,000 yr (obliquity) and 23,000 yr and 19,000 yr (precession of the equinoxes) (Berger 1977). The response of past climate to these slowly changing orbital parameters has been identified in ocean sediments, coral deposits and a variety of continental archives, including ice cores. It was the interpretation of $\partial^{18}O$ data obtained from deep-sea cores that demonstrated, for the first time, that a frequency spectrum similar to that derived mathematically for the orbital parameters is also evident in the natural spectrum of palaeoclimatic change throughout the late Quaternary (Hays et al. 1976).

Objective

- *To determine the role of external forcing mechanisms in fixing the climate of the late Quaternary, including that of the last 2000 yr, and identify the feedbacks in the natural Earth system that respond to these forcing mechanisms to bring about major climatic changes.*

These feedbacks are now thought to include, among others, changes in the partitioning of carbon or distribution of biota, changes in atmospheric composition, turbidity and cloud cover, and ice-sheet growth and decay.

Initial planning for this Core Activity should establish the minimum critical data that must be obtained from each of the different natural archives in order to evaluate the role of external forcing mechanisms in driving both decade to century-scale climatic changes and those of longer term.

Stream I Tasks

- Reconstruct an improved history of solar activity using annually-resolved records of tree-ring ^{14}C and ice-borne ^{10}Be for the last 2000-3000 yr combined with available historical records. Apply to this record the information obtained from spaceborne measurements of changes in solar output to reconstruct a 2000-yr history of insolation changes, describing both total and spectral irradiance.

Stream II Tasks

- Obtain sequences of lacustrine, palaeosol and aeolian (loess and marine) deposits that extend through the last full glacial cycle. Continental records are needed to compare responses to external insolation forcings over land and ocean regions in both hemispheres and to provide data comparable with the relatively high-resolution atmospheric records of ice cores.
- Deconvolve the responses of the Earth system to external (orbital and solar) and internal forcing mechanisms. The frequency spectrum of reconstructed ice-sheet volume changes must be compared with variations in the external insolation forcings that have been determined independently, particularly the mathematically-derived record of orbital forcing, and, if possible, with reconstructions of changes in the cosmogenic production of ^{14}C and ^{10}Be (regarding possible changes in solar luminosity). Also required are measurements of $\partial^{18}O$, $\partial^{2}H$, the composition of entrapped gas bubbles, and the chemistry and physical properties of particulate and dissolved substances in both existing deep ice cores and those now expected from programmes planned or underway in Greenland and Antarctica.

Activity 2

Fundamental Earth System Processes

The major components of the geosphere are the atmosphere, oceans, and solid Earth, which are linked by complex and interactive physical, chemical and biological processes. Presently, our clearest insights into the fundamental biogeochemistry of the globe concerns the more distant past: namely, the findings from polar ice cores that associate glacial-interglacial changes in surface temperature with concurrent changes in CO_2, CH_4 and aerosols (Raynaud et al. 1988, Stauffer et al. 1988). The nature of these records now precludes an unambiguous distinction between cause and effect. Greater knowledge is needed of the natural processes and feedbacks that establish the fundamental chemistry and chemical cycling of the geosphere/biosphere system; the relationship between changes in biogeochemical cycles and changes in the physical climate system; how the magnitude of human-induced changes in chemistry compares with the range of naturally-induced changes of the past; and the extent to which the activities of man have disturbed the natural cycling of chemical constituents through the major reservoirs of the Earth system.

Objective

- *To develop a better understanding of the internal dynamics of the coupled Earth system that are relevant to global environmental changes, including climate change.*

An initial and particularly pressing element of this goal is to determine the phase relationship between past changes in atmospheric composition and global surface temperature: that is, which came first, and by what interval of time.

This Core Activity will initially address three subject areas: Atmospheric Trace-Gas Composition and Climate; Global Impacts of Volcanic Activity; and the Role of Ice-Sheet Mass Balance in Global Sea-Level Change.

Task 1. Atmospheric trace-gas composition and climate

The discovery of pronounced variations in the atmospheric concentration of CO_2, CH_4 and aerosols in ice cores implicate the existence of a strong interaction between the physical climate and the chemical and biological components of the total Earth system. Understanding the origin of the changes now documented in trace gases, ions and aerosols, and the processes of interaction that are involved, can provide insights regarding feedbacks in the Earth system that almost certainly pertain to modern concerns regarding enhanced greenhouse warming. Moreover, these records of past changes in atmospheric composition will be of continued use in separating natural changes from those due to human activities, which is one of the major challenges of the IGBP.

Stream I Task

- Reconstruct comparable records of climate and of the abundance of atmospheric CO_2, CH_4, and other trace gases throughout the last 2000 yr, with a temporal resolution of at least 10 yr and with emphasis on periods of known or suspected changes in mean global surface temperature, such as the Medieval Warm Interval, the Little Ice Age, and the period of subsequent global warming. A detailed reconstruction of these more accessible periods of Earth history may give new information on the phasing of changes in temperature and in atmospheric composition and help differentiate between human-induced and natural changes in atmospheric composition. Both will require GCM and time-dependent modelling. The record of atmospheric chemistry may be obtained through the collection of short, annually resolvable cores from polar ice, supplemented by low-latitude ice cores which give information on regional climate, air quality and other parameters. Lacustrine and other sediments, tree-rings and historical data will yield additional information regarding local climate conditions in this period.

Stream II Tasks

- Improve the temporal resolution of climatic and trace-gas data through the collection of short, annually-resolvable ice cores and the expanded collection of longer ice cores with optimum attainable resolution to give additional information on climate and air composition and quality; collect additional high-resolution marine and terrestrial sediment cores; compile from these and other records time-series data on atmospheric composition and climate variations throughout the period of the last two glaciations to identify the phase relationships that have applied in the past between changes in climate and in CO_2 and CH_4.

- Determine whether there were significant differences in timing between glacial and postglacial transitions in the Northern and Southern Hemispheres, and establish the phase relationship between them.
- Document changes in the partitioning of carbon among the ocean, atmosphere, sediments, and biomass throughout a full glacial cycle. This will require a reconstruction of atmospheric composition and of the history of deep water formation in the North Pacific, Southern Ocean and Arctic latitudes throughout the late Quaternary. In addition, the total carbon content of the ocean, including exchanges with the sediment column, should be estimated for the same time interval. Palaeoecological data obtained from global mapping (Activity 4) should be used to deduce changes in the storage of biomass on the continents and its potential for CH_4 production. This information, combined with changes in atmospheric chemistry, can be used to test hypotheses regarding the linkage among physical aspects of climate and the CH_4 concentration in the troposphere.
- Determine the causes for differences in the CH_4 concentration during glacial and interglacial periods (such as changes in sources or in atmospheric chemistry) and the phase relationship between significant changes in CO_2 and CH_4.

Task 2. Global impacts of volcanic activity

Documentary evidence from large volcanic eruptions, such as the eruption of Tambora in 1815, suggests that injections of volcanic matter into the atmosphere have exerted significant short-term impacts on mean global surface temperature and circulation, presumably through changes in the turbidity and composition of the atmosphere that have the potential to affect the Earth's heat budget. The record of even such large events, however, is incomplete for the last 2000 yr, and little is known of the potential effect of a number of smaller, nearly-synchronous volcanic eruptions. Moreover, our knowledge of the emission chemistry of any but the most recent events is grossly incomplete. Additional data are required on the chemistry and stratigraphy of tephras, as well as research focused on developing methods to infer the chemistry of volcanic gas emissions from information stored in volcanic archives. Organized tasks within this subject area must include both hemispheres so that comparisons between northern- and southern-hemispheric climate records can be used to elucidate the relative importance of volcanism as a global forcing mechanism. These efforts will require coordinated field programmes as well as expanded laboratory investigations. Concerted efforts will be needed as well to establish the accurate dating of volcanic events in order to ascertain their direct or indirect effects on the composition of the atmosphere.

Research Tasks (Streams I and II)

- Expand the store of available data on the detailed stratigraphy and chemistry of tephras from major explosive volcanic events in both hemispheres, including the accurate dating of these events. This task can be initiated by updating the catalogue of precisely dated, global volcanic events. Considerable field work will also be required. In many parts of the world, such research is undertaken as part of geological programmes, but this project will require that special emphasis be placed on more precise dating of volcanic events and developing a better characterization of the chemistry of volcanic exhalations.
- Define critical periods marked by either a single, large volcanic event, or by a number of smaller events, closely spaced in time, which, from their output and chemistry, are likely to have produced climatic effects.
- the conductivity and concentrations of anions and cations on a greater number of ice cores and from different areas. Ice cores may record both a strong, local signal of volcanic events and a record of hemispheric events, but samples from areas other than Greenland or Antarctica are necessary to separate local from hemisphere-scale effects.

Task 3. The role of Ice-sheet mass balance in global sea-level change

Global sea-level rise is acknowledged as a potentially important result of greenhouse warming, although the amount of increase to be expected over the next 50-100 yr is as yet uncertain. The uncertainty in identifying the cause of the observed rise over the last century and in forecasting future changes stems in part from incomplete knowledge of the mass balance of the major ice sheets, and particularly those of the Antarctic continent. Ice sheets are not in dynamic equilibrium and there are large uncertainties in estimating mass-balance parameters such as accumulation, melting, and ice discharge. An uncertainty of +/- 20% in the estimated ice accumulation (i.e., about 2000 km^3/yr) is equivalent to a change in sea level of about 10 cm/century. Enhanced greenhouse warming may significantly increase the yearly amount of water stored in the Antarctic ice cap, which would result in lowered sea level. A much better knowledge of the mass-balance parameters is needed to resolve these uncertainties, and of the dynamic response of ice sheets to climatic changes. Past alpine glacier fluctuations are another factor. This information is needed to evaluate the importance of ice-sheet mass balance relative to other factors that alter sea level (e.g., tectonic/glacial isostatic, eustatic, and human intervention) and to estimate more accurately both past and predicted variations.

Changes in ice storage that result from climatic fluctuations can be evaluated from modern data and from records of the past. Trends in mass balance, for example, can be determined by studies of ice dynamics and ice-sheet modelling. Complementary data can be supplied from the remote sensing of the extent of ice sheets, their rates of thickening or thinning, and contemporary rates of flow.

Research Tasks (Streams I and II)

- Obtain time-series data on snow accumulation over polar ice sheets since 2000 B.P.
- Quantify temperature-accumulation relationships for specific ice sheets using palaeodata from ice cores.
- Use remote-sensing tools and ground investigations (including shallow ice coring) to monitor the behaviour of ice sheets and glaciers.
- Model ice-sheet mass balance changes using palaeodata and contemporary remote-sensing data to evaluate the dynamical response of ice sheets to climatic changes and their relative stability.

Rapid and Abrupt Global Changes — *Activity 3*

The abrupt climatic changes of decade to century scale that have been identified in palaeorecords, such as the Younger Dryas event and features found in Pleistocene reconstructions of temperatures from Greenland ice cores, may pertain directly to modern concerns of rapid climate change. Such changes are possible analogues of the greenhouse-induced warming now anticipated in the first decades of the next century. They reveal, moreover, the natural potential for rapid change, including possible abrupt changes in ocean circulation and in the physical climate system. They are as well our only source of information on the stability and natural regulation of the climate system. The interpretation of data from natural archives will improve our understanding of abrupt changes and extreme events, including our ability to quantify magnitudes, recurrence rates and the spatial and temporal impacts of such changes.

Sequences of annually-laminated lake sediments provide a unique archive for the identification of abrupt climatic changes and will provide much of the information necessary to calculate the time lag between climatic events and the biotic response recorded in aquatic and terrestrial records. Long records with high accumulation rates will allow studies of abrupt changes during the early part of the last glacial age. All studies of abrupt climatic changes require the collection and comparison of the full spectrum of palaeoinformation available.

The Younger Dryas event was an abrupt cooling that occurred around 11,000 B.P. It is found in palaeoclimatic indicators from eastern North America, Greenland, the North Atlantic, and western Europe. Palaeoclimatic reconstructions from pollen diagrams and lake sediments from North America and Europe have been shown to be linked with changes in North Atlantic deep-water production (Boyle and Keigwin, 1987). Broecker (1987, Broecker and Denton 1989) hypothesized that the reason for the onset of this episode was a major diversion of meltwater into the northern Atlantic and that its abrupt end corresponded to the cessation of this modified flow. By this hypothesis, during the period of meltwater input the salinity of surface waters was too low to permit deep water to form and the heat supply by warm waters moving northward was interrupted. There is evidence that at about 11,000 B.P. meltwater was diverted from the Mississippi to the St. Lawrence River and at 10,000 B.P. back to the Mississippi (Broecker, 1987; Broecker and Denton 1989). Greenland ice cores and North Atlantic sediments are now being used to further study this rapid, short-lived cooling event and its impact on other regions of the globe. Needed are analyses of high temporal-resolution sediment sequences from all over the world, as well as new high-resolution ice cores from the Antarctic.

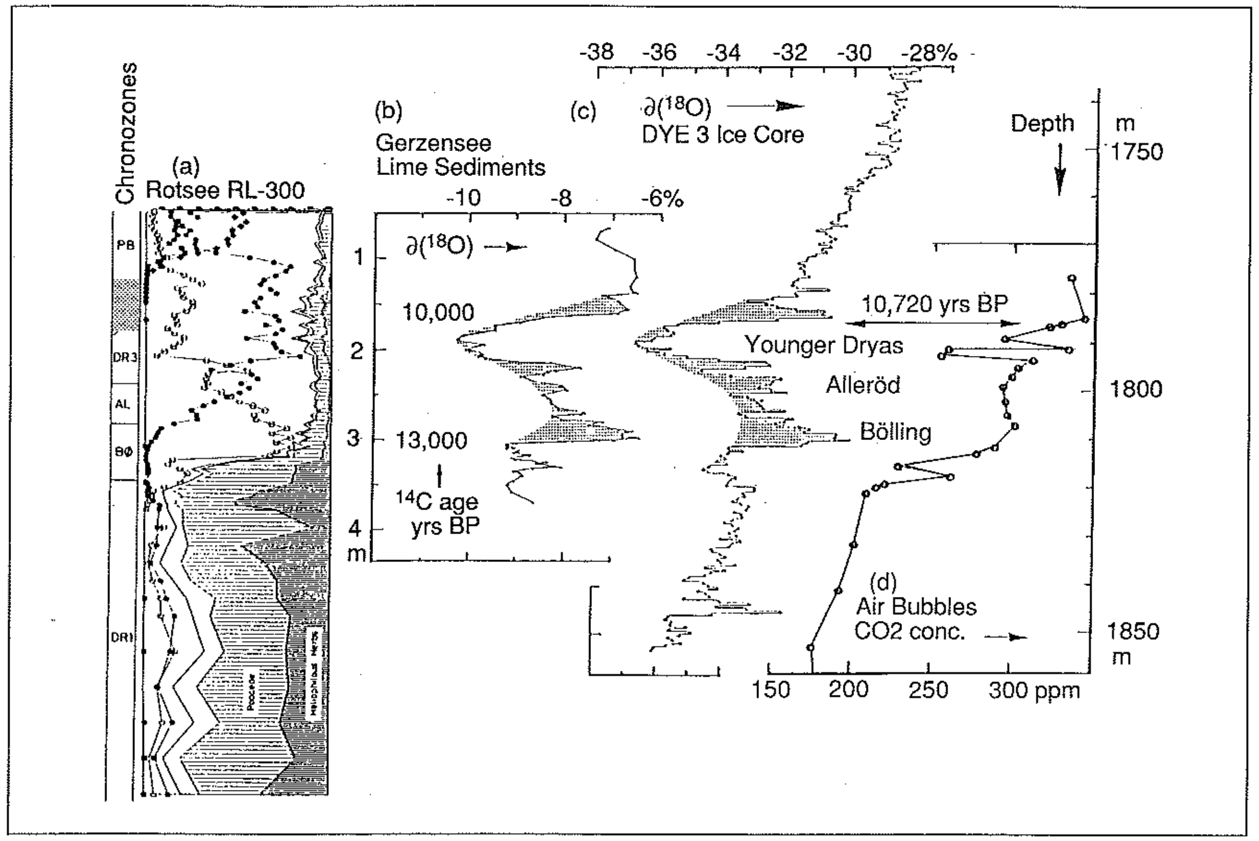


Figure 5. Records of the late glacial transition and the Younger Dryas cold event. Curve a, pollen diagram from a core from Rotsee, Switzerland (Lotter and Zbinden 1989). Curve b, $\partial^{18}O$ of lake marl from Lake Gerzen, Switzerland. Curve c, $\partial^{18}O$ profile along a 120 m section of the Dye 3 (Greenland), ice core (Dansgaard et al. 1984). Curve d, atmospheric CO^2 concentration obtained from gas trapped in polar ice (Dansgaard et al. 1984). Curves b-d reproduced from Dansgaard and Oeschger (1988).

A search for abrupt changes in the ensuing Holocene Period is of particular importance, in that this period of about 15,000 yr is representative of the present interglacial state of the Earth system. Climate predictions for the next 50-100 yr must rely on careful analyses of climatic changes during the Holocene Period, including their causes and possible cyclic nature. It will be necessary to determine the internal or external causes of each event and to distinguish natural forcing (i.e., variation of solar radiation, solar flux, volcanic dust loading of the atmosphere and stratosphere) from possible human influence (such as changes in albedo, hydrology, the evapotranspiration balance, aerosol loading, and at-

mospheric trace-gas concentrations), and to distinguish either type of forcing from what may be stochastic changes within the system. Previous events, such as the rapid climatic oscillations recorded in the CH_4 and $\partial^{18}O$ records of Greenland ice cores throughout the period 70,000-30,000 B.P., may have been caused by processes similar to events that are found in the more recent past, including the Younger Dryas or events of the last 2000 yr.

Objective

- *To identify abrupt environmental changes in the record of the past, and establish their characteristics, including duration and global extent, and their causes and effects, including impacts on the biosphere.*

Research Tasks (Streams I and II)

- Identify short-term, high-amplitude changes in chemical, biological or physical indicators of climatic variability; identify patterns of recurrence of these anomalies through time at a variety of locations. Through the efforts of this task, a record of extreme events and short-term fluctuations in the Late Quaternary will be established as they are imposed on the baseline of environmental changes of longer term.
- Determine the external and/or internal forcing mechanisms that are responsible for specific abrupt global changes.
- Design tests to determine the possible role of preparatory or compounding events, preconditions, or initiating factors other than external forcing mechanisms in bringing about abrupt environmental changes.

Multi-Proxy Mapping — *Activity 4*

An underlying activity of PAGES will be the collection and intercomparison of a variety of data from the spectrum of historical and natural proxy sources that are available. The ability to integrate information extracted from natural archives of many different kinds is a prerequisite for constructing a composite picture of climatic anomalies and trends in all of the preceding activities. It defines the needed contribution of PAGES to modelling activities of the IGBP and WCRP. The composite records that will be compiled will transcend the immediate goals of the IGBP, in making available for future generations of Earth scientists a fuller and more organized record of the recent history of the Earth system.

The accomplishment of this task will require a critical review of each of the available types of proxy records, including the environmental information they contain, their present spatial and temporal coverage, temporal resolution, and inherent temporal and spatial integration, and lags in the incorporation of environmental information into the various proxies. It will also require a determination of the feasibility of precise dating of abrupt or short-term responses to environmental change and of our ability to develop palaeoclimatic transfer functions. The potential for establishing a readily accessible data base adequate to address critical scientific questions will also be considered.

Modelling is an integral part of the IGBP effort to understand past and future global change, and it is imperative that modelling experts and modelling groups be included in the planning of mapping activities. Direct input from modellers and a close interaction between palaeodata and modelling groups will ensure that the models are properly validated; that the best available data are used in the definition of model boundary conditions; and that modelling experiments are designed with the goal of improving our understanding of the forcing factors that drive the climate system. Modelling will provide information on the sensitivity of each proxy to changes in the major climatic variables produced as output from GCM simulations and will also help to identify the critical periods and most sensitive regions for study.

The selection of appropriate time slices and sites for mapping emphasis within this activity will be dictated by the scientific questions that are posed in the other three Core Activities of PAGES, taking into consideration the data requirements of both the mapping and modelling tasks that are planned. Data currently available are particularly lacking for the Southern Hemisphere and for the Tropical and Intertropical Zones; additional data are also needed from North America for the period between the last interglacial and the maximum cooling of the last glaciation. Some studies of past and present global changes will require that data be obtained over a region encompassing a critical climatic system, such as the Northern Hemisphere monsoonal belt through Africa, Asia and North America, or the key sites for the study of ENSO events (i.e., Indonesia, the equatorial Pacific, Peru, and Ecuador). In addition, an attempt should be made to obtain records from the polar regions of the Earth, which are more responsive to short-term climate changes, particularly in surface temperature.

The Stream I mapping effort will focus on the recovery, calibration, correlation, and interpretation of high resolution (seasonal, annual, decadal) historical and natural proxy records. The emphasis of this activity in Stream II will be placed on the integration of long records (including reliable land-sea correlations), which will provide the data necessary to complete the studies of global changes over the last glacial cycle. The mapping activity will integrate other activities of the PAGES project, and provide the raw data from which parameters necessary for the validation of general circulation models can be quantitatively derived. It will also allow an assessment of the extent to which the past represents a useful analogue for future global changes.

Objective

- *Establish an authoritative record of global climatic changes of the past 2000 yr with a temporal resolution of at least 10 yr, and multi-proxy record that describes significant global changes through a full glacial cycle.*

Stream I Task

- Determine and refine the transfer functions used to convert the information recorded in the various proxies into a form that can be interpreted quantitatively in terms of physical, chemical or biological parameters. This task is a prerequisite to efforts aimed at comparing the climatic signals archived in the various types of proxy records and at assessing the relative merits of each proxy in large-scale climatic reconstructions.
- Combine and integrate annual-resolution environmental proxy data from representative geographic locations to reconstruct maps of the spatial patterns of global climatic anomalies, with particular attention to seasonal/annual surface temperature and precipitation. The goal is to map the geographical extent of significant climatic events and to determine whether or not they are global.
- Collect annual time-series data on climatic fluctuations in regions that are representative of major sub-systems of the global climate system (e.g., ENSO, North Atlantic Oscillation, Monsoonal System of East Africa, South and Southeast Asia).
- Acquire historical and high resolution proxy records (e.g., cores from ice caps with summer melting, cores of laminated lacustrine sediments from lakes at various altitudes that are characterized by a long history of undisturbed fine-grained sedimentation, tree-ring samples, and coral reefs) from the Tropical and Intertropical Zones, where data are now severely lacking.
- Evaluate the response of the climate system at times in the past for which specific forcing factors have been implicated, such as the Maunder Minimum/Little Ice Age and the Mt. Tambora eruption, which was contemporaneous with the globally cooler temperatures of the early 19th century.

Stream II Tasks

- Define key sampling sites that will provide the data required to answer the scientific questions that are posed in the three other Core Activities of PAGES. These include sites that are particularly sensitive to global climatic fluctuations (which are necessary for studies of abrupt or high-frequency events); sites that can provide long, continuous and recoverable proxy records (for establishing the time-series of global changes resulting from both internal and external forcing); and a selection of sites chosen to be representative of

environmental and climatic characteristics that are necessary for model validation.
- Recover high-quality proxy records from a variety of natural archives (such as tree-ring data, the chemical composition of ice and gas inclusions in ice cores, palaeosol stratigraphies, and terrestrial and ocean sediments) on a global basis, spanning the last glacial cycle.
- Establish precise correlations between land and ocean archives throughout the last full glacial cycle. This research is needed for the study of phasing and time lags among the different system responses as recorded in different archives around the globe; it will also require new or improved dating approaches, particularly for pre-Holocene ice cores. Key sites for land/sea correlation are Europe/North Atlantic Ocean, Antarctica/Southern Ocean and Asian loess plateau/central North Pacific Ocean. Reconstructions of surface water $\partial^{18}O$ values may help in interpreting complimentary lake marl data.
- Construct palaeoenvironmental maps for time intervals encompassing key climatic events that represent various degrees and absolute rates of change (as established by detailed time-series studies at key locations). These include the climatic optimum of the previous interglacial age (O-isotope substage 5e); the climatic optimum of the Holocene Period (7000-6000 B.P.); the Younger Dryas/Bolling-Allerod complex (13,000-10,000 B.P.); and the last glacial maximum (18,000-20,000 B.P.).
- Produce palaeoenvironmental maps to investigate transitions between major vegetation regimes throughout the late Quaternary and to enable the estimation of plant biomass at various times in the past, in order to quantify carbon storage in vegetation and to improve our understanding of the CO_2 and CH_4 cycles.

Cross-Project Needs

Palaeoclimatic and Palaeoenvironmental Modelling

The goals of PAGES demand a strong interaction between data acquisition and interpretation and the modelling of palaeoclimatic and palaeoenvironmental changes at various time scales. Involved as subsystems in a more general model are elements involving the atmosphere, ocean, cryosphere, hydrosphere, biota, soils, and the biogeochemistry of the Earth system. The inclusion of modelling in other activities of PAGES is necessary for several reasons:
- Testing climate models. Palaeodata are useful both in defining boundary conditions (e.g., sea-surface temperature, sea-ice extent, ice-sheet topography, land albedo) and in identifying the climatic forcing factors (e.g., insolation, atmospheric concentration of greenhouse gases, dust and aerosol loading) that are used in atmospheric general circulation models (GCMs) and future coupled geosphere-biosphere models. The key variables for assessing GCM simulations are temperature, precipitation, other parameters linked to the hydrological cycle, and, to a lesser degree, wind intensity and direction.
- Providing insight into how the climatic system functions. In addition to GCMs, which produce steady-state simulations, there is a particular need for the development of models that are time-dependent (such as ice-sheet mass-balance models). Such models need to include both internal and external forcing mechanisms, as well as human-induced effects. A hierarchy of such time-dependent models, based on time scales extending over the full range of Earth system changes of the past, can provide valuable insights into the operation of the Earth as a system.
- Estimating the sensitivity of the climate system to various forcing mechanisms. Knowledge of climate sensitivity is one of the key parameters needed for predicting anticipated changes in the next 50-100 yr. Climate simulations may also be useful in identifying appropriate regions for palaeoclimatic reconstructions (i.e., those that are particularly sensitive to fluctuations in climatic parameters).
- Understanding long-term variations and rapid changes in the concentration

of atmospheric CO_2 and CH_4, as well as the interaction of these gases with the climatic system. Such studies require the use of a hierarchy of models with the ultimate goal of coupling biogeochemical models with models of the physical climate system (see also Chapter 8.1). To achieve the ultimate goal of reliable simulations of climate and environmental changes on a global scale, nested, hierarchical models must be based on transfer functions that accurately describe the storage of climate data in each of the various archives.

Types of models that are particularly needed in paleo-studies include:

- Models of ice-sheet dynamics, which correctly simulate both the growth and decay of ice sheets (for Stream II tasks) and of shorter-term glacier and icesheet mass balance (for Stream I research).
- Tracer models that rely on GCMs to track specific aerosols (e.g., desert dust) on a global scale, or to pinpoint the source region of precipitation. Such models are also useful in establishing the link between climatic parameters and proxy data.
- Vegetation models that establish the linkages between climate and the response of biota.
- Coupled ocean-atmosphere-cryosphere models at various levels of complexity.
- Nested models for regional simulation studies.

Advances in Technology

Sampling

Many palaeoclimate records are derived by coring into sedimentary deposits. Limitations on the length and the quality of these records are often imposed by limitations in the equipment currently available for recovering long, undisturbed sediments. In the case of polar ice-core drilling, where technology is relatively advanced, it is not yet possible to drill through the deepest part of the Antarctic ice sheet, yet such a long core should yield a unique record of atmospheric composition spanning many glacial-interglacial cycles. Similarly, many deep lakes which are known to contain long sedimentary records and lakes that contain finely laminated sediments with the potential of providing detailed, high-resolution palaeoenvironmental information have not been adequately studied, because of the technological problems of core recovery.

Efforts will need to be made to develop advanced coring equipment for the purpose of recovering long, high-quality ice core and terrestrial (primarily lacustrine) and marine sedimentary records. International cooperation and the sharing of experience and technology will be required to design and construct equipment capable of operating in a wide range of often remote environments.

Analytical methods

Techniques of accelerator mass spectrometry (AMS) have led to significant improvements in the dating and quantitative analysis of palaeomaterials. They have also proved important in studying the cycling of tracers in the Earth system. Adapting other analytical techniques developed for classical physics and chemistry may also lead to significant advances in the study of records of the past. The application of new exploratory and analytical methods should prove particularly valuable in lacustrine sediment research, including the use of acoustic profiling systems, digital X-ray systems, micro-sampling and analytical procedures, and high-precision microscopic techniques. Particularly promising is the establishment of analytical centers that may help speed technical advances for specific applications, in this and other areas.

Needed, in many areas, are efforts to streamline and automate analytical facilities and to maximize the rate of sample processing. Few laboratories can handle the very large number of samples necessary for the reconstruction of climatic fluctuations at the high frequencies required for many of the tasks proposed for implementation in PAGES.

Obtaining and interpreting regional, high temporal resolution historical and climatic proxy data should be included as a priority task of any IGBP Regional Research Center (Chapter 11) that is established in the Intertropical

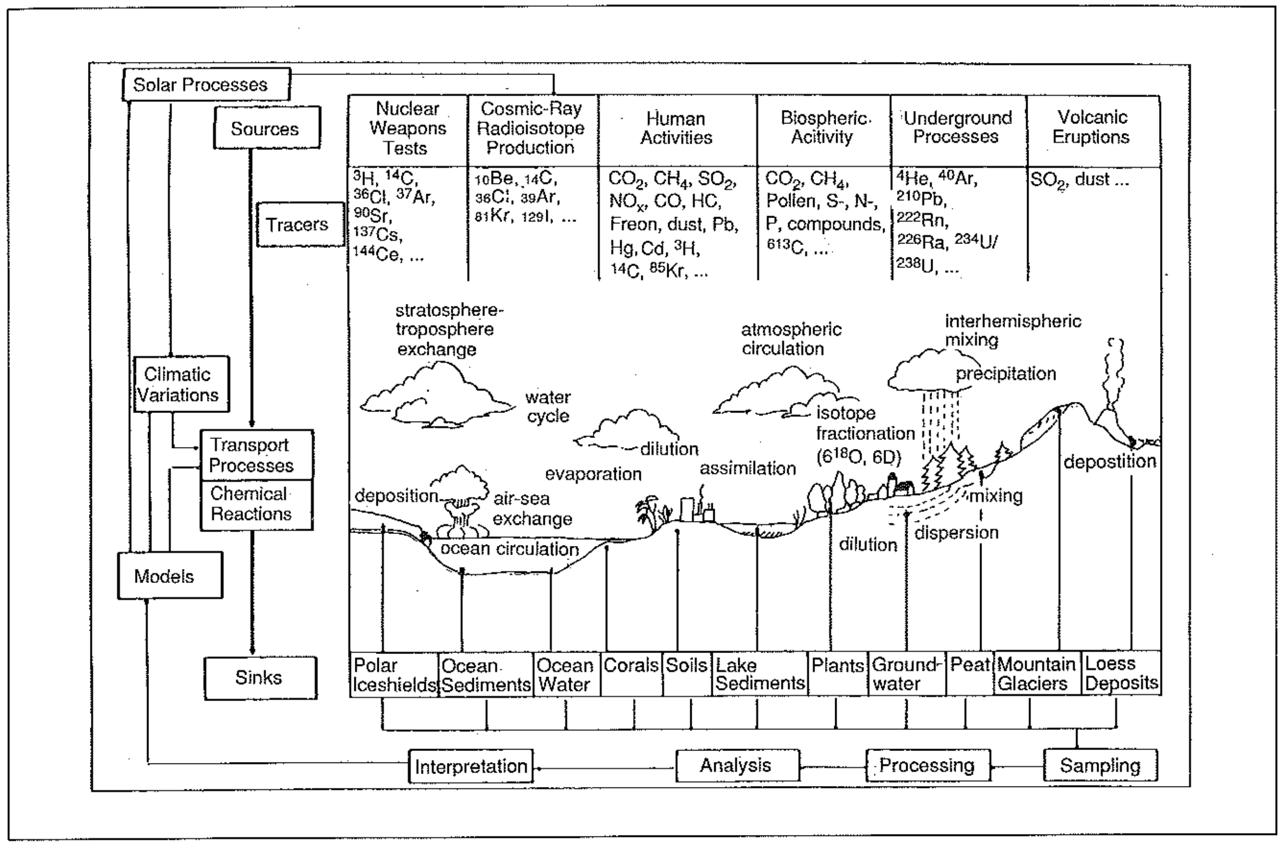


Figure 6. Geochemical tracers of use in documenting past global changes, showing the natural archives in which they are sequestered and the processes through which they are deposited.

Zone. Some research effort should be directed toward the development of special analytical techniques that are applicable in tropical environments, such as the use of isotope geochemistry in tree-ring studies (to complement conventional ring-width measurements that are often impossible to obtain or inappropriate), or by applying high-resolution dating and isotopic methods to the study of corals. It is imperative that the transfer of dating technology from established tree-ring laboratories to the RRCs is facilitated through the IGBP. The analytical centres proposed below could be given the responsibility for insuring such transfers.

Management of Palaeodata

Data management is a key requirement in the development of a research programme of the scale of the IGBP to insure maximum data accessibility (Chapter 9).

As global-scale reconstructions of past climate are made, the need for the integration of diverse proxy records will increase. This will require the establishment of well-organized data bases that can be interrogated electronically, and which can respond to diverse enquiries. A European Palynological Data Base system is currently being developed along these lines, particularly for use in IGBP-related research. Careful consideration has been given to issues of data acquisition and accessibility, ensuring data quality, ease of interrogating the data set, the future integration of regional palynological data bases with data bases that may be developed for other types of proxy data, and the management structure, facilities and resources required for successful implementation. In the U.S. the National Geophysical Data Center of NOAA is establishing a paleoclimate data base to bring together a computer-based, interactive archive of palaeoclimatic information for purposes of research in global change. It will include data from tree-rings, ice-cores, marine sediments, pollen, and eventually documentary records. A design requisite, as with the European Palynological Data Base, has been that of ready access on a world-wide basis.

Calibration of proxy data

In addition to data base development, the management of paleo datasets also involves their calibration and careful attention to the quality of the data that are made available. All proxy records must be calibrated with modern observational data from the same or similar sites if meaningful, quantitative palaeoclimatic reconstructions are to be made. It is often the case that the observations necessary to accomplish this task are not available and the researcher is forced to rely on less-appropriate data, or data from a site far from where the proxy was recovered. This may result in a poorly understood climatic signal in the natural archive, and a less than optimum palaeoclimate reconstruction.

It is important to PAGES to take full advantage of the data obtained through monitoring programmes of the IGBP and WCRP in the development of quantitative transfer functions. This may involve ocean buoys to record ocean temperature and other parameters, or observational platforms designed for continuous trace-gas and aerosol sampling and meteorological measurements in remote polar or tropical environments. For example, the IGAC Polar Air-Snow Experiment (Chapter 2.1) will provide data on the relationship between atmospheric composition and the chemical composition of ice in central polar areas.

Methodology

Dating and Correlation

A common requirement in almost any aspect of environmental research is the accurate specification of the time of observation, or in the case of palaeodata, an accurate specification of the age or date of deposition of sampled materials. In order to detect or identify synchronous global changes, to fix the time of long- or short-term events in the past, or to specify the phasing of the different environmental parameters that are invoked, records from different parts of the ocean-atmosphere-cryosphere-biosphere system need to be correlated. This requires precise age determinations and reliable estimates of errors associated with them. In correlating parameters obtained by different techniques from a variety of natural archives, often differing in precision and accuracy, effects of uncertainty in the dating of any of them are compounded. A thorough understanding of the inherent limitations of each method is a prerequisite for a proper evaluation of the time scale. This task of fixing dates and their error bars, often slighted, is one that deserves as much attention as the analysis and interpretation of the data themselves.

Methods applicable to the type of high-resolution dating required for the study of changes during the past 2000 yr (Stream I) include historical records and the precise identification of annual layers in archives such as tree-rings, ice cores and laminated sediments. In some cases, fossil corals or floating tree-ring chronologies are useful sources of annual-resolution data. When laminated sediments are not available, undisturbed sediment sequences with high accumulation rates that allow fine-resolution radioisotopic dating (e.g., ^{14}C, U-series methods) are also useful. The combination of lake, mire and bog data with annual information from tree rings offers another useful tool. Reference horizons, particularly volcanic ashes, can often be used as stratigraphic markers for dating young deposits. These can sometimes be calibrated with accounts in historical records such as those of volcanic eruptions or modern thermonuclear tests, or their ages determined by counting annual layers in ice cores where the tephras are found.

Methods that may aid in establishing dating control in the longer span of Stream II studies include isotopic disequilibrium studies of uranium series isotopes and conventional ^{14}C measurements; radiogenic trend analyses (e.g., fission track ^{238}U-series and K-Ar measurements); detection of ionization radiation due to radioactive decay by either thermoluminescence (TL) or electron spin-resonance (ESR) methods; and methods performed on biological materials such as amino-acid racemization. It has been demonstrated that spikes in the ice-borne ^{10}Be record, though few and far between, can serve as useful reference horizons in correlating samples of polar ice; since these are of presumed extra-terrestrial origin, they seem of particular promise in correlating records from the two poles of the Earth.

Absolute dating of records less than about 50,000 yr old can be done on small samples using the AMS-^{14}C method on a variety of materials (e.g., $CaCO^3$ tests in marine sediment). Ar-Ar, K-Ar and fission-track methods can be applied in dating older tephras and other volcanic products. U-series dating of calcareous tests from marine organisms holds great promise, even though problems with U-trend analysis remain unresolved. TL dating has been applied to aeolian sediments less than 100,000 yr old with general success, but problems have been encountered using electron spin resonance to date carbonate material. Ice sheets exhibit annual layering or resolvable annual patterns in isotopic composition throughout the Holocene Period; the age of older ice is most commonly estimated through the use of ice flow models, although the accuracy of such estimates is questionable and the resolution often inadequate to answer many of the most significant questions.

Relative dating and correlation methods such as amino acid racemization, magnetostratigraphy, the comparison of stable isotope signatures, and tephrochronology should help considerably in regional and global correlations of equivalent units.

Particularly important, because of its now common use in the dating of continental, oceanic and cryospheric samples, is ^{14}C dating, either by AMS or conventional radioactive decay measurements. Present or inherent limitations in the method, however applied, are often overlooked. Insufficient information on the ^{14}C content of the atmosphere prior to about 8000 B.P. limits the accuracy of the ^{14}C-dating of older materials. It is this information, reflecting changes in ^{14}C production and storage, that is used to convert dates derived from ^{14}C measurements to calendar years. For this reason, PAGES should apply all available means to improve and extend, to at least 15,000 yr, the data base that will permit the accurate interpretation of high-precision ^{14}C ages. This extended span of time now seems in reach of known tree samples, and would cover the Holocene Period. This will include studies of tree-rings; long, annually-laminated lake sediments; coupled U-Th and ^{14}C age determinations of corals; annually-banded corals; and planktonic-benthic foram age differences as determined by AMS-^{14}C.

Efforts will be defined through this element of PAGES to develop new approaches to absolute age determination and to improve the precision and accuracy of all methods currently used to establish dating control, including numerical-, calibrated-, relative-, and correlated-age methods. Uniform sampling and analytical methods will need to be established to reduce errors in the interpretation of information obtained by various dating methods (Rutter et al., 1989).

Data Sources

The most powerful tools available to PAGES are; (i) the potential to collect and synthesize information from many sources to provide clearer global pictures of the past; and (ii) the power to focus effort on selected time slices or regions for particular emphasis through coordinated campaigns. Both involve combining data derived from different techniques.

Five of these techniques, or data sources, are described briefly below with recommendations for advancement; other sources, equally important, will also contribute to the project.

Historical records

Parameters Recorded: Proxy information (e.g., vine harvest dates and yields, snow and ice records) and direct descriptive information (e.g., daily weather observations, sea-level and coastline data, reports of volcanic eruptions and other extreme events).

Spatial and Temporal Coverage: New World: < 400 yr; Europe and Eurasia: < 900 yr (the earlier part as a more subjective record); ancient China, Korea and Japan: continuous record to 2200 B.P. Oriental accounts are generally most the extensive, continuous, detailed, and useful. The presence of natural archives for the same region (Tibetian ice caps, Chinese Loess Plateau) identifies the Asian continent as an area of particular promise for reconstructing natural and anthropogenic changes in the environment.

Recommendation: The tools for building a large, international data bank on climate history have been developed; however, a much greater effort to extract relevant climatic/environmental information from historical records, particularly in China and southeast Asia, is necessary and should be encouraged through regional workshops.

References: Ingram (1981), Pfister (1990).

Tree-rings

Parameters Measured: Tree-ring width, wood density, tissue structure, stable isotopes, and trace-element chemistry.

Resolution and Dating: Annual resolution by counting tree-rings (many tropical species have no clear annual layers); seasonal resolution is possible for certain studies, based on distinction between early and late wood. ^{14}C analysis of cellulose in dated rings is the primary source of information on the variation of ^{14}C production in the past, and hence on ^{14}C/calendar-year conversion.

Spatial and Temporal Distribution: Most extensive data are for temperate latitudes, most valuable in higher or drier regions were tree-growth is a more sensitive indicator of environmental conditions; data are concentrated in North America, the Arctic, Europe, and the USSR; greatest potential for new information is in Siberia, India, China, and parts of the Southern Hemisphere (Argentina, Chile, Tasmania, New Zealand); data from the Tropics would be of great value, although technical difficulties must be overcome.

Continuous chronologies extend to A.D. 1700 for most temperate Northern Hemisphere land masses; coverage to 2000 B.P. is sparse (samples of living trees must generally be combined with archaeological and geological timbers); only ten chronologies exist that are longer than 2000 B.P., with potential to obtain perhaps ten more; potential for only one central European and one western U.S. chronology longer than 10,000 B.P. Floating chronologies of 1000+ yr are obtainable from sub-fossil wood older than 10,000 B.P. in many places (several areas have trees in 20,000-30,000 yr age range), but there is little chance of these being joined in continuous sequences.

Recommendations: There is an urgent need to collect samples from tropical regions before the old-growth trees (e.g., teak) are exploited. More fundamental research is needed to assess the possibility of obtaining annual records from arid zones and the Tropics. Some species without clear annual rings, for example, may still have usable isotope records. Samples of sub-fossil wood must also be collected from areas where exploitation is active (e.g., Huon pine in Tasmania, Kauri wood in New Zealand) before the archive is lost. Such samples are necessary for the development of additional long chronologies, particularly in the Southern Hemisphere.

Methods to merge tree-ring records from diverse archaeological and subfossil sources should be developed to enable the use of very long records. Efforts should also be made to obtain more long isotopic records from tree-rings. Additional basic research is needed to improve our limited understanding of the incorporation of isotopic signals into tree wood, and of the relationship between the isotopic signatures of different tree species, collected from various sites and living under different climatic conditions.

References: Cook and Kairiukstis (1990), Fritts (1976), Schweingruber (1988).

Ice cores and glacier records

Parameters Measured: Ice cores: CO_2, CH_4 (restricted to polar sites where there is limited annual melting), aerosols, volcanic sulphate and other dust, cosmogenic nuclides (i.e., ^{14}C, ^{10}Be), organic chemistry. Alpine glaciers: glacier extent, altitude, annual mass-balance, velocity of advance/retreat.

Resolution and Dating: Recent ice (< 10,000 B.P.) offers the potential of annual resolution (by counting layers of snowfall or through measuring the annual

variation of $\partial^{18}O$); seasonal resolution is also possible in ice of this age by detecting seasonal variations in $\partial^{18}O$ (temperature). Dating precision and accuracy decrease in older polar ice; dating involves geochemical analysis and reliance on ice-sheet compaction and flow models. Annual resolution is available in some older mid-latitude maritime glaciers due to conditions of heavy snowfall or seasonal melting.

Spatial and Temporal Distribution: Polar ice sheets have been cored to 150,000 B.P.; deep drilling projects now underway will extend records to 300,000 B.P. High-altitude, mid-latitude glaciers in the Andes, Alps, and Tibetan Plateau complement polar data and reach back several thousand years with annual resolution. For alpine glaciers a detailed record of fluctuations exists since 1850, and for annual mass balance since 1950, with reconstructions available to 1850.

Recommendations: Deep ice-core drilling involves appreciable logistical effort, and should be planned judiciously to obtain the data necessary to test the scientific hypotheses described above. Deep drilling in East Antarctica is required to obtain a long, high-resolution record; whereas drilling in West Antarctica is needed for other reasons (i.e., filling a geographical gap, to study the stability of the ice sheet during the previous interglacial) and should be planned accordingly. Studies of alpine glaciers should focus on mass balance reconstructions.

Reference: Lorius (1989), Porter (1981).

Terrestrial deposits: lacustrine sediments, leess and palaeosols

Parameters Measured: Lacustrine sediments (lake, bog, mire, and peat deposits); pollen analysis, fossil assemblages, stable isotopes, organic and inorganic chemical composition, mineralogy, palaeomagnetism. Loess: accumulation rates, sedimentology (e.g., grain size distribution, shape), sediment geochemistry and mineralogy, palaeomagnetism. Palaeosols: presence or absence of specific vegetation types.

Resolution and Dating: Lacustrine sediments: annual to seasonal resolution (if varied and undisturbed); dating by annual layers, ^{14}C, TL, U-series, etc. Loess: variable resolution, depending upon local conditions and availability of fiducial; layers can sometimes be tied to historical accounts of dust storms. Palaeosols: dating generally based on stratigraphy.

Spatial and Temporal Distribution: Lacustrine sediments; presently available data are mostly from Europe, North America, and the Arctic; potential for broad, global coverage (South America, Africa, Asia); longest continuous records > 300,000 yr. Loess beds; generally located down-wind of continental areas subject to erosion (although dust is transported at heights up to 10 km); longest records are found in China, followed by the U.S., and Central Europe. Palaeosols; associated with continental sediments, particularly loess deposits.

Recommendations: Multi-disciplinary case studies of carefully-selected sites that can provide long records of annually- or seasonally-resolvable lake sediments should be undertaken, with the goal of extracting palaeoenvironmental time-series of biotic and abiotic responses to climate changes.

References: Lacustrine sediment: Berglund (1986), Loess: Liu (1985), Palaeosols: Beget et al. (1990).

Marine sediments and coral deposits

Parameters Measured: Sediments: organic and inorganic chemical composition; stable isotopes; age (^{14}C, U-series radiochemistry); number/distribution of foraminifera. Corals: $\partial^{18}O$ (surface water temperature); $\partial^{14}C$, Cd and Ba (nutrient content of water); $\partial^{13}C$ (combined effect of nutrient supply and light intensity); annual layer thickness and density.

Resolution and Dating: Anoxic ocean margin varied sediments: annual or greater; open-ocean sediments: variable resolution, variety of dating techniques. Corals: coastal zones, annual resolution (X-ray densitometry detects effects of seasonal changes in surface salinity/temperature on coral growth); gyrus regions, U-Th dating.

Spatial and Temporal Distribution Sediments: up to 20x10^6 yr long record in some locations (limited by thickness of soft sedimentary material, coring methods); varied records, < 10,000 yr (deep, anoxic marginal basins); most cores sampled from open ocean at water depths of 2500-4000 m. Corals: Tropical and intertropical waters; some occurrences to 30^0, if warm surface currents are present; maximum temporal range to several millennia.

Recommendation: To accomplish the high-resolution studies planned for PAGES, it will be necessary to exploit rapidly-deposited deep-sea sediment (e.g., drift deposits, abyssal fans, ice-rafted debris) and continental shelf/slope/rise sediments. Although there are inherent difficulties in the study of such records, they have the potential to improve our ability to correlate land and ocean records and will provide information on the continental flux of dissolved and particulate weathering products and pollen, the nature of bottom circulation and the biological productivity of surface waters.

References: Marine sediments: Shackleton et al. (1990), Corals: Druffel (1981), Shen and Lea (1987), Thompson et al. (1986).

Implementation

Core Project Office

A Core Project Office will be opened in Bern in 1991, as an international activity jointly sponsored by Switzerland and the U.S. Its purpose will be to coordinate the scientific activities and tasks that comprise the PAGES project and to provide information on plans and progress to the international community. The first goal is to organize and initiate the research activities that will move the PAGES project into an operational stage. Specific functions are:

1. Initiating and organizing international workshops and planning meetings to support the project.
2. Publishing and distributing a quarterly newsletter.
3. Compiling and distributing scientific reports of plans and progress to programme participants as well as to governments and to national and international funding agencies.
4. Apprising national funding agencies on request in connection with individual proposals that may relate to the goals of the PAGES project.
5. Disseminating information that reports on aims and opportunities in the project to aid in recruiting needed efforts from scientists and technicians from all countries.
6. Raising funds for project activities from non-governmental sources, and for the staffing and operation of the Core Project Office.
7. Establishing and coordinating data centres for various types of palaeodata that can be accessed internationally.
8. Establishing and maintaining an active directory of scientists and technicians who are involved in the PAGES project.

Scientific Workshops

A number of planning meetings and workshops will be needed to refine the general research strategy of the PAGES project and to design specific tasks within each of the four activities that are described above.

The following workshops and planning conferences are proposed to refine the definitions of the Core Activities described above, and to lay plans for specific activities within each of them:

Activity 1

Solar and Orbital Forcing and Response

1. An interdisciplinary workshop should be convened to refine research needs, to define a multi-year programme and to coordinate the funding required to mount the field programmes necessary to obtain long records. Preliminary discussions on these topics should be organized in conjunction with existing bodies such as the International Ice Core Forum, IUGS and INQUA communities. The workshop should involve representation from STIB (Chapter 2.2).

Activity 2

Earth System Processes

2. The Carbon Cycle and Climate Change. A workshop is needed to formulate a coordinated strategy to address problems related to the partitioning of carbon among the atmosphere, ocean (including bottom sediments) and biosphere and the phasing of CO_2, CH_4 and climate changes. This should be coordinated with the IGAC (Chapter 2.1), JGOFS (Chapter 3.1) and GAIM (Chapter 8.1).
3. Global Impacts of Volcanism. A workshop should be convened to develop a strategy for correlating the various types of records of volcanic events that are now available and to plan the coordinated field programmes and laboratory investigations that will be needed to improve and extend this record. The workshop should be coordinated with IUGS and with activities of INQUA.
4. Modelling Ice-Sheet Mass Balance. A scientific workshop is needed to attempt to compile representative figures for current rates of ice-sheet accumulation; melting and ice discharge at a continental scale; a definition of the data required for modelling the impact of climatic changes on mass-balance parameters; and the development of a strategy for evaluating the dynamic response of ice sheets to climatic changes. The workshop should be coordinated with BAHC (Chapter 5.1) and with activities of SCAR.

Activity 3

Rapid and Abrupt Global Changes

5. Understanding the Younger Dryas and Other Abrupt Climatic Events. A scientific workshop should be organized to assess the present state of understanding of the Younger Dryas cooling that interrupted the last glacial-interglacial transition. Attention should also be given to the development of methods to identify abrupt climatic changes recorded in proxy records, and to the identification of pilot projects that can be used to test the utility of these methods. The workshop should be coordinated with activities of the WCRP.

Activity 4

Multi-Proxy Mapping

6. PAGES Mapping Strategy. A workshop that brings together scientists with expertise in various proxy methods and from all regions of the globe is needed to establish an overall mapping strategy for PAGES. Needed is general agreement regarding which time slices will be mapped, and their relative priorities; where time series should be collected initially; which proxies can best provide the key data required to carry out the project activities; and general standards for how the data will be obtained, interpreted, mapped, and managed. The meeting should also assess the need for additional resources to carry out the project; develop plans for implementing the mapping programme; take necessary steps to enlist the aid of scientists in regions where data are particularly inadequate, including the developing nations; lay plans for the involvement of IGBP Regional Research Centres (Chapter 11); and foster the initiation of collaborative research projects between local scientists and established world experts. The meeting should involve representatives from the IGBP Standing Committee on Regional Research Centres and be coordinated with activities of INQUA and IUGS.
7. Workshop on Past Records. A study workshop should be convened to address practical methods of correlating and comparing the information on climatic variability and system responses obtained from diverse types of proxy data, at required levels of spatial and temporal resolution. The workshop should address the goal of assembling comprehensive data bases that describe selected global changes that have occurred in the past: a prerequisite to the eventual global-scale reconstructions envisaged as one

of the primary tasks of the Multi-Parameter Mapping Activity. One task of such a workshop would be to frame the regional boundaries that define the major climate sub-systems (such as the East African monsoon region). Other tasks that will need to be addressed include establishing an overall mapping strategy (including decisions about which time slices will be mapped; determining where time series data should be collected initially; determining which proxies can best provide the key data required to carry out the project activities; establishing general standards for how palaeodata for PAGES will be obtained, interpreted, mapped, and managed; and developing plans for implementing the mapping programme.

Analytical Centres

Advances in the technology of recovering and interpreting environmental records of the past that are called for in PAGES will be accelerated and strengthened by the designation of Analytical Centres that concentrate on particular proxies and specific techniques. Such a center for carbon isotope analysis has now been proposed in the Netherlands. The designation of an analytical centre as an affiliate of PAGES will require ready international access to its activities, even though funding for such centres will of necessity come from the host country.

Participation in the PAGES Project

Participation in the research activities of the PAGES Project will be addressed in a Project Implementation Plan (to be developed in early 1991). The Science Plan described here, after review by the IGBP Scientific Advisory Council and subsequently revised as needed by the Scientific Steering Committee, will be outlined in a brochure that will be distributed to individual scientists, academic (particularly graduate) programmes, research institutions, and to governmental and nongovernmental agencies. Communication among participating scientists will be encouraged through a semi-annual newsletter issued by the PAGES Core Project Office.

Participation in the PAGES Project is open to all scientists and technicians who deal with past records of any kind that relate to the project objectives. The intent is to encourage collaborative, multi- and inter-disciplinary research at a time when a fuller knowledge of past changes seems a particularly urgent need.

References

An, Z., Kukla, G. J., Porter, S. C. and J. Xiao. 1990. Magnetic susceptibility evidence of monsoon variation on the Loess Plateau of central China during the last 130,000 years. Quaternary Res. (in press).

Barnett, T. P. 1988. Global sea level change. In: National Climate Program Office report, Climate Variations Over the Past Century and the Greenhouse Effect, NCPO/NOAA, Rockville, MD, USA.

Barnola, J. M., Raynaud, D., Korotkevich, Y. S. and Lorius, C. 1987. Vostok ice core provides 160,000 year record of atmospheric CO_2, Nature, 329:408-414.

Beer, J., Siegenthaler, U., Bonani, G., Finkel, R. C., Oeschger, H., Suter, M. and Wolfli, W. 1988. Information on past solar activity and geomagnetism from ^{10}Be in the Camp Century ice core. Nature 331:675-679.

Beget, J. E., Stone, D. B. and Hawkins, D. B. 1990. Palaeoclimatic forcing of magnetic susceptibility variations in Alaskan loess during the late Quaternary. Geology 18:40-43.

Berger, A. 1977. Support for the astronomical theory of climatic change. Nature 268:44-45. Berger, A. 1978. Long-term variations of daily insolation and Quaternary climatic changes. J. Atmos. Sci. 35:2362-2367.

Berglund, B. E. 1986. Handbook of Holocene Period Palaeoecology and Palaeohydrology. John Wiley & Sons, Chichester. 869 pp.

Boyle, E. A. and Keigwin, L. 1987. North Atlantic thermohaline circulation during the past 20,000 years linked to high-latitude surface temperature. Nature 330:35-40.

Bradley, R. S. (ed). 1990. Global Changes of the Past (Proceedings of the 1989 Global Change Institute at Snowmass). Publication OIES-6.

Broecker, W. S. 1987. Unpleasant surprises in the greenhouse. Nature 328:123-126.

Broecker, W. S. and Denton, G. H. 1989. The role of ocean-atmosphere reorganizations in glacial cycles. Geochim. Cosmochim. Acta, 53:2465-2501.

Broecker, W. S. and Denton, G. H. 1990. What drives glacial cycles? Sci. Am. 262(1):43-50.

Cook, E. R. and Kairiukstis, L. A. (eds). 1990. Methods of Dendrochronology: Applications in the Environmental Sciences. Klüwer Academic Publisher, London. 394 pp.

Dansgaard, W. and Oeschger, H. 1988. Past environmental long-term records from the Arctic. In: Oeschger, H. and Langway, Jr. C. C. (eds). The Environmental Record in Glaciers and Ice Sheets. John Wiley & Sons Ltd, New York.

Dansgaard, W., Johnsen, S. J., Clausen, H. B., Dahl-Jensen, D., Gundestrup, N., Hammer, C. U. and Oeschger, H. 1984. North Atlantic climatic oscillations revealed by deep Greenland ice cores. In: Hansen, J. E. and Takahashi, T. (eds). Climatic Processes and Climate Sensitivity. pp 288-298.

Druffel, E. R. 1981. Radiocarbon in annual coral rings from the eastern tropical Pacific Ocean. Geophys. Res. Lett. 8:59-62.

Eddy, J. A. and Oeschger, H. 1989. Global Changes of the Past. IGBP Report No. 6. IGBP Secretariat, Stockholm. 39 pp.

Fritts, H. C. 1976. Tree Rings and Climate. Academic Press, London. 567 pp. Grove, J. M. 1988. The Little Ice Age. Methuen, New York.

Guiot, J., Pons, A., de Beaulieu, J. L. and Reille, M. 1989. A 140,000-year continental climate reconstruction from two European pollen records. Nature 338:309-313.

Hanson, J. E. 1989. J. Geophys. Res. 94:1641-1647.

Hays, J. D., Imbrie, J. and Shackleton, N. J. 1976. Variations in the Earth's orbit: pacemaker of the Ice Ages. Science 194:1121-1132.

Imbrie, J. 1984. The orbital theory of Pleistocene climate: support from the revised chronology of the marine delta 18O record. In: Berger, A. (ed). Milankovitch and Climate, Part I:169-305. Reidel, Boston.

Ingram, M. J., Underhill, D. J. and Farmer, G. 1981. The use of documentary sources for the study of past climates. In: Wigley, T. M. L., Ingram, M. J. and Farmer, G. (eds).pp 180-213. Cambridge University Press, Cambridge.

Jouzel, J., Lorius, C., Petit, J. R., Genthon, C., Barkov, N. I., Kotlyakov, V. M. and Petrov, V. N. 1987. Vostok ice core: a continuous isotope temperature record over the last climatic cycle (160,000 years). Nature 329:403-409.

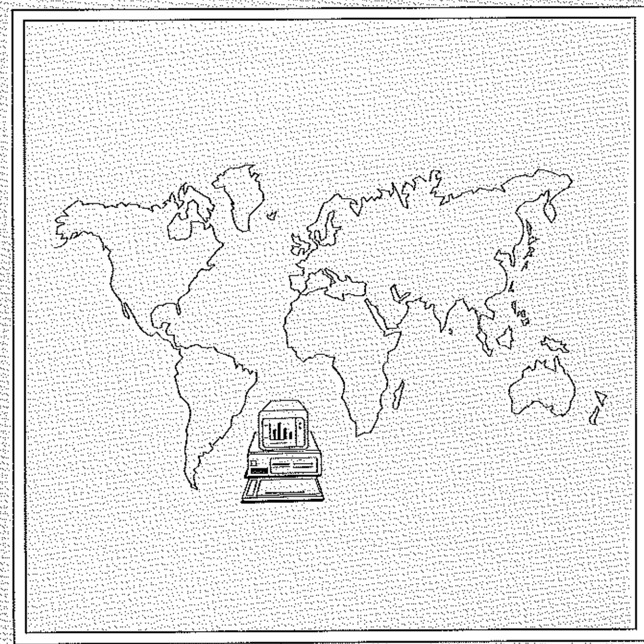
Lotter, A. F. and Zbinden, H. 1989. Late-Glacial pollen analysis, oxygen-isotope record, and radiocarbon stratigraphy from Rotsee (Lucerne), Central Swiss

Plateau. Eclogae geol. Helv. 82(1):191-202.
Liu, Tungsheng. 1985. Loess and the Environment. China Ocean Press, Beijing. 251 pp.
Lorius, C. J. 1989. Polar ice cores and climate. In: Berger, A. et al. (eds). Climate and Geo-Sciences. pp 77-103. Kluwer Academic Publishers.
Pfister, C. 1990. Monthly temperature and precipitation patterns in Central Europe from 1525 to the present: a methodology for quantifying man made evidence on weather and climate. In: Bradley, R. and Jones, P. (eds). Climate Since 1500 A.D. (in press).
Porter, S. C. 1981. Recent glacier variations and volcanic eruptions. Nature 291:139-142.
Raynaud, D., Chappellaz, J., Barnola, J. M., Korotkevich, Y. S. and Lorius, C. 1988. Vostok ice core reveals glacial-interglacial CH_4 change about 140,000 yr ago: climatic and CH_4 cycle implications. Nature 333:655-657.
Rutter, N., Brigham-Grotte, J. and Catto, N. (eds) 1989. Applied Quaternary Geochronology. Quaternary International Vol. 1.
Schweingruber, F. H. 1988. Tree Rings: Basics and Applications of Dendrochronology. Kluwer Academic Publisher, London. 276 pp.
Schweingruber, F. H., Bartholin, T., Schr, E. and Briffa, K. R. 1988. Radiodensitometric-dendroclimatological conifer chronologies from Lapland (Scandanavia) and the Alps (Switzerland). Boreas 17:559-566.
Shackleton, N. J., van Andel, T. H., Boyle, E. A., Jansen, E., Labeyrie, L., Leinen, M., McKenzie, J., Mayer, L. and Sundquist, E. 1990. Contributions from the oceanic record to the study of global change on three time scales. Report of the IUGS Interlaken Working Group for Past Global Changes (in press).
Shen, G. T. and Lea, D. W. 1987. Cadmium in corals as a tracer of historical upwelling and industrial fallout. Nature 328:794-796.
Stauffer, B. 1988. Ziele und Ergebnisse klimatologisch-glaziologischer Forschungsprojekte in der Arktis und Antarktis. In: Swiss Commission for Polar Research (SKP), Die Polarregionen und die Schweizerische Forschung, pp 95-110. Schweizerischen Naturforschenden Gesellschaft (SNG).
Stauffer, B., Lochbronner, E., Oeschger, H. and Schwander, J. 1988. Methane concentration in the glacial atmosphere was only half that of the pre-industrial Holocene Period. Nature. 332:812-814.
Stuiver, M. and Braziunas, T. F. 1989. Atmospheric ^{14}C and century-scale solar oscillations. Nature 338:405-408.
Thompson, L. G., Mosley-Thompson, E., Dansgaard, W. and Grootes, P. M. 1986. The Little Ice Age as recorded in the stratigraphy of the tropical Quelcaya Ice Cap. Science 234:361-364.
Zumbuhl, H. J. and Holzhauser, H. 1988. Alpengletcher in der Kleinen Eiszeit. Die Alpen 64(3):129-322.
Zumbuhl, H., Budmiger, G. and Haeberli, W. 1981. Historical documents. In: Switzerland and Her Glaciers. Kummerly and Frey, Bern. pp 48-69.

Suggested Reading

Barnola, J. M., Raynaud, D., Korotkevich, Y. S. and Lorius, C. 1987. Vostok ice core provides 160,000 year record of atmospheric CO_2. Nature, 329:408-414.
Bradley, R. S. 1985. Quaternary Palaeoclimatology. Allen Unwin, Boston. 472 pp.
Birks, H. J. B. and Birks, H. H. 1980. Quaternary Palaeoecology. Edward Arnold, London. 289 pp.
Eddy, J. A. and Oeschger, H. 1989. Global Changes of the Past. IGBP Report No. 6. IGBP Secretariat, Stockholm. 39 pp.
Grove, J. M. 1988. The Little Ice Age. Metheun, London. 498 pp.
Oeschger, H. and Langway, Jr. C. C. (eds) 1989. The Environmental Record in Glaciers and Ice Sheets. John Wiley and Sons, Chichester. 401 pp.
Wigley, T. M. L., Ingram, M. J. and Farmer, G. 1981. Climate and History. Cambridge Univ. Press, Cambridge. 389 pp.

GLOBAL IGBP CHANGE

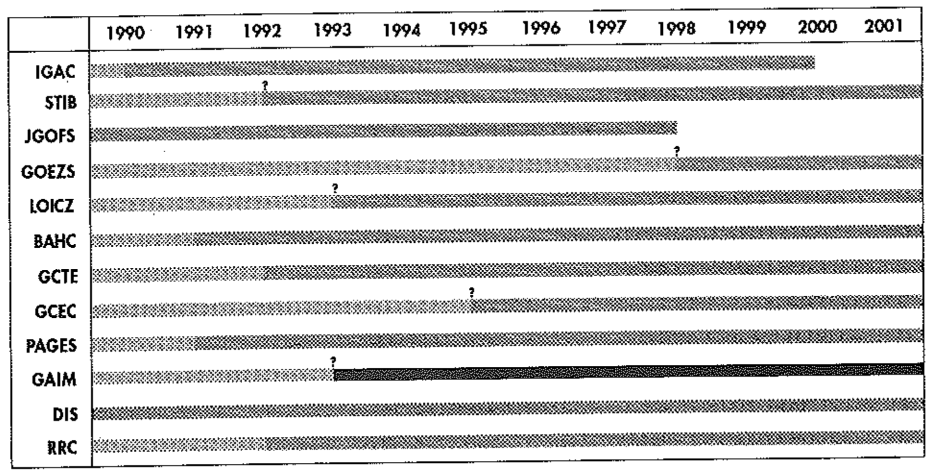


How Can Our Understanding of Components of the Earth System be Integrated and Synthesized in a Numerical Framework That Provides Predictive Capability?

"The development of advanced geosphere-biosphere models will be an important task for the IGBP. Such models are needed to introduce, as dynamic variables, the biological source and sink terms into descriptions of the way in which greenhouse gases will vary with climate change. That will become feasible with super computers available early in the 21st century. Such models will simulate detailed events with sufficient and temporal resolution to permit explicit treatment of the strong non-linear interactions between physics, chemistry and biology that occur on small scales."

IPCC (1990)

Contents



1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
IGAC
STIB
JGOFS
GOEZS
LOICZ
BAHC
GCTE
GCEC
PAGES
GAIM
DIS
RRC

8.1 Global Analysis, Interpretation and Modelling (GAIM)

A Proposed Core Project

Introduction

The various IGBP Core Projects aim to achieve predictive understanding of the processes and interactions within and among rather distinct components of the global Earth system (Chapters 2 through 7). The collection, analysis and interpretation of new data obtained in these projects, as well as development of new instruments, exploitation of satellite and other remote-sensing information will enable models of the interactions for the various components of the Earth system to be developed. A consistent effort is required to ensure that the knowledge gained about the components of the Earth system fits into a globally consistent and internally compatible description that can be used not only to understand the important biogeochemical cycles and processes, but also the feedback and interactions between the various sub-components that regulate the Earth system. Only in that way will a predictive capability for the global Earth system become a reality. Obviously, a major effort is required to ensure that this will be achieved.

To advance our knowledge of the structure and behaviour of the global geosphere-biosphere system in an orderly manner, a numerical model based on integrating/synthesizing activity that coalesces the knowledge gained from other IGBP Core Projects is essential. Such global models are of course simplified representations of reality. Still, they are useful for internally consistent analyses of the plausibility and compatibility of hypotheses concerning the interaction of key processes in the system. They are indispensable in serving an integrative function in the analysis and interpretation of the data that are being assembled. The development and employment of models is therefore a central activity within a comprehensive Earth system science programme such as the IGBP.

As a starting point it is useful to construct a reasonably detailed qualitative picture of basic interactions. To do so, available data for the various subsystems are combined into as complete a description as possible of the internal structures of these subsystems and particularly their interactions. In such an analysis the over-all requirement of energy balance and other dynamical constraints for the system as a whole, such as mass continuity in the biogeochemical cycling of all significant elements, is imposed. Such model developments for the various subsystems also provide a series of physical, chemical and biological constraints that must be considered in the construction of a plausible picture of the overall structure and pattern of interactions.

It is important in the development of such a conceptual picture of the dynamics and changes in the Earth system to specify the characteristic time scales with which we are concerned. Focusing on changes over decades and centuries, as given in the programme definition of the IGBP, should, however, not exclude the consideration of processes operating on longer time scales. The changes that have occurred during Holocene and late Pleistocene, associated with the variations between glacial and interglacial conditions, are particularly important (PAGES, Chapter 7.1). When testing models that are being developed for the study of present, more rapid changes, we can learn from studies of changes that have occurred on such longer time scales.

The following discussion of global change modelling is based on the conceptual diagram of the Earth system that has been developed by the United States Global Change Committee (Fig. 1). The upper part of the diagram shows the physical characteristics of the system, which determine the climate of the Earth. Modelling the climate system has progressed rapidly during the last few decades and its present characteristic features can be reasonably well understood by considering the physical interactions of the atmospheric, oceanic and terrestrial subsystems and prescribing the chemical and biological features as given but not changing. The promotion and co-ordination of climate modelling is a responsibility of the World Climate Research Programme (WCRP).

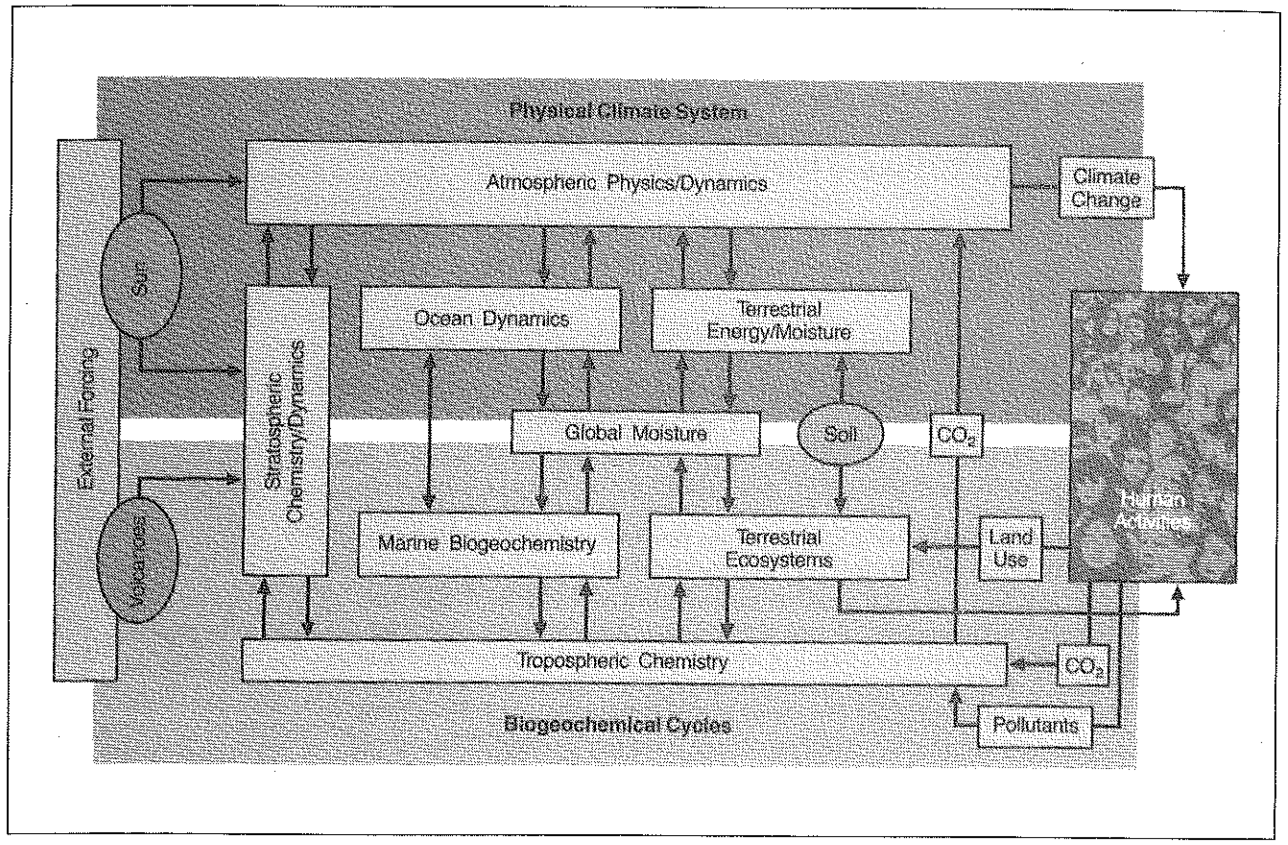


Figure 1. Conceptual model of global system links all earth processes - from the top of the atmosphere to the depths of the ocean - as they take place during time scales ranging from decades to centuries.

For understanding the climatic changes during the last millennium, and particularly over the last 100,000 years, the time-dependent chemical and biological processes and changes of their spatial distributions are of fundamental importance. The carbon dioxide concentration in the atmosphere has varied between 200 to about 350 parts per million during this period of time. However, changes in the global biogeochemical cycles have not yet been documented in a quantitatively convincing manner. An attempt to depict conceptually the key processes and interactions of this kind in the Earth system is given in the lower part of Figure 1. The challenge in a modelling project for the IGBP is to attempt to address the following:

Objective

- *With the aid of models, synthesize a fundamental quantitative understanding of the global physical, chemical and biological interactions in the Earth system during the last 100,000 years and assess possible effects of future natural and/or man-induced changes.*

Before a more detailed description of the characteristic features of the subsystems and their interaction is given, certain general questions related to development of global models for the Earth system must be addressed. The following overview is to a considerable degree based on the discussions and recommendations made at the first meeting of the IGBP Scientific Advisory Council (SAC) in October 1988.

Fundamental Issues in Global Modelling

Models as Simplifications of the Real World

Any attempt to understand or explain observed phenomena in our environment is based on a model of one kind or another. They always represent a simplification of the real world. Even complex models still describe reality only very approximately.

It is useful to distinguish between diagnostic and prognostic models. A diagnostic model is empirical and may well describe processes that are of importance only for some particular space and time scales. In general, the analysis is based on the further assumption of a quasi-steady state, so the diagnostic model defines a relationship between those processes that have been included in the model. This often represents a very useful first approximate description of the system that is being considered. The use of a diagnostic model to analyze a transient change of the system might, however, be misleading. The response characteristics of the model must be carefully analyzed in order to ascertain that changes are within the range of validity of the model. Validation of both steady state and transient characteristics is necessary. If all important processes are included, then the model be used for prognostic purposes with the hope for some success.

There are in principle three different reasons for the uncertainty in the results obtained with the aid of models: (i) only a limited number of physical, chemical and biological processes can be included in the model formulation; (ii) the processes that are included are treated inadequately and may not be representative across scales; and (iii) the spatial and/or temporal resolution is inadequate.

Even in the most complex models of the Earth system that are available today, the so called General Circulation Models (GCMs), the processes included are rather few and their theoretical formulation crude. The incompleteness of models in this regard also makes it difficult to assess the uncertainties of their results. We simply do not know how different a model would be, if another process was included until such an inclusion has been attempted. In some cases we are even ignorant of what are the key processes. This may be the case when small amounts of a compound play a significant (catalytic) role, such as micronutrients in both the terrestrial and marine environment.

Scaling and Parameterization

In any model there is always a minimum scale below which the real features of the system cannot be resolved. This is usually due to limited computer capability, but may also depend on inadequate knowledge of how to formulate a more appropriate model. The basic problem becomes: How to properly consider the collective importance of processes on scales less than those being resolved by the model when we wish to describe the large scale interactions that are of prime concern in the global context? We need to express the role of the small scale processes in a simplified manner, i.e., parameterize them in order to develop an adequate model. Examples of parameterization schemes in climate models are: (i) The role of convective clouds for the vertical transfer of energy, momentum and water in the atmosphere; (ii) The role of small scale motion fields for transfer processes in the oceans; and (iii) Determination of radiative transfer through the atmosphere whereby the integration over the relevant spectral ranges is markedly simplified.

In formulating models of biological and chemical processes, additional problems encountered are illustrated by the following questions: (i) How are biogenic emissions transferred vertically by convective processes and transformed by chemical reaction in the gas and/or water phases?; (ii) How do we describe stomatal resistance in the leaves of tree canopy as a regulator of transpiration, if the minimum scale that is resolved by the model is, much larger, say 100 km?; and (iii) How do we compute net primary production in the euphotic zone of the sea without explicitly considering the small scale patterns of upwelling and downwelling?

The problem of parameterization is a central one and is so far often only dealt with crudely. Effort is required to provide more systematic procedures in order to make further progress. Thus, a central theme for the global modelling project should be the systematic development of parameterization schemes for subgrid-scale processes to be included in global biosphere models.

Hierarchy of Models

The model formulation leads to a set of equations that describe the steady state or time dependant characteristics of the system. The results of numerical integrations are compared with observations of the variables that define the model. Models of the Earth system must be developed stepwise. In the first instance, when considering the most important processes, simple global models with a limited number of equations often formulated as changes between different reservoirs, i.e., box-models, need to be developed in order to explore the basic modes of interaction between major components of the system. One- or two-dimensional models permit spatial resolution, usually vertically and in a meridional plane, respectively. They are useful in highlighting specific aspects of the full three-dimensional problem and can serve as preparations for more thorough analyses. Models spatially resolved in three dimensions are usually based on General Circulation Models (GCMs) developed for the atmosphere and/or the oceans for studies of climatic (i.e., physical) interactions.

A suite of sub-component models are required to represent quantitatively specific processes that are the building blocks of the global models. Such process models also define additional observational requirements. An example is studies of land surface processes begun by the WCRP with the aim of improving our understanding of the physical boundary conditions between land and the atmosphere as employed in global climate models. Another approach is to make use of inverse methodology, whereby information about processes are deduced by determination of key parameters by requiring a best possible fit to data, i.e., inverse models are diagnostic rather than prognostic. Here one can derive a direct measure of how well the processes included into a model are compatible with available data. Such an approach complements the efforts to develop models for direct integration. It should be recognized, however, that an inverse methodology can lead to mathematically ill-conditioned problems and care must be exercised when employing inverse methods. They become cumbersome and require large computer capacity when applied to large systems.

Simple Box-Models

Numerous attempts have been made to describe global interactions in the Earth system by defining simple models having merely a few interacting compartments and comparatively few variables. The major questions that can be resolved by such an approach are:

- What constraints on the prime interacting variables are imposed by a strict application of the requirement of mass continuity and a steady state? (In some cases a few additional constraints are imposed when such can be easily formulated.)
- Which linear eigne-modes characterize the system and in which way is the linear model modified, if non-linear interactions are included?

In the former case an overview of the system is obtained that is useful, both with regard to the formulation of more complex models and setting priorities on data acquisition programmes, and in the later case, the internal oscillatory characteristics of the system and its response to forcing can be determined.

Simple conceptual models have been used to estimate anthropogenic CO_2 uptake and transient temperature change as atmospheric concentration of trace gases increases. Such simple models are usually too crude to provide credible predictions of future changes. However, their results can be valuable in formulating specific questions to be studied more in detail using models with better resolution.

Geosphere-Biosphere Models (GBMs)

The first step in development of such models is the formulation of a computational scheme for the time integration of the hydrodynamical equations as applied to the large scale motions of the atmosphere, where key features of the motion systems, the synoptic weather patterns, can be dealt with reasonably well at modest spatial resolution of 100-200 km, although higher resolution seems to

improve the realism of the model. Inclusion of the oceans in a corresponding manner pose more difficulties, because the energy carrying modes of the motions are of much smaller scale and the observational base is much more fragmentary. Still, there are ocean models that are able to describe the overall features of the general circulation of the oceans. It is likely that with the advent of more powerful computers, much higher resolution for ocean models can be attained in the future.

A second step is to deal with other physical processes which influence the large scale motions of the system. In the atmosphere we are particularly concerned with a proper treatment of the energy transfer by radiative processes, energy conversion and transfer due to cloud processes, and turbulent exchange processes between the atmosphere and the surface of land/oceans. In the oceans we need similarly to develop means to include the exchange processes with the atmosphere and also with the bottom of the sea, particularly in coastal zones. Formation and melting of sea ice require careful treatment in view of the fact that the exchange processes with the deep sea are decisively dependant on winter conditions in polar regions. All these considerations are central themes in the development of climate models and the WCRP carries a prime responsibility for the international coordinations of the efforts in this direction.

A modelling project for the IGBP should primarily consider chemical and biological processes and their interplay with physical processes. This kind of model development constitutes the core of the IGBP. The problems of devising models of the component subsystems of the Earth system have partially been addressed by the other IGBP core projects. Development of a global model of the Earth system based on general circulation models of the atmosphere and the oceans and including the mutual interplay of physical, chemical and biological processes, i.e., Geosphere-Biosphere Models (GBMs), will be the focus of the GAIM project.

Problems of Predictability

The Earth system, as defined above, is a very complex one. The question arises to what extent is it predictable? Three decades of research and development in the field of numerical weather forecasting has conclusively shown that there is a very definite scale dependant limit to deterministic weather forecasting. Weather patterns cannot be predicted with any skill beyond two weeks (theoretical limit of the deterministic predictability), and present models are able to predict weather for about one week in advance with reasonable success. The limit for predictability for the smaller scale features of the weather patterns is much less, even less than a day for predicting cloud distributions and convective precipitation. The large-scale and slowly varying features of the atmospheric circulations can be predicted on longer time-scales. Clearly, the interactions of the atmosphere, the oceans and the terrestrial biosphere may have to be considered in this context.

The predictability of a system depends on how chaotic its behaviour is and indeed the Earth system has many chaotic features. It is also well known that non-linear systems may have multiple states, the transitions between which becomes of fundamental importance when assessing the predictability of the system. It is important to establish the criteria that determine if major changes in the system, e.g., from one preferred quasi-steady state to another, will occur or not. There has been a rapidly growing interest in theoretical studies of chaotic behaviour of non-linear systems. Such research is of importance for improving our understanding of fundamental characteristics of the global models for the Earth system that are being developed.

Science Components

The preceding sections have summarized the complexities we encounter in the development of the geosphere-biosphere models. It is also clear that there are close similarities between the development of global climate models and geosphere-biosphere models. For the development of GBMs, it is desirable that formal links between the WCRP and IGBP be established. Appropriate joint working arrangements need to be agreed between WCRP and IGBP in order to ascertain an optimal international organization for the development of numerical models of the global Earth system.

It is essential to recognize the need to promote both the ongoing attempts to formulate and develop rather simple box-type models, as well as the construction of complex truly global geosphere-biosphere system models (based on coupled atmosphere - ocean GCMs and coupled atmosphere-ecosystem models), that can take advantage of the major increase of computer capability that can be expected during the 1990's. The former should focus on improvement of our understanding of the global biogeochemical cycles, the later should address fundamental problems that will be encountered in attempts to build large and complex system models. This core project accordingly will have two foci.

Focus 1

Modelling the Global Biogeochemical Cycles and Their Interactions

It is proposed that the development of Geosphere-Biosphere Models, GBMs be focused on description and better understanding of the global biogeochemical cycles. Although there are close links between all these cycles, it is considered appropriate that efforts focus on the global carbon and nutrient cycles.

Global Carbon Cycle Modelling

For the past 30 years, CO_2 concentrations in the atmosphere has been measured directly at a few marine sites around the world. More recently, CO_2 concentrations for the past 160,000 years have been extracted from air bubbles trapped in glacial ice. These observations show a dynamic carbon cycle that undergoes large natural fluctuations and rapid anthropogenic modification.

Atmospheric and oceanic models of varying degrees of complexity, ranging from box-models to global three-dimensional GCMs, have been used to deduce the strengths, timing and geographic distributions of terrestrial and oceanic sources and sinks of CO_2. Despite all these efforts, understanding of carbon exchanges among atmosphere-land-ocean reservoirs is still rudimentary and reliable projections of future CO_2 levels in the atmosphere remain elusive.

Simple models of net photosynthesis and decomposition of the terrestrial biota with regard to their seasonal and geographic variations have yielded atmospheric CO_2 variations compatible with the observations. Air-sea transfer of CO_2 is not very well known, but experiments with ocean circulation models yield preliminary results about the sources and sinks for CO_2 in the world ocean. Inconsistency in our understanding of the global carbon cycle were revealed when atmospheric, terrestrial and oceanic exchanges were included in an atmospheric GCM. It is clear that the simultaneous consideration of all three carbon isotopes ^{12}C, ^{13}C and ^{14}C as well as the use of other tracers both in the atmosphere and in the oceans will permit more stringent tests of the models.

The development of more advanced global carbon cycle models requires an expansion of the present network of observations of CO_2, primary productivity, etc., in order to permit adequate testing. The following highlights both key problems that should be addressed and the need for enhancement of the global data base.

Atmospheric carbon dioxide and the importance of isotopic studies

There are no direct means to distinguish biospheric and oceanic exchanges of CO_2 by interpretation of atmospheric CO_2, but isotopic ^{13}C measurements provide an indirect method to do so. This is because this rare isotope of carbon is fractionated relative to the abundant isotope, ^{12}C, when plants withdraw CO_2 from the air during photosynthesis, but is passed back to the air with little or no further fractionation, during decomposition. In contrast, when CO_2 passes between the air and the oceans little kinetic fractionation occurs.

The combined data on concentration and $^{13}C/^{12}C$ ratio of atmospheric CO_2 yield information on the distribution and strength of sources and sinks and allow distinction between biospheric and oceanic CO_2 sources and sinks. The isotopic

measurements must be of a high overall precision available at only a few laboratories in the world today. For an expansion of present studies of the isotopic composition of atmospheric CO_2 to be fruitful, close collaboration between laboratories and the establishment of reference standards specific to the study is required.

Additional insight into the carbon cycle may be afforded by studies of the ^{18}O to ^{16}O ratio of atmospheric CO_2, but too little is known at present about the patterns and causes of variations in this ratio.

Interpretation of CO_2 measurements may require the use of mesoscale models nested (embedded) into GCMs. Nested models are crucial for linking ecosystem dynamics models and GCMs. In addition to having higher spatial and temporal resolution, nested mesoscale models have a more physically realistic treatment of atmospheric processes (e.g., cloud formation, flow over terrain) than GCMs. Embedded models can potentially bridge the scale disparities in the Earth system.

The ocean component of the global carbon cycle

A central goal of ocean carbon cycle research is to determine the air-sea exchange of carbon dioxide in the past, present and future. Long-term uptake of carbon dioxide is determined by the intermediate and deep waters, modulated by near surface biology, and must be modelled in terms of the circulation and the biogeochemistry of the whole ocean. It is generally assumed that until anthropogenic influences become much larger than at present, the large-scale ocean circulation will remain in an approximate steady state. Programmes, such as WOCE, have been designed to obtain a diagnostic snapshot of this circulation for interpretation primarily in terms of ocean dynamics. However, the carbon content of the ocean is continuously changing, and future predictions of its concentration depend upon our ability to simulate with confidence the controlling processes. Monitoring this changing carbon content is a prerequisite for effective validation of global models of the carbon cycle.

In the deep ocean, below the direct influence of seasonal variability, we can reasonably expect that data are needed on decadal time scales, with spatial resolution comparable to what was achieved in the Transient Tracers in the Oceans programme (TTO) in the North and Tropical Atlantic. However, in the layers nearer to the surface, particularly where biological processes are active, the spatial and temporal variability is much larger and a different measurement strategy is required to develop and validate predictive models. We need: (i) local process studies summarized in terms of process models; (ii) sustained time series at a limited number of locations; (iii) horizontal sampling in particularly active regions; and (iv) continuous monitoring of patterns of such activity from space, by observing ocean colour, wind stress and sea-level variations.

In principle, the measurements of the partial pressure of CO_2, total carbon and alkalinity in the oceans together with wind speed can provide an independent diagnostic estimate of the flux of CO_2 dioxide through the surface and can thus serve as an essential constraint on predictive models. There is clear evidence that the carbon flux is highly variable in space and time, so that obtaining reliable integrated measurements requires an appropriate sampling strategy. In practice, it may be necessary to model some of the most rapidly changing aspects, such as the biological response to nutrients brought up to the surface by strong wind events. The data needed for this are congruent with those required for studies of the role of biology in the carbon cycle at the surface of the ocean.

The development of models is necessary both as a technique for making predictions and hindcasts of the behaviour of the ocean carbon cycle, and as a method to be used in conjunction with data assimilation techniques to interpreting ocean colour observations from satellites. The oceans are an important sink for anthropogenic carbon dioxide. Models must simulate the gas exchange rate at the air-sea interface and the circulation within the ocean in order to estimate oceanic uptake of carbon dioxide. In addition, there is clear evidence from measurements of carbon dioxide partial pressure in trapped air bubbles in ice cores that the carbon dioxide concentrations differed significantly between glacial and interglacial times. The response of the ocean carbon cycle to changes of climate is probably of significance for the explanation of such fluctuations. It is therefore important that we learn to model the carbon cycle sufficiently well to predict how it might respond to future climate change. Finally, satellite measurements of ocean colour provide a measure of ocean pigment for a relatively thin layer of the ocean surface (approximately 20 m). This information needs to be translated into information on the role of biological processes in the entire oceanmass. The way to do this is by the use of models.

A successful long term research effort on ocean carbon cycle modelling requires a further development of ongoing observational programmes such as the JGOFS (Chapter 3.1). It is essential that a more precise formulation of an observational programme to follow after the realization of the present JGOFS plans be pursued in parallel with the development of models (Chapter 3.2).

The World Ocean Circulation Programme (WOCE) and JGOFS will provide a global survey over the next 5 to 10 years which represent a follow-up of the Geochemical Ocean Sections Programme of 15 years ago, and the Transient Tracers in the Oceans programme, which recently completed a survey of the Atlantic Ocean. The strategy of periodic global surveys needs to be continued on a time scale of every 10 - 15 years.

Terrestrial processes

The land surfaces serve as sources and sinks for atmospheric CO_2 and must be modelled carefully in any attempt to analyze the global carbon cycle accurately. The key processes, such as photosynthesis and decomposition of organic material, are highly dependent on climate. Present rates of emission and absorption of CO_2 varies around the Earth depending on the prevailing ecosystem, the development of which in turn are dependent on the geological substrate and climatic conditions. The former, i.e., soil conditions, conversely have been modified by the succession of vegetation and climate types during the Holocene. While short term analyses of the role of the land surfaces in the carbon cycle can be assessed on the basis of present distribution of ecosystems and their characteristics, the analysis of changes over time periods of centuries or longer requires the formulation of models that describe the mutual interplay between the carbon cycle and the climatic system.

Earlier international programmes devoted to studies of specific ecosystems of the world and their possible modification due to anthropogenic activities, e.g., the International Biological Programme (IBP) and Man and the Biosphere (MAB), have contributed significantly to our present understanding of these issues. The IGBP must now strive for an extension of those previous studies by attempting to model quantitatively the complex global patterns of interplay between physical, chemical and biological process that characterize the functioning of the biosphere today as well as its evolution during the last 10,000 to 100,000 years. This necessarily requires the recognition of the interaction of the global carbon cycle with the global cycles of other key elements, particularly nitrogen, phosphorus, sulfur and some crucial micro-nutrients.

Biogeochemical Cycles and Their Interactions

The carbon cycle is but one of the many biogeochemical cycles that play a role in the Earth system. A penetrative analysis of the carbon cycle necessarily involves a treatment of the major nutrient cycles and their interactions with the carbon cycle. Few such attempts have been made so far. During the last few years general circulation models for the atmosphere have been used for studies of the chemical interactions in the atmosphere. Similarly ocean circulation models have been employed in order to grasp in a more precise and internally consistent manner the biological and chemical interactions in the oceans. Still, truly global models including a more precise treatment of the mutual interactions between the atmosphere, the oceans and the terrestrial system are as yet available only in the form of crude box-models.

In view of the central importance of the carbon cycle for biogeochemical interactions it is rational that the modelling of the more complex interactions of the Earth system grows out of the present attempts to model the carbon cycle. Much will depend upon the knowledge about the key processes gained from the other IGBP Core Projects and the possibilities to generalize, i.e., parameterize, those results into globally applicable numerical algorithms.

Core Activities

(1) The development of global models for the Earth system will depend on our understanding of the characteristic features of the key subsystems. A series of IGBP Core Projects have been proposed in order to coordinate and stimulate such a development. The development of models for these sub-systems will be a necessary prerequisite for the work in GAIM. A workshop should be organized with the aim of laying the foundation for the development of global, spatially resolved, geosphere-biosphere models with the emphasis on biogeochemical interaction.

(2) Joint meetings with the WCRP Working on Group Numerical Experimentation should be arranged in order to acquaint those engaged in biosphere modelling thoroughly with the present status of climate modelling. The fundamental problem of matching the different space and time scales should be addressed, particularly procedures for parameterizing the small scale biological processes.

(3) In view of the fact that man's activities have caused major disturbances of the carbon cycle, it is essential that models for the transient behaviour of the carbon cycle be further developed. A workshop should be planned for the summer of 1991 to analyze present capability and simulate further work.

(4) A determination of an optimal strategy for data acquisition to ascertain validation of present generation of carbon cycle models is urgently needed.

(5) A workshop for global modelers and key representatives for satellite agencies and COSPAR should be arranged soon with the aim of defining the global data sets that should be aimed for towards the end to the 1990s.

Long-Term Model Development *Focus 2*

Aims

The development of advanced geosphere-biosphere models must be a central task for the IGBP and steps should be taken now to develop a strategy for the long-term efforts. The aim of this focus of the Core Project is to design comprehensive quantitative predictive models of the Earth system, which will become feasible on super-computers available early in the 21st century with expected computing rates exceeding those available today by several orders of magnitude. Such models will simulate the detailed events that occur in the geosphere-biosphere with sufficient spatial and temporal resolution and permit explicit treatment of the strong non-linear interactions between physics, chemistry and biology that occur on small scales (e.g., primary production patchiness in the sea and terrestrial ecosystems). One of the aims should be to achieve a much finer horizontal resolution than currently possible.

The planning should produce a strategy for the design of integrated high resolution global models, but the activities will, to begin, with not be concerned with the implementation of such models. The emphasis will rather be on a balanced approach, in which relative allocation of computer power to simulating the various sub-systems (terrestrial biosphere, ocean biosphere, atmospheric and oceanic circulation, etc.), will reflect the relative importance of the global cycles being modelled. As the model design becomes clearer, attention will have to turn to the specification of data needed to run and to test such advanced models.

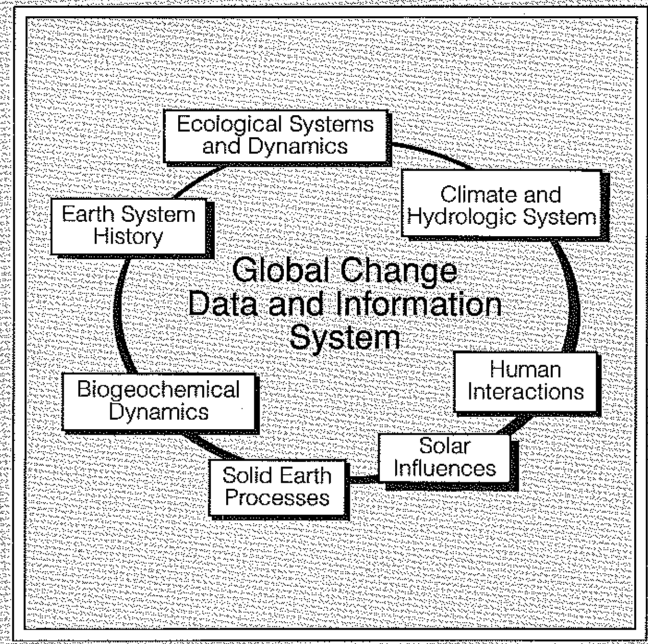
The practical task of designing an integrated model will provide a guide to the relative priorities of IGBP core projects and it may lead to the identification of gaps in the IGBP research strategy.

An ad hoc Planning Committee should be established consisting of scientists involved in developing geosphere-biosphere models by coupling general circulation models for the atmosphere and the oceans. It is essential to keep in close touch with expertise that is taking part in the development of the next generations of computers.

References

IPCC. 1990. Report of the Working Group 1 on Scientific Assessment of Climate Change. WMO/UNEP (inpreparation).

GLOBAL IGBP CHANGE

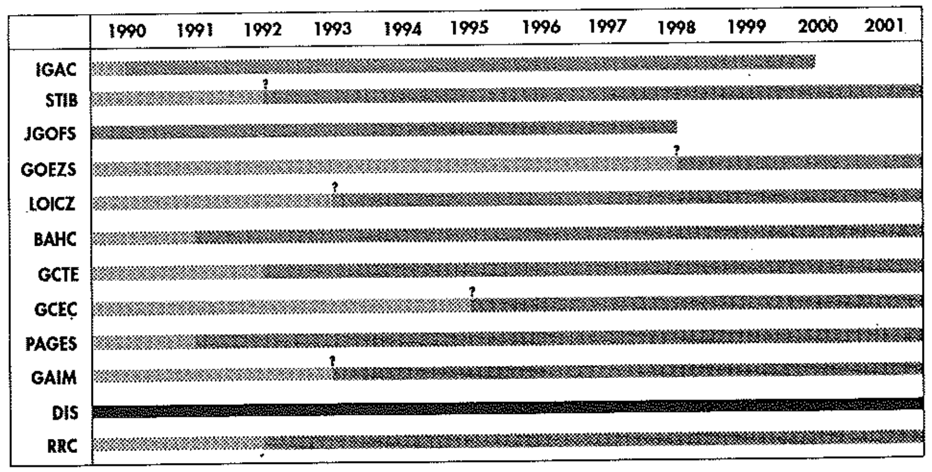


Data and Information Systems for the IGBP

"In spite of the enormous volumes of data currently being collected annually, it is questionable that specific data have, in fact, been acquired and are in a form required by a particular user. For this reason, in establishing the new international endeavour on global change, the scientific needs must be discussed and reviewed by scientists on a multidisciplinary basis. Once the problem has been clearly stated and agreed to, the data needs (especially in terms of precision and accuracy) have been established, then data systems and computer experts specializing in spatially distributed data may provide advice on how best to proceed. The final decision, however, should rest with the scientists, who are also responsible for deciding what priority is to be given to data acquisition and storage".

(Hutchinson and Bie 1985)

Contents


1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
IGAC
STIB
JGOFS
GOEZS
LOICZ
BAHC
GCTE
GCEC
PAGES
GAIM
DIS
RRC

9. Data and Information Systems for the IGBP (IGBP-DIS)

Background

The foundation of IGBP lies in the coupling of observations over a range of spatial and temporal scales with process studies and models in order to understand and eventually predict global change. But currently, global change research is data limited and it is important to begin developing the mechanisms to ensure that global change research can be properly supported by the necessary measurements and data sets.

The crucial role of information systems and the importance of data-management methodologies in support of global change research have been identified during the IGBP planning phase. Two important themes run through these discussions. First, an essential prerequisite for improving our understanding of Earth system processes is the development of geographically referenced models and data sets. Such models typically exploit a wide variety of data and this requires organized and systematic procedures to permit the integrated use of data sets of many different types and formats over a wide range of scales (Fig. 1). Second, methods and protocols for handling the large volume of data inherent in geographically-referenced models need to be developed. Coupled with this, methods need to be developed to enable interpretation of remotely sensed data, and their translation into parametric information that can be used in models and analyses.

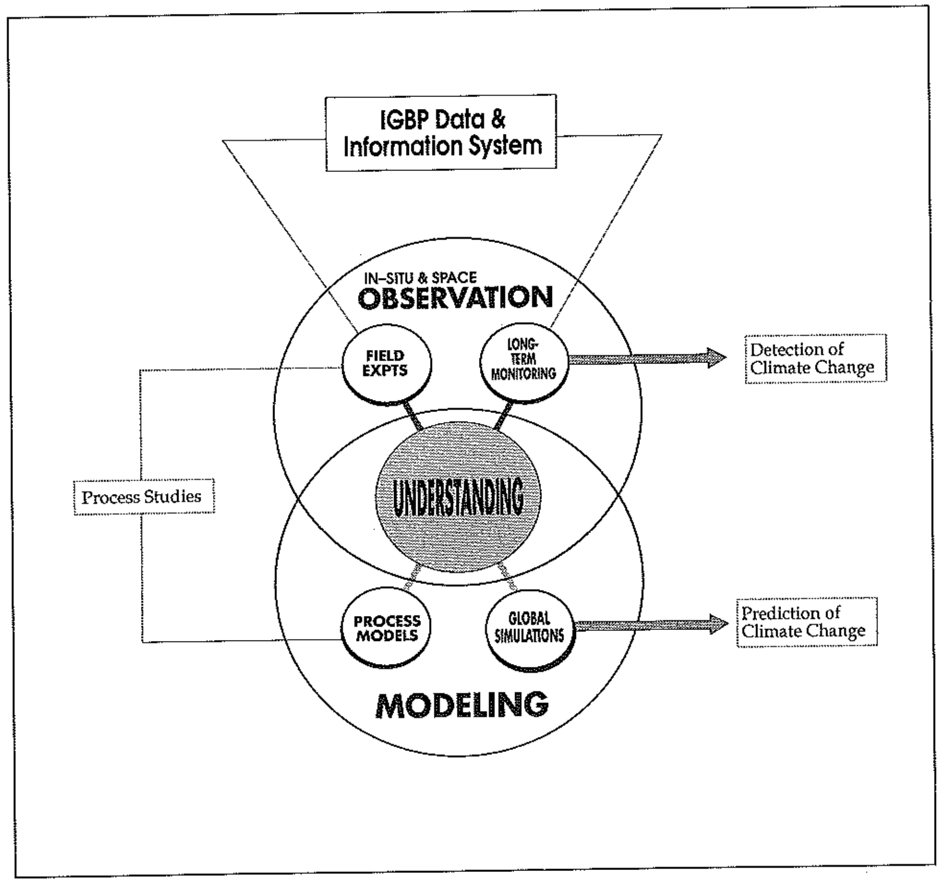


Figure 1. The role of IGBP-DIS in relation to the IGBP research components.

There are two kinds of data requirements considered in this chapter. The first is data sets that document global change. These include data precisely calibrated to show subtle changes in ambient conditions such as; land and sea surface temperature, global precipitation patterns and amounts (i.e., spatial and temporal distribution), changes in global land-cover characteristics and ecosystem dynamics. The second kind of requirements relates to the provisions of data sets for support and parameterization of global process studies. Such studies include:

- Studies of water and energy balance and dynamics, which require data on latent heat flux, water movement, land topography, soil moisture, canopy evapotranspiration, and other dynamic parameters, many of which are derived from land cover.
- Modelling of global biogeochemical cycles, which require data on trace-gas emissions, ocean circulation and gas exchange, and ecosystem element cycling.
- Studies of ecosystem dynamics for different climatic regimes, which require data on land-surface characteristics including vegetation and soil changes, topographic information and data on climate change.
- Marine studies to understand exchange processes of atmospheric trace gases with the marine biosphere. These will certainly involve global-scale data sets on, for example, ocean chlorophyll, seasurface temperature at high spatial and temporal resolution, CO_2 concentration in the upper oceans, and surface winds.

Some of the most basic data sets either do not exist at a global scale or are inadequate to support these areas of research. A prime example is that of land cover. Although probably the single most important and universally needed terrestrial data set, it does not exist on a coherent long-term basis, yet observations recorded over the past eight years from satellites are available from which the needed global time series can be derived. Land-cover data are needed for three of the four areas of research listed above. Another example is land-surface temperature. This data set is critical for documenting global climate change, yet does not exist with sufficient precision or accuracy, coverage and representativeness for the task. This chapter will discuss mechanisms by which these two issues on developing a data and information system and developing global data sets will be resolved.

Plan for Action

Focus 1 — *Management of Data*

Structure of IGBP Data and Information System (IGBP-DIS)

Rationale for a mechanism

The large variety of types and sources of global data needed for IGBP studies makes it important that a structure be in place at the earliest possible date to document what exists, assess its quality, check on accessibility of the data available and finally to foster the exchange of data sets.

A number of impediments exist to the free exchange and distribution of data in an international programme. Some of the more important impediments are:

- the lack of a comprehensive inventory of major existing data banks;
- even where data sets exist, there are often major uncertainties about their quality and accuracy;
- there are no consistent international policies and protocols for data exchange, which leaves uncertainties on issues such as charging and licensing (which constrains data sharing) copyright restrictions, import/export restrictions, and technology transfer issues;
- there is no long-term (10-20 years) commitment from any national or international organization to develop the policies and programmes to facilitate data exchange, in the new areas of research of the IGBP;
- the bit stream of data is large, but our ability to analyze the data, or produce information from data, is slow due to the lack of trained interdisciplinary scientists and due to the paucity of experience and methodologies for utilizing large amounts of data.

If the IGBP is to succeed, each of these impediments must be removed, and this requires the recognition that data management is a fundamental, if not primary, component of a research programme. As such it transcends engineering. It must be an integral component of an overall research strategy and embedded within the implementation plans for each established Core Project. Thus, the implementation of a data-management scheme for the IGBP must be a visionary one, but must also be realistic. In particular, it must capitalize on existing structures and national-level efforts. A phased approach is needed and the highest priority in the early period of IGBP implementation (1990 - 1992) must be on managerial and policy aspects. During this period, IGBP would make no effort to develop centralized facilities for data processing and product generation, but would instead focus on three major activities; (i) developing a programmatic infrastructure; (ii) performing pilot studies to develop methodologies for producing globally consistent data sets; and (iii) attempting to install data directories around the world in order to make data more accessible to the global community of scientists.

Later, in the next phase, as specific data needs are articulated by the Core Projects and as critical data gaps are found, the IGBP will begin to utilize data facilities, which meet the research needs or to propose new developments to ensure that these needs are met. This phase would focus on installing an IGBP-DIS facility, which would be co-located at some existing data centre, and which would conduct preliminary tasks such as data reformatting or algorithm development for the IGBP scientific community.

As the IGBP projects develop, it may be necessary to expand the role of the data-management facility. This could be done in two ways: (i) by expanding operations, to include the development of an IGBP data archive; and (ii) by expanding the number of facilities around the world, linking them together physically through data communications networks.

In accordance with established ICSU policies on open and unrestricted data and information exchange, and the principles governing the ICSU-WDC System, the following policies are proposed:

(1) The IGBP places high priority on the establishment, maintenance, validation, description, accessibility and distribution of high-quality, long-term global data sets, including the synthesis, or generation of new global data sets.
(2) Full and open sharing of the full suite of global data sets, and other data sets needed for global change studies, is the primary objective of IGBP-DIS.
(3) Consequently, IGBP-DIS should have the following characteristics:
   - suitable preservation of all data needed for long-term, global change research must be ensured;
   - data archives must include readily accessible and comprehensive information describing data sets (metadata about the data holdings, including quality assessments, supporting ancillary information, and guidance and aids for locating and obtaining the data);
   - national and international agencies with responsibilities for archiving and distributing global change data should, to the greatest extent possible, use media and processing and communication systems which are consistent with internationally accepted standards and protocols;
   - in those cases in which individual scientists have initial periods of exclusive data use, data should be made openly available as soon as they become widely useful;
   - data should be provided at the lowest possible cost which, as a first principle, should be no more than the cost of reproduction and distribution.

Management structure

The near-term data management role of IGBP will be one of support and coordination. This will be implemented through a small coordinating office, guided by a Standing Committee, with support from a technical staff.

The IGBP Office of Data and Information Systems should serve the following functions:

- Facilitate and coordinate access to, and exchange of, IGBP data sets by encouraging the development of standards and protocols for data exchange.
- Assist in locating important IGBP data sets, which are currently stored elsewhere. There is also a need to coordinate the development of new data sets, which would otherwise not come on-line because they fall outside the domain or interest of a specific Core Project.
- Provide the initial data processing and management experience by coordinating and monitoring a series of prototype projects, the first two of which have been identified as the Land Cover Pilot Study and the Surface Temperature Pilot Project. These pilot studies will also perform the role of developing two much-needed new data sets.
- Provide for outreach and training at an international level through the dissemination of sample diskette data sets and instructional material including software through workshops and other related activities.
- Encourage and organize a system for data set and data product review to ensure the development of the best possible data and to provide an environment, which encourages the development and dissemination of data sets by investigators.
- Implement and maintain an international system of data directories which would provide scientists with information on the location of various IGBP and non-IGBP data sets.

The professional staff of the IGBP-DIS Office will have both the scientific background relevant to the Core Projects and some detailed understanding of information systems, remote sensing, and GIS. The IGBP will encourage scientists to be actively involved in data management of the Core Projects.

One key function of the IGBP-DIS Standing Committee and staff would be assisting in acquisition of essential data sets which are needed by the Core Projects, but which do not exist in current holding, at the various national and international data centres, and will not be produced by the Core Projects themselves. The IGBP-DIS Office will coordinate the generation of these data products. The two pilot studies, land cover and surface temperature, are examples of this kind of effort and are now under way by the working group as demonstrations.

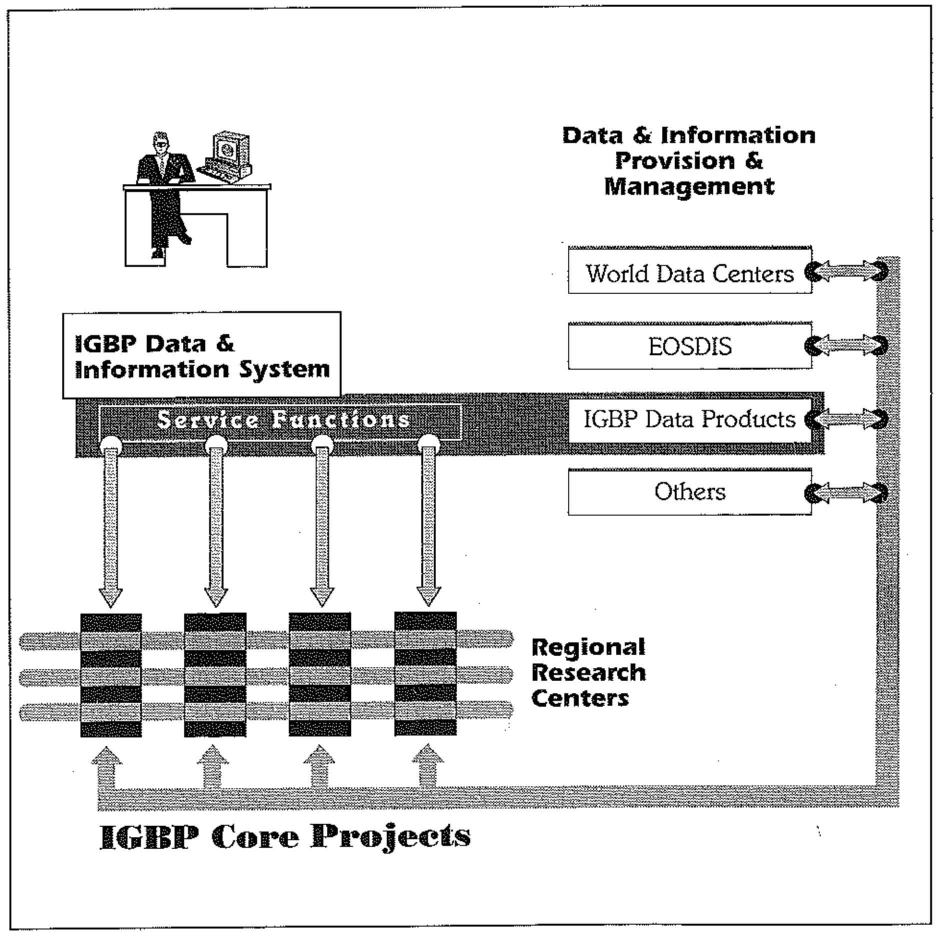


Figure 2. Relationships between IGBP-DIS and IGBP Core Projects.

The relationship between participants in the research process, various data centres, the Core Projects, and the Regional Research Centres, is clearly defined by the need to exchange information (Fig. 2). The establishment of a directory system, managed by the IGBP-DIS Office with cooperation from participating national centres/agencies (e.g., NASA), will provide information to the various participating IGBP scientists around the world on the location of data sets. As shown in this diagram, the IGBP-DIS Office provides the critical link between data centres and Core Projects, as well as facilitating the management of data.

The IGBP-DIS Office must participate actively with the various IGBP Core Projects to deal with their data needs. Personnel could be provided to the Core Projects by the IGBP-DIS Office to act as a liaison with the IGBP-DIS Office, thereby providing assistance to the Core Projects in the way of data management and to the IGBP-DIS Standing Committee in the way of articulating technical needs.

One tangible function of the IGBP-DIS Office during this phase will be to install a system of data directories, the IGBP Global Environmental Data Directory (IGBP-GEDD, Fig. 3). The directory system will be organized around the NASA Master Directory and would be installed in GRID/Geneva as a central location in Europe. The purpose of the directory system will be to tell scientists where they could find existing data sets and to provide online information about their characteristics. It would not be the purpose of this effort to actually archive the data sets.

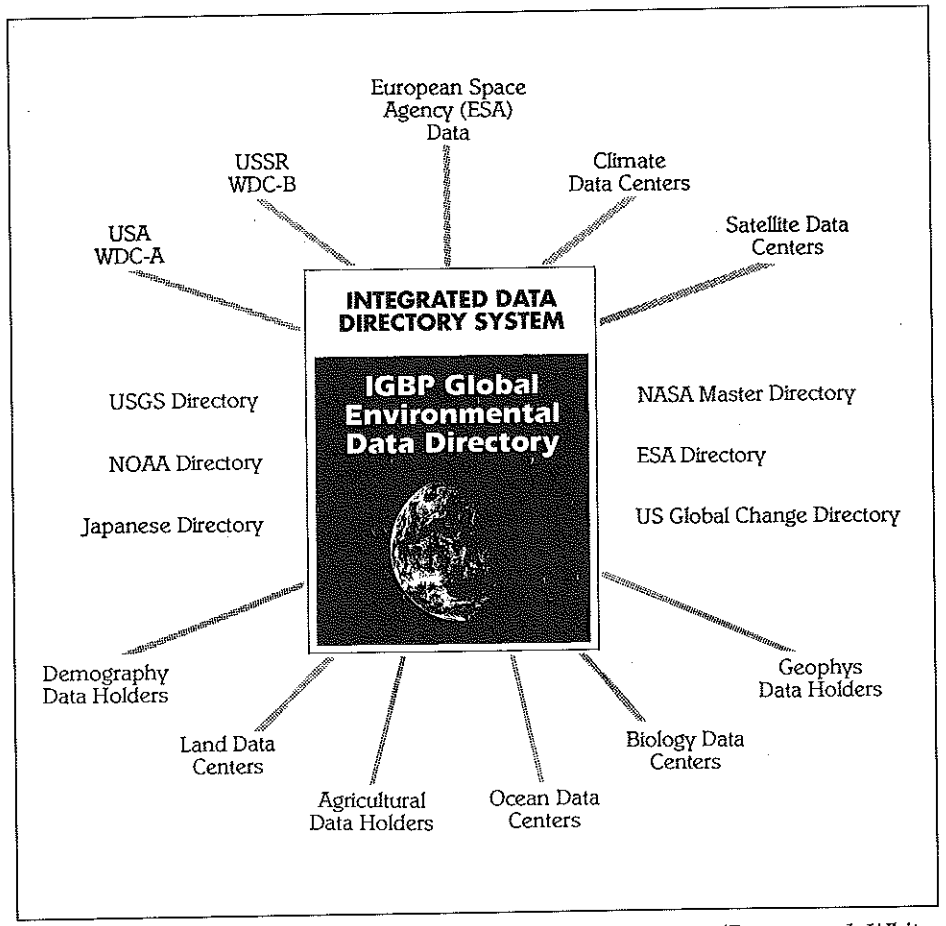


Figure 3. Integrated data directory system and IGBP GEDD (Barton and Whitee unpublished).

Data management beyond 1992

A number of facility-based needs are expected to arise during the early implementationphase as the Core Projects begin collecting and assembling their own data sets and begin to exchange data with other groups. A mechanism will have to be developed to facilitate data retrieval, processing, data conversion, and archiving. A facility to conduct these activities must be identified or developed for the IGBP. In addition, the land cover and surface temperature data sets, being produced in collaboration with the IGBP-DIS Office, will be ready for archiving and distribution and will need the appropriate outlet to the scientific community.

It is believed that the initial processing facility should be co-located with an on-going archiving and processing facility, such as in the UNEP or WDC system. One possible candidate would be the EROS Data Centre, since it is, or will soon be, a land processing facility for the EOS Data and Information System, and a facility in the World Data Centre network.

The chief responsibilities of this facility will be very circumscribed and restricted during the early development period. In time, it would serve as a distribution centre, a training centre, a reprocessing and data conversion centre, and, to a limited degree, an archiving centre.

Data Access and Directory of Directories

Introduction

The IGBP-DIS, because of its multi-disciplinary and multi-user characteristics, must be an open and flexible system of data and information exchange. The diverse types of data, which will populate the IGBP data system and be needed by the IGBP research community, demand the development of a system capable of cataloguing and accessing a data directory or Directory of Directories for the IGBP. This will be necessary in order to facilitate accessibility to the needed information.

The IGBP-DIS should be a distributed system to provide more convenient access to scientists in all countries and provide safety for preservation of IGBP data sets. The IGBP-DIS should interface with, and collaborate as appropriate, the various data systems operated under the auspices of ICSU (e.g., the WDC system, WDDES, IGU, etc.), UN bodies (e.g., GRID/UNEP, the WMO, IOC/UNESCO data systems and SOTER) and important national data systems (such as those being developed for space-based operations).

Scientists who, in the course of their research, produce new global data or information products should be encouraged to contribute these to the IGBP-DIS, so that they may be readily accessible to others. There should be mechanisms to ensure that scientific and professional credit is given to scientists, who publish or otherwise prepare data sets for public distribution.

Global environmental data directory

A priority goal of the IGBP-DIS is a management system, which describes data and information useful for Global Change Studies. The IGBP Global Environmental Data Directory (GEDD) will be developed as a computer tool to satisfy this requirement. The model for the GEDD is the NASA Master Directory (MD), which has been operational since 1988. The MD is the core of an evolving international system of data directories, which includes the European Space Agency in Italy, the NOAA Earth Systems Data Directory, and copies of these directories will be installed in Japan, Geneva, and USA. A copy of the MD will be installed by NASA at the UNEP/GRID computer. The GEDD will use the NASA Directory Interchange Format (DIF) for describing data sets. The DIF is the standard format used in the data directory system. A task group will be formed to develop a standardized protocol for use in the IGBP. It is intended that the GEDD will be a user friendly system, with access via a computer terminal. Information will be displayed on the computer screen. The user will be prompted, in an interactive manner, for search parameters such as Discipline, Location, Parameters, Keywords, and Data Centre. Titles of data sets which satisfy the search criteria will then be displayed. The user can then display the description

of a selected data set. Information will be given about the data set, with the key field being the Data Centre where the data set is available.

Data-management functions for the GEDD will be performed by a coordinator responsible for the control of data descriptions in the Directory. This function provides a central point for monitoring the input and update of data descriptions in the GEDD. The IGBP-DIS Standing Committee will provide a forum for locating data sets which should be included in GEDD, for reviewing data descriptions and for deciding which descriptions should be included in the IGBP-GEDD.

The GEDD will allow complete data descriptions to be generated on files, which can be printed or used in word-processing systems. Two options will be available: the DIF format, and a general listing format throughout the DIF System. These allow the preparation of printed catalogues from the GEDD. It will also be possible to use this output to prepare PC diskettes of data descriptions. These can be used with word-processing software to view and search through the descriptions. A subscription service could be developed by the IGBP-GEDD to distribute directory information to locations, which do not have access to telecommunications networks. Another alternative for distribution is a PC version of the Master Directory software system. This option will be explored for future implementation. Alternatively, scientists will connect to the GEDD using telecommunication systems such as OMNET, SPAN, EARN, BITNET in various regions of the world.

Data Sets for Training and Education

A pilot project consisting of a library of data sets useful for global change studies has been initiated (IGBP 1989). A global vegetation index (VI) derived from satellite observations has been compiled from NOAA-AVHRR data. The data sets were made available on computer floppy diskettes to facilitate ready access by scientists in developing countries.

A demonstration project for Africa has been completed with four years of data, composited monthly. Africa was chosen as the first demonstration area, since UNEP-GRID and the UN Institute for Training and Research (UNITAR) indicated interest in using the data sets as hands-on training modules for workshops scheduled for Africa in 1989-1991. In addition, suitable ancillary data sets have been included so that the annual and seasonal vegetation-index could be studied in the context of other land-surface and climatic variables. The data sets will be expanded to include South America and Asia.

This data set and software package was successfully used at a GRID/UNITAR workshop in Accra, Ghana, November 1989. The participants seemed eager to participate and the idea of collaborative efforts, between research groups and scientists in developing countries to provide improved information to the project, was accepted.

Significant long-term national and international support is needed to assure that the project will be able to continue workshops with GRID/UNITAR beyond 1990 in other regions.

A number of groups in both developed and developing countries have offered to use the data sets in global change case studies, and to provide an evaluation of the data set for tutorials in training workshops. These groups have been asked to share any relevant tutorials they develop in using the data sets. Such tutorials or case study exercises are needed to develop a library of training exercises for the GRID/UNITAR workshops.

The Global Change Diskette Project now needs a national-level commitment to provide development efforts that will continue beyond the pilot phase to assure stability of the project, to assist GRID/UNITAR in developing the necessary training materials and tutorials, to provide a focus of feedback of improved data into the project, and to be responsible for updating the database sets and distributing the updated versions. Some relationships might also be possible with the ISY Encyclopedia of the Earth project.

The ICSU WDC Panel should also remain as an active partner in the project, to assist with international aspects, provide assistance in obtaining new equipment such as CD-ROM readers, and, through the WDC System, ensure the appropriate connection to other interested ICSU bodies. In this regard, the Panel, through ICSU, is seeking UNDP support for 1990-1991 as a pilot phase to enhance and accelerate assistance already in place for scientists in developing countries.

Focus 2

Development of Global Data Sets

Land-Cover Change

Introduction

The need for a comprehensive global data base on land-cover change has been identified as having critical importance for a number of IGBP Core Projects. These include International Global Atmospheric Chemistry Programme (IGAC), Biospheric Aspects of the Hydrological Cycle (BAHC), Global Change and Terrestrial Ecosystems (GCTE), and Global Analysis, Interpretation and Modelling (GAIM).

It is clear that the requirements for local land-cover information vary considerably for the different projects. The first project, for example, requires only broadly defined land-cover types, whereas others will require much more detailed information. Existing data sets on land-cover characteristics are derived almost entirely from the compilation of local data sources (FAO 1988; Mathews 1983, 1985), relying mostly on conventional ground-based methods. As a result the information varies considerably in reliability and in the consistency with which major categories are defined. In recognition of this major omission in environmental data bases for global investigations, a Land-Cover Pilot Study has been initiated.

Objective

- *To develop, validate and demonstrate a methodology capable of monitoring land-cover characteristics and its changes in a range of environments which subsequently can be used globally.*

In order to achieve this objective a number of tasks have either been carried out or are in the process of being executed within the next two years.

The encoding, processing, and utilization of large volumes of variously formatted data require adoptions of new methodologies, procedures, and approaches to data acquisition, processing, management, and interpretation. Clearly, new global change research initiatives will need to be coupled to efforts to develop special geo-based information systems. This has been a consistent priority of the global change studies, highlighted in several national and international studies and publications (National Research Council 1986; Earth Systems Science Committee 1988; NASA Earth Observing System 1988; International Geosphere Biosphere Programme 1988, 1989; and Space Agency Forum for International Space Year (SAFISY) 1988, 1990). The IGBP Working Group on Data and Information Systems was established to explore ways in which this could be achieved. Because remote sensing holds the greatest promise for obtaining geographically referenced data over large areas of the Earth's surface, it has become an important focus of efforts by the IGBP and is dealt specifically in Chapter 10.

The integrated global land-cover data base

The original concept of the global land-cover product centred around the production of a global map (IGBP 1989). It is now proposed that this concept should be substantially modified, in large part because the varied requirements for the IGBP cannot be satisfied by a single map of one set of attributes. Instead, it is proposed to develop a comprehensive global land-cover data base, which will contain the following sets of data planes: (i) basic calibrated remote sensing data sets; (ii) pre-processed remote sensing data set; (iii) key ancillary data planes; (iv) attribute data sets (base-line and change); and (v) parametric data sets (base-line and change).

Data sets used in the IGBP will largely be derived from the latter two of these data layers. The attribute data sets will contain spatial products including conventional class maps. Ultimately, it is anticipated that several different types of products will need to be generated. For the parametric data sets, quantitative derived characteristics of the land surface will be derived, through statistical approaches, and through full-scale inversions of remotely-sensed data assisted by techniques such as scene modelling. It is anticipated that these latter data sets will eventually be the most significant for the IGBP, because of the requirement to develop quantitative environmental models.

Definition of land-cover classification

During the planning discussions, a classification scheme has been developed, which is hierarchical in character. Initial discussions have focused on the broad, general classes of cover types, and include: evergreen forest, deciduous forest, shrub, grassland, desert, snow, ice, tundra, cropland, and urban land cover (see IGBP 1989). These can be derived from existing satellite data, with satisfactory accuracy for a wide range of applications. Further work is now being carried out to quantitatively define the boundaries between the categories and to define other levels of the classification hierarchy suitable for research studies conducted in other IGBP Core Projects.

Choice of remotely sensed data and pre-processing procedures

Data from the Advanced Very High Resolution Radiometer (AVHRR) of the NOAA series of satellites have been selected as the prime source of data for the land-cover data base. This choice is based on the appropriate pixel size of the data in relation to the global coverage requirements, the ability of the data to generate land-cover classes of the type required, the past and future continuity of this data source and its frequent global coverage. For several of the pilot areas, AVHRR data have already been collected, composited and processed, notably those for the US, Canada and West Africa. Pre-processing of these data are necessary before use and a considerable number of options are available under pre-processing procedures. These include: (i) compositing methods; (ii) time period for compositing; (iii) atmospheric correction procedures; (iv) geo-referencing coordinate systems; and (v) resampling procedures. Standardization of these procedures is necessary for precise intercomparison of cross-site study evaluation as well for infra-site temporal coherency.

Acquisition of AVHRR data with 1-km resolution has largely depended on the use of ground receiving stations, due to limitations of storage on the sensor's tape-recorders. Agreement on re-processing procedures of these data are essential for the creation of internally consistent global data sets. In order to gain international agreement on pre-processing standards, an international meeting of ground-station organizations collecting AVHRR 1-km data has been organized by the IGBP Working Group on Data and Information Systems to evaluate the various techniques currently being used. Presently, even coverage information on the availability of 1-km data from the AVHRR sensors is difficult to obtain. The task of establishing the availability of AVHRR data in order to obtain a global picture of gaps in AVHRR coverage has been initiated. This exercise will be used to make recommendations for the future use of on-board tape recorders, so that a more complete global coverage can be obtained.

Selection of pilot studies

In the original formulation of the pilot studies (IGBP 1989), it was envisaged that a number of separate areas of comparable size would be selected covering a representative sample of vegetation and land-cover types. Subsequent activities of the Working Group in consultation with other IGBP Coordinating Panels and other organizations (e.g., SOTER, ISRIC, UNEP, etc.) have broadened this concept to include pilot areas varying in both geographic extent and in objectives.

A two tier approach appears most desirable. One class of studies will address the methodology to document and monitor changes in various classes of vegetation types over large areas (approx. 1,000x1,000 km) with a surface resolution of 1 km. The second class of studies will involve producing a number of complementary data sets over a small region (approx. 100x100 km) to be used for deriving fluxes of energy, water and trace gases. The following pilot sites have been identified and in some cases work has already been initiated in early 1990 for first results to be available in 1992. Figure 4 shows the selected sites for both classes of studies.

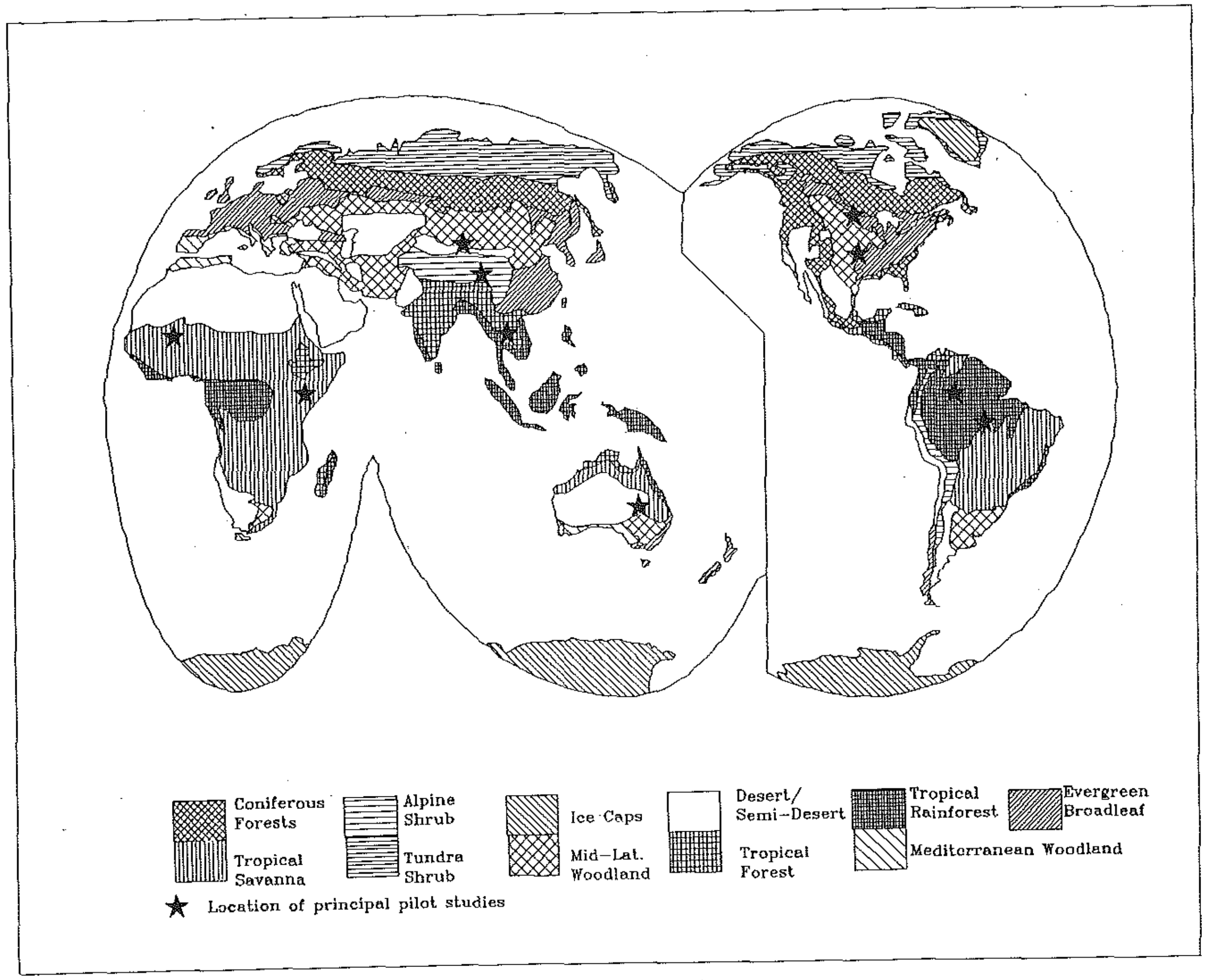


Figure 4. Location of IGBP study sites for pilot project on land use change.

West African Pilot Study. This project introduced remotely-sensed energy measurements into models of energy and matter fluxes at the atmosphere and interface in an area which extends from the semi-arid areas of the Sahel to the humid areas of the Sudanian. Direct measurements of land surface parameters will allow the quantitative description of vegetation relevant to global climate and will provide new ways to characterize ecosystems and their interface with the atmosphere.

The work will contribute to methodology through an assessment of the temporal and spatial scale needs for the land-cover information data base relevant to process studies and modelling efforts relevant to IGBP Core Projects (i.e., IGAC, BAHC, GCTE). It will also lead to a better choice of data and pre-processing options to make the data more suited to the requirements of the models being developed in these core projects.

South East Asian Pilot Study. The general objectives of this study are to develop, validate and demonstrate a methodology capable of monitoring land cover and its changes in a range of environments, which can then contribute to global investigations. Specifically a study is being undertaken in representative

areas of Thailand and Sumatra, including tropical wetlands (natural and artificial), and a tropical mountain zone. In the methodological studies, emphasis will be placed on the integrated use of multiple sets of remotely-sensed data including AVHRR data, and higher resolution SPOT and Landsat data. This would be accompanied by the use of aerial photographs and ground-data collection, focusing on those changes in land-cover and land use that contribute to, or are induced by, global climatic and sea-level changes.

East Africa-South Turkana Ecosystem Project. It is intended to integrate several types of remotely-sensed vegetation index data with a GIS-based vegetation and land-cover maps of Ngisonyoka, Turkana to analyze patterns of vegetation response to precipitation. The analysis will be used to: (i) distinguish the production and phenological patterns among vegetation types and land-cover patterns in Turkana; (ii) characterize the degree to which other different East African ecosystems display the pulsed pattern of production observed in Turkana; and (iii) test the hypothesis that the total amount of rainfall is less important for ecosystem stability than the period over which it is delivered.

Gansu Grassland Project. Transition zones between grassland, croplands and deserts are being investigated in the region of Gansu, China. Specifically, a climatological investigation is focusing on sustainable development. In this area the hydrological cycle is closely controlled by glacier and snow-pack development in the Tibetan Plateau. Changes in climate could well lead to dramatic changes in land-surface characteristics, involving increased soil erosion and desertification. This area of mixed land use will be used to assess the extent to which current methods of information extraction can be used to classify land cover in a semi-arid region.

Ubsu Nur Pilot Project. The Ubsu Nur basin lies across the border of the USSR and Mongolia. It forms a valuable natural laboratory containing an extremely wide range of natural zones within a relatively small area. These zones include deserts, steppes, forests, tundra, and ice fields. Both lowland and mountainous areas are found in the pilot-study area. It will be used therefore for investigations into the quantitative characterization of vegetation types, for hydrological modelling, and quantitative extraction of information from an integrated use of remotely sensed data and ground investigations.

Amazonian Land Use Project (AMUSE). The study area of Amazonia represents a very significant portion of the Earth's forest cover. In the context of the present project, the specific objectives will be to investigate an area of tropical rain forest undergoing both rapid and drastic changes in land cover and areas undergoing regeneration through time. It is anticipated that the results of the land-cover characterization of the area will input directly into investigations of biogeochemistry under human influences, especially in relation to the carbon cycle. Methodologically, the project will contribute to the assessment of the deforestation "signal" with low resolution data, and sub-sample finer resolution data from Landsat and SPOT for validation purposes. As part of this project, a prototype fine-scale mapping procedure will also be developed for use in a GIS.

Australian Pilot Project. The Australian pilot project forms an integrated part of a larger multi-disciplinary study on biospheric inputs to Global Climate Models. The objective of the study is to dramatically improve the representation of terrestrial surfaces currently being used in models parameterized for Australia. Studies will be carried out within carefully selected sample areas occupying less than 1% of the continent. However, these areas will be sufficiently representative to allow the development of a methodology to extend the analysis through the use of thematic mapper data and AVHRR to structurally analogous habitats at global scales. It is further intended to parameterize a number of landscapes into surface roughness, albedo and conductance. Methodologically, the study will contribute to development of mixture models for estimating landscape component contributions at the pixel scale.

Canadian Land Cover Pilot Study. The Canadian pilot area has now been extended to include the whole of the country. It will contribute to the objectives of IGBP through a study of land-cover change on seasonal and inter-annual time scales at an initial resolution of 1-km. It is intended to parameterize vegetation development and dynamics through measures such as length of growing season. Phytomass distribution and annual changes will be estimated to provide input to the modelling of carbon and nutrient cycling. Models and predictions will be derived from long-term vegetation changes based on observed or postulated climate trends. Methodologically, the project will contribute through the setting up of a Canada-wide data base of satellite data and ancillary data. A multi-year consistent data base will be created for AVHRR cloud-free composites. Improved pre-processing procedures will be developed. Algorithms will be developed and validated for land-surface parameterization. Procedures will be developed for integrating remotely-sensed data at various resolutions.

United States Data Set Development. Methodologies will be developed for land-cover characterization that can contribute to the quantification of land-cover processes. The work will lead to the development of procedures suitable for use at very broad continental scales. Specifically, data sets will be prepared that incorporate time-dependent calibration, justifiable atmospheric corrections, automatic correction for image to image registration and data compositing improvements. Methods will also be derived for change detection and land-cover monitoring as well as for the production of land-cover maps.

South American Continental Scale Mapping Using 4-16 km Data. For South America a land-cover data set which is well suited for biogeochemistry and water-balance models will be developed. The land-cover map will be developed around coarse resolution AVHRR data, first at the 16-km level of resolution and later at 4-km. Finer resolution AVHRR data (i.e., 1-km) will be used to define boundaries and provide sub-pixel information. The goal of the project will be two fold: (i) it will develop a functional classification of land-cover which can readily be parameterized with parametric information, such as biomass; (ii) it will examine the utility of this data set by linking it to continental scale biogeochemistry models (carbon cycle and trace gases) and water and energy-balance models. This project will interface with the pilot studies on Amazon Land Use and in Africa.

African Continental Scale Mapping using 4-km Data. For the African continent, so-called Global Area Coverage (GAC) data from the AVHRR with a resolution of 4-km will be used for land-cover characterization. Currently, 1-km data do not exist for the globe with sufficient cloud-free frequency. However, recent GAC data have been processed and are available for the whole of Africa, and these will be used to up-date existing land-cover maps, to provide a template of information upon which to base change-detection studies and to provide test for investigating existing AVHRR data for global land-cover mapping. It is intended to develop sampling procedures for the spectral classification of areas using all five available spectral bands, which will then be used to supplement the classifications based on the temporal profiles of the vegetation indices. Also, procedures will be investigated to integrate the 1-km with the 4-km data sets and with the 8-km global data set discussed below.

Global Classification Using 8-km Data Sets. A global data set, suitable for land-cover characterization now exists, which has been registered, atmospherically corrected, and cloud screened, and it is proposed to use this data set as the prime source for a global mapping exercise, relying primarily on the temporal variations of a spectral vegetation index to carry out the classification. The data have been derived from the 4-km GAC data and have been composited and screened using thermal data to reduce cloud effects by NASA/GSFC. The results of this work should lead to a product processing more than one order of magnitude more detailed information than is currently available from global digital data sets of land cover. Validation and testing of this product will be carried out through cooperative activities with the various other pilot projects described above.

Data Validation and Quality Control Pilot Studies

In order to be usable for quantitative analysis and scientific research, data sets must be validated and quality controlled. Furthermore, the users are generally not interested in the raw-data of radiances measured by satellite, but in the secondary geophysical data which can be extracted from these radiances. Therefore, a protocol for data validation and quality assurance must be developed. A pilot study using Earth surface temperature measured from space has been initiated. The main reasons for this study are: (i) surface temperature is a good indicator of the energy balance of the planet; (ii) the evolution with time of surface

temperature is therefore a good indicator of the greenhouse effect; and (iii) surface temperature is one of the key variables controlling fundamental biospheric and geospheric processes between the Earth's surface and its atmosphere.

From a consideration of the physics of thermal infrared radiation, it is necessary to treat sea-surface temperature and land-surface temperature separately. The main reasons being:

- the spectral emissivity of sea-surface temperature in the 10-12m domain is almost the same in the two channels of AVHRR and is very close to unity, but it is more variable over land and may take very small values in the desert area (0.85);
- the emissivity and skin temperature are homogeneous over large areas of sea surface, but quite variable over land. The methods and algorithms inferring surface temperature for sea (SST) and for land (LST) should therefore be different and use different approaches.

These approaches will be reviewed and intercompared using well-designed data sets in two intercomparison workshops. The same scientists will participate in both pilot studies to insure coherence between the two aspects. In both pilot studies, the calibration of the various sensors and validation procedures will be addressed.

A first workshop is being organized (i) to analyze the characteristics of the existing algorithms used to determine land-surface temperature, namely the four main steps of such algorithms: cloud filtering, atmospheric correction, emissivity correction, and scaling to a standard reference; (ii) to identify the best data sets and the best sensors suitable for intercomparison of algorithms; and (iii) to determine the processes and criteria for intercomparing the algorithms and the sensors used. The meeting will then be followed by an intercomparison workshop.

Implementation Strategy

As described above, implementation will occur in three phases. Throughout the term of implementation, 1990-1997, there must be a ramped up commitment of resources. The largest share of resources will be needed in the last phase. But we must begin now with the following activities if we are to be successful in the later phase.

- Training of students at the post-graduate level in interdisciplinary science with experience in the fields of remote sensing and geographic information systems.
- Providing Global Change related data sets on diskettes to scientists in developing countries. Assure continuity for at least three years to evaluate results.
- Developing a global network of functional data centres, which would be mature in terms of infrastructure, facilities and programme direction to take on the sophisticated tasks of data management after 1997.
- Developing a user-friendly and complete directory of data sets suitable for IGBP science, and developing the technologies to make the directory system function for science (e.g., geographical browse capabilities and on-line quick looks).
- Developing the experience and methodologies for integrating many sources and formats of data, including remote sensing, *in situ* data, and GIS data, into a commonsystem for use at a research site.

The immediate course of action required to implement the IGBP-DIS described above includes: (i) establish an IGBP-DIS Office and provide a professional staff of a few scientists; (ii) implement the NASA Master Directory at GRID in Geneva and establish the IGBP GEDD; (iii) link GRID Geneva to other IGBP "centres" (e.g., RRCs) around the world; (iv) define a set of IGBP data sets within the current holdings, define a list of data sets needed based on a scientific review of IGBP Core Project demands, then establish a plan for developing the designated data sets; (v) complete the development of the Land Cover Data Sets and the Surface Temperature Data Sets; and (vi) identify a primary data facility for the Mid-Term phase activities.

References

FAO/Unesco 1988. Soil Map of the World. Revised Legend. World Resources Report 60. FAO, Rome.

Hutchinson, W. W. and Bie, S. W. 1985. Data management and global change. In: Malone, T. F. and Roederer, J. G. (eds) Global Change, pp 441-453. Cambridge University Press, Cambridge.

IGBP 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. IGBP Report No. 4. IGBP Secretariat, Stockholm.

IGBP 1989. Pilot Studies for Remote Sensing and Data Management. Report of a Meeting of the IGBP Working Group on Data and Information Systems, Geneva, Switzerland, 1989. ed. by Rasool, S. I. and Ojima, D. S. IGBP Report No. 8. IGBP Secretariat, Stockholm.

Matthews, E. 1983. Global vegetation and land use: new high resolution databases for limited studies. J. Clim. Appl. Meteor. 22:474-487.

Matthews, E. 1985. Atlas of archived vegetation, land-use and seasonal albedo data sets. NASA Technical Memorandum 86199. Washington, DC.

NASA 1986. Earth Observing System Data and Information System. Report of the EOS Data Panel. Volume IIa. NASA Technical Memorandum 86F5001. Washington, D. C.

NASA 1988. Earth System Science: A Programme for Global Change. Earth System Sciences Committee, National Aeronautics and Space Administration Advisory Council. Washington, DC.

NRC. 1986. Global Change in the Geosphere-Biosphere. Initial Priorities for an IGBP. Washington, DC. National Academy Press.

Suggested Reading

Hopke, P. K. and Massart, D. L. 1989. Environmental data management. In: Directions for Internationally Compatible Environmental Data. CODATA Workshop, Montreal, Canada, 1986. Codata Bulletin 21(1-2):188-216.

Mounsey, H. and Tomlinson, R. (eds). 1988. Building Databases for Global Science. Taylor & Francis, London-New York-Philadelphia.

SCOR 1988. Joint Global Ocean Flux Study. Report of the JGOFS Working Group on Data Management, Bedford Institute of Oceanography, September 1988. Platt, T. and White, G. (eds). Scientific Committee on Oceanic Research, ICSU, Halifax, Canada.

Sellers, P. J., Hall, F. G., Asrar, G., Strebel, D. E. and Murphy, R. E. 1988. The First ISLSCP Field Experiment (FIFE). Bull. Am. Met. Soc. 69(1):22-27.

Shields, J. A. and Coote, D. R. 1989. SOTER Procedures Manual for Small Scale Map and Data Base Compilation and Procedures for Interpretation of Soil Degradation Status and Risk. Rev. ed. ISRIC, The Netherlands.

UCAR 1990. Recommendations from an Interdisciplinary Forum on Data Management for Global Change, Baltimore, 1988. Office for Interdisciplinary Earth Studies, Boulder, CO. USA.

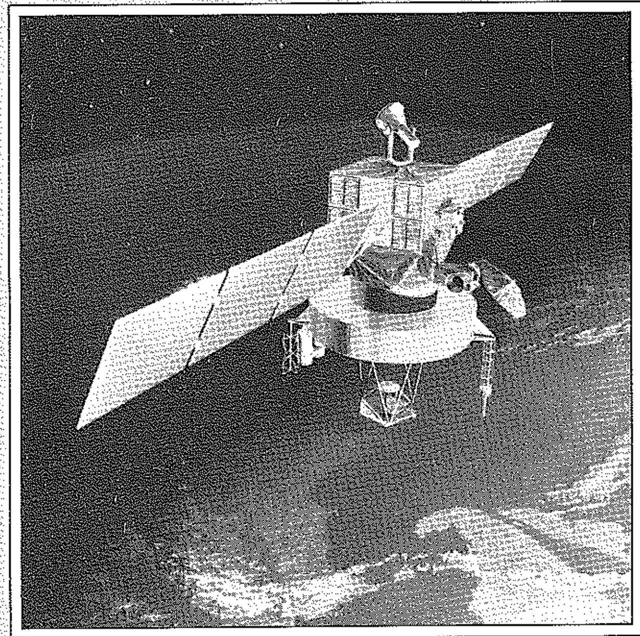
UNEP 1987. GRID - Pilot Phase Report. GRID Info Series No. 14, December 1987

WDC 1979. Guide to International Data Exchange through the World Data Centres. 4th ed. ICSU Panel on World Data Centres (Geophysical and Solar).

WDDES 1987. Report on World Digital Database for environmental Science - an IGU/ICA Project.

Wilson, M. F. and Henderson-Sellers, A. 1985. A global archive of land cover and soil data for use in general circulation climate models. J. Clim. 5:119-143.1

GLOBAL IGBP CHANGE



Needs For Remote Sensing Data In the 1990s and Beyond

"The global change programme will call for coordinated measurements on a global scale of those interactive physical and biological processes that regulate the Earth system. The programme will rely heavily on the emerging technology of remote sensing from airborne vehicles, particularly satellites. Satellites offer the potential of continuously viewing large segments of the Earth's surface, thus documenting the changes that are occurring. The task, however, is not only to document global change, which will be an enormous job, but also to understand the significance of these changes to the biosphere ... The possibility of measuring biosphere function remotely and continuously from satellite imagery must be explored quickly and thoroughly in order to meet the challenge of understanding the consequences of global change."

(Mooney and Hobbs 1989).

Contents

10. Needs for Remote Sensing Data in the 1990s and Beyond

Importance of Space Observations for Global Change

Introduction

As the IGBP Core Projects begin to be defined and the research becomes formulated, we must focus our attention on specific needs of the IGBP for global observation from space. A first study carried out by COSPAR (Rasool 1987) described in some detail the existing space capabilities, the upcoming programmes of various agencies and how a number of key data sets, acquired from space satellites, can be useful in Global Change studies.

Now, in early 1990, we are at a critical point not only in the definition of a focused research projects for the IGBP but also in the formulation of plans of space agencies of the world for consolidating their activities for space for the decade of the 1990's through the International Space Year (1992) and beyond.

Elements of Global Change Observing System

IGBP has now established five Core Projects and a number of others are in definition phase. Four of the established Core Projects involve process studies on continental and global scales that can make substantial use of remote sensing: IGAC (Chapter 2.1), JGOFS (Chapter 3.1), BAHC (Chapter 5.1) and GCTE (Chapter 6.1).

Although a measurement strategy for these projects is only beginning to be formulated, it is clear that the measurement needs are going to be global with varying temporal and spatial scales. Also, high quality measurements will be needed over the long-term (decades) for a large number of variables related to the: (i) physical state of the atmosphere, land and oceans; (ii) chemical changes in the atmosphere, oceans and land; and (iii) biological state of the land cover and of the upper layer of the oceans.

The measurement programme will be derived from a variety of observation systems. These include satellite systems for long-term, global coverage and large-scale field experiments for process studies using satellites, aircraft, balloons, and surface stations. It is essential to maintain high quality surface observing networks and that these be appropriately linked to remotely sensed data. These data sets will be instrumental to the development of Earth system models to improve our predictive capability, because such data can be used both as an input to the models and as a test to the model predictions. An integral component of the data measurement activities is a data and information system. The IGBP Data Information System (IGBP-DIS) is proposed to facilitate data collation and dissemination of the various types and sources of data and users. Information flow between various research projects and scientific groups is essential to the success of the IGBP.

The IGBP needs space-derived data for three overriding reasons. These are (i) document precisely global-scale changes in key variables to assess the way the planet as a whole is evolving with time; (ii) measure the long-term trends in the forcing functions of the global change; and (iii) simultaneous measurements of several parameters to study the interactive processes which regulate the earth system. These are the measurements which are needed for the IGBP Core Projects and will be discussed in the following section.

Despite current availability of remote-sensing data, many of the measurements are only loosely coordinated in time and space. The international collaboration to maintain and coordinate the collection of pertinent Earth system data for global change studies will need an evolutionary Earth observing system to fulfill the IGBP needs.

In the near-term (1990-1995) the programme will be based on:

- Continuing operational meteorological, geostationary and polar orbiting satellites (GOES, Meteosat, IRS, GMS, NOAA Landsat, SPOT);
- Already planned research missions (ERS 1, UARS, TOPEX/POSEIDON, SeaWiFs, NASA-Scatterometer, JERS, Radarsat, ADEOS, SPOT 4);
- Instrument development for space use by the mid-1990's (multi-channel imaging spectrometers, SAR, Lidar, Laser altimeter, high resolution images);
- Ground validation and field experiment programme.

In the longer term (1996 and beyond), we will have a new generation of space observing systems based on polar orbiting platforms, which will become available in 1998 and later. Observational requirements for the IGBP are being identified now, so that they can be incorporated in the design of the Earth Observing System. The following is a preliminary attempt to outline the need from remote sensing from space for the established Core Projects IGAC, JGOFS, BAHC, and GCTE.

IGAC Needs

A major challenge for IGAC will be to acquire information on a number of trace gases in the troposphere. Data on the concentration and vertical distribution, with appropriate time and space resolution of these trace gases, are needed. It will be important to be able to measure the magnitudes of the terrestrial and oceanic sources and sinks for radiatively and chemically important tropospheric trace gases, in particular CO_2, CO, CH_4, O_3, N_2O, NO_2, NH_3, $(CH_3)_2S$, H_2S, OCS, and SO_2. We will need to know their atmospheric distributions, annual and latitudinal variations, and regionally and globally averaged long-term trends. Because H_2O plays such a key role in tropospheric chemistry, time variation measurements of global water-vapour distribution are an important requirement as well. In order to quantify the fluxes of these trace gases at the land and ocean surfaces, we will need to make simultaneously a variety of measurement from ground, aircraft and space to assess the rate of change of land cover and the ocean biosphere. The measurements needs will include characterization of land cover types, canopy height and density, biomass burning and net primary productivity on land and oceans together with measurements of temperature, albedo and moisture.

So far, most satellite experiments to detect and measure trace gases in the atmosphere have been confined to the stratosphere. Gross estimates of tropospheric water vapour are obtained from current meteorological satellites. The only trace gas in the troposphere with a relatively low mixing ratio, detected up to now, is CO. This has been measured with the MAPS (Measurement of Air Pollution from Satellites) experiment during OSTA-1 Space Shuttle mission in November 1981 and October 1984 for a one week period only. The results showed differences between Northern and Southern Hemispheres and higher concentrations were noticed in the area of South America, which may be caused by tropical fires. Such measurements were, however, never repeated.

Efforts of several space agencies to develop new instrumentation for measuring and monitoring tropospheric trace gases from satellites and to provide better characterization of the biospheric functions are noteworthy.

- Vegetation Mapping Instrument (VMI) on SPOT 4 for global daily coverage at 1.1 km resolution in 1994.
- Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) and ESA polar platform for trace gas measurements in the troposphere in 1997.
- Moderate Resolution Imaging Spectrometer (MODIS) for high temporal detailed investigation of biosphere for NASA/EOS-A and High Resolution Infrared Spectrometry for high spectral and spatial detail of biogeochemical conditions.
- Measurements of Pollution in the Troposphere (MOPITT), Tropospheric Radiometer for Atmospheric Chemistry (TRACER) on NASA/EOS-A in 1997
- Tropospheric Emission Spectrometer (TES) on NASA EOS-B in 2000.

Because the existing satellite system is adequate for surface imaging, but severely limited for measuring most of the tropospheric trace gases accurately, a satisfactory observational system for the next decade might evolve as follows:

(1) Ground-based measurement network of high accuracy for tropospheric gases or complementary data.
(2) Balloon and aircraft measurements for field studies, for complementary measurements, or for instrument technique testing along with overlapping observations from space for surface imaging and radiances.
(3) Experimental instrumentation on polar platform and/or on special research free flyers for testing new techniques for measuring trace gases in the lower troposphere.
(4) "Permanent" baseline instrumentation in orbit on a polar platform to measure gases in the stratosphere and troposphere, simultaneously with the detail characterization of the land and ocean biosphere.

JGOFS Needs

The feedbacks between climate, ocean primary production and ocean CO_2 storage depend 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 physical, chemical and biological processes 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 physical properties and their effects on global biogeochemical cycles, including feedback to atmospheric concentrations of radiatively active trace gases of biogenic origin.

Current observational studies in the ocean sciences support the goals of the IGBP to the extent that they focus on ocean surface temperatures and how they might vary with climate change, ocean colour and how these relate to seasonal blooms, and on how the oceans store and exchange radiatively important trace gases. Complementing the sparse data coverage by the many ship-based programmes, satellites provide regular global observations over the ocean surface temperatures, sea-ice cover, and in the future, wind stress from roughness, winds over the ocean, sea-level height, and ocean colour. Long-term monitoring of these marine characteristics is essential in the development of our understanding of how the ocean system interacts with other components of the global system.

Important oceanographic data are already being acquired by NOAA, Japanese MOS-I and by the Defense Meteorological Satellite Programme (DMSP). Ocean and ice measurements will also be provided from the ERS-1 of ESA, scheduled for launch in 1990, and the US/French Ocean Topography Experiment (TOPEX/POSEIDON) in 1992. Together, these satellites will provide the necessary global coverage of ocean and ice surface properties needed for understanding global change. The properties to be measured or inferred include surface wind stress (scatterometer); sea-surface temperature (infrared-microwave images); ocean currents, fronts, and eddies (altimeter); ice extent, surface properties, and temperature (microwave images); and detailed ice and ocean surface mapping (synthetic aperture radar).

One critical area of measurement specific to the IGBP and important for the success of JGOFS is ocean colour mapping pioneered by the Coastal Zone Colour Scanner (CZCS) on Nimbus 7. It has been shown that ocean colour measurements can provide quantitative maps of near-surface phytoplankton pigment concentration. Data analysis and processing techniques are well developed and are being improved, and the links between the satellite measurements and the total water column productivity are being better determined. Continuation of such measurements hasbeen planned through the deployment of instruments such as the Seaviewing, Wide Field-of-view Sensor (Sea-WIFS), Ocean Colour and Temperature Scanner (OCTS) and Polarization and Directionality of Earth Reflectances (POLDER).

However, in the early 1990s, none of these satellite missions are presently on a firm schedule, particularly SeaWIFS which was initially planned for launch in 1992 and now may slip beyond 1994. This will be a major setback to the JGOFS

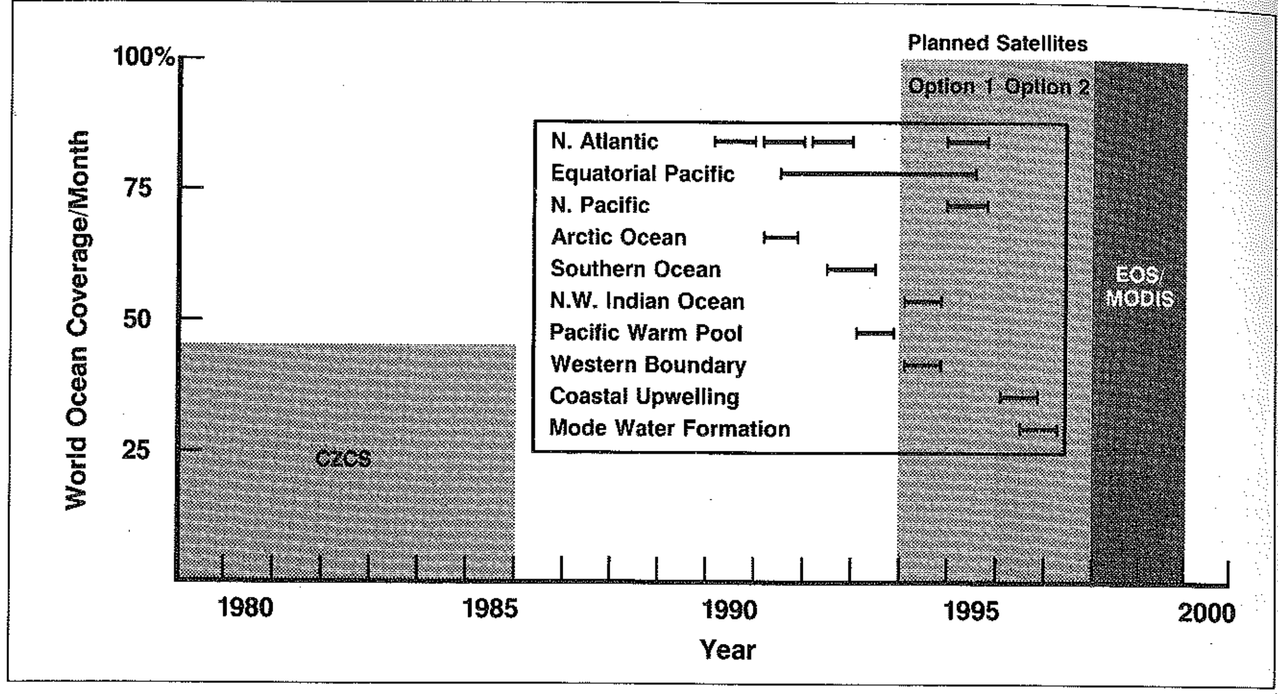


Figure 1. Satellite coverage for ocean colour and IGBP/JGOFS process cruises.

ocean surface observing project, which was initiated in 1989 in the North Atlantic and, as shown in Figure 1, will reach the period of peak activity in 1994-1995. Minimizing this gap should be one of the major concerns of the space agencies.

Plans beyond the late 1990s appear adequate. For the IGBP, it is important that ocean colour be measured simultaneously with ocean surface temperature, wind stress and other euphotic zone properties. With the advent of the Earth Observing System, the Moderate Resolution Imaging Spectrometer (MODIS) in 1997, EOS-A and MERIS in ESA-1 platform along with other atmosphere and ocean viewing instruments will largely fulfill this requirement.

BAHC Needs

The climate and land surface subsystems are dynamically coupled through the physical processes of energy and water supply, transformation, and transport at the land-atmospheric interface. The biosphere interacts with these physical processes to further modify this coupling. Large-scale patterns of climate are influenced by regional variability 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.

Definition of global hydrological balances requires measurement of three key hydrologically active components: (i) the climate as a forcing function; (ii) the soil as storage function; and (iii) 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 100 x 100 km cells. For this purpose, satellites can provide important, and in many cases the only, means of data collection.

Certain surface meteorological conditions can be directly calculated from optical and infrared 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 grassland, with a second experiment being planned for boreal forests. Accurate, consistent and compatible data sets are crucial to validating remotely sensed data and developing and evaluating models. Field experiments are also required to develop new algorithms and validate existing ones.

The most hydrologically important surface variables measurable by satellite are land and vegetation characteristics, topography (best done currently with stereo SPOT data or Landsat TM), 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 the AVHRR or the next EOS generation MODIS sensor at 250 m - 500 m with twice daily overpasses. Current satellite NDVI products may provide good measures of seasonal vegetation phenology, but must be calibrated for viewing conditions and the differing bi-directional reflectance properties of different biome types (e.g., forest vs. grassland). Initial efforts to obtain land-cover and vegetation characteristics are now being conducted in the IGBP Land-Cover study (IGBP 1989).

A current research need is the incorporation of these variables directly measurable by satellite into hydrological models. 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. 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.

Perceived needs for future advancement in satellite measurements have been classified in terms of the feasibilities of meeting the needs with existing or firmly planned remote-sensing data from satellites. Using the joint criteria importance and likelihood of achieving useful goals in the foreseeable future for satellite application in hydrology the following priority items are proposed: vegetation and land-surface characterization; rainfall monitoring, surface-water monitoring and inventory (e.g., of rivers, lakes, marshes, reservoirs); measurements and monitoring of snowcover; soil moisture measure, mainly for non- or sparsely-vegetated areas; estimation and monitoring of evapotranspiration. The remote-sensing satellite needs for these parameters are summarized in conjunction with the requirements for GCTE.

GCTE Needs

The overall objective of GCTE is to develop the capacity to interpret and predict effects of global change phenomena on terrestrial ecosystems. Global change phenomena include changes in climate, atmospheric composition and land use. This capacity is required for two reasons. The first reason is to forecast the consequences of global change for ecosystem structure and function, since these ecosystem attributes have direct effects on human welfare including primary productivity, future land use and biotic diversity. The second reason is to be able to predict the potential feedbacks of the terrestrial changes on further atmospheric, climate and land use change.

One of the most important means of measuring terrestrial ecosystem change will be through remote sensing, and data derived from remote sensing will be a central part of the necessary GIS data base developed for the IGBP. The initial and most basic data set is that of land-cover vegetation characteristics of the Earth. Currently, satellite coverage exists, but continuity and spatial resolution of remote-sensing data sets must be maintained for the long-term interpretation of ecosystem change. Coverage with instruments such as the AVHRR, with higher resolution data (e.g., SPOT) nested within the grid cell to enhance interpretation, should continue and be archived. Long-term calibration of the instruments is essential. Equally important is ground validation of the remote sensing data.

The research design for this and the previous Core Project would involve a hierarchy of measurement and prediction scales that will allow researchers to interpolate between global and local levels as needed for appropriate modelling and prediction testing. Remote-sensing data will be essential for such studies. For example, to predict change in plant cover, simulation models coupled with environmental conditions set by GCM derived scenarios will be run to give a range of future system states across landscapes for various regions of the Earth. These will extrapolated upward in scale with a GIS system, and compared with data derived from remote sensing. Remote sensing will be even more central to the process of observing Earth system changes over extensive areas and over time.

Ecosystem properties to be addressed will be both structural and functional in nature. Examples of structural properties are leaf area and the distribution of leaf area in the canopy profile. Functional examples include standing biomass, live-dead ratio of plant material, canopy chemical concentrations (e.g., leaf N, chlorophyll *a*, and lignin), net primary production, evapotranspiration and trace-gas efflux. Remote sensing is most directly adaptive for measuring structural properties, but some functional attributes will be estimated across extensive areas by coupling remotely sensed data to ecosystem models (e.g., remotely sensed surface temperature and soil moisture as inputs for simulation models to estimate evapotranspiration.

Different kinds of remotely sensed data will be vital to meeting this Core Project and the previous Core Project objectives. These are:

(1) A moderate resolution capability for measuring gross structural attributes of vegetation and soils with high temporal frequency but medium spatial resolution. This role is presently filled by the AVHRR for areas with complete canopy cover, but with development of EOS instruments, this role will be filled even better by MODIS. For areas with incomplete canopy cover, that have mixed pixel problems of rock, soil, and plant signals, other low resolution methods need to be improved. It is possible that passive microwave methods for semiarid and arid lands will be the method of choice. This is being tested with SMMR data at present and if it seems satisfactory, will be fulfilled by AMSR in the EOS suite.

(2) A high resolution sensor with low temporal frequency for detailed analysis at the landscape level and for chemical assessment of canopy and soil properties is required. The spatial component is presently served by LANDSAT 4 and 5 but there is no routine sensor for chemical analysis. At present AVIRIS is being used as a test system for very detailed spectrometry that may measure chemical properties. High resolution infrared spectrometry (HIRIS) may provide reliable estimates of canopy nitrogen and lignin concentrations. These estimates are extremely useful for assessing the metabolic condition of foliage, which together with leaf area measurements provides a good estimate of primary production. In addition, canopy chemistry may be useful to estimate the chemistry of below-ground parts and litterfall and provide a means for calculating biogeochemical properties of ecosystems such as decomposition and nutrient turnover. In the EOS suite of sensors, HIRIS will fill this role. In addition, high resolution data on canopy structure may be provided by SAR.

(3) Digital elevation data are fundamental to the GIS data set required for global modelling of terrestrial ecosystem structure and function. The present digital elevation data are inadequate and new models based on better altimetry are essential. An Earth Probe mission, separate from the EOS, is required to obtain the needed data. In the meantime stereo imaging by SPOT can begin to provide source information for this parameter.

(4) Principle driving variables for terrestrial ecosystems are air temperature, canopy surface temperature, soil temperature and soil moisture. Air temperature is not presently measured by any remote-sensing device below the planetary boundary layer. It must be calculated from models driven by surface temperature (see below).

(5) Remote sensing will be extremely useful for assessing structural ecosystem properties and of lesser value for estimating driving variables as described above. Many of the driving variables necessary for predicting changes in terrestrial ecosystems will have to be calculated indirectly from simulation models or algorithmic routines, or by direct ground measurement. This last process will be vastly facilitated by robotic samplers that can measure a variety of environmental variables at one point and relay them to geostationary satellites such as GOES for retransmission to ground stations. This will give researchers nearly "real time" direct measures that can be extrapolated across landscapes to estimate functional processes. Robotic sensor systems and satellite relay systems might play a large role in achieving the objectives of this GCTE.

In summary, remote sensing will be vital to developing models for predicting changes in terrestrial ecosystems and for observing the changes over long time periods and across the vast areas of the globe. Further development of remote sensing technology and ground validation of the information for interpretation of biosphere function and changes in the coming years must be continued. It is also important to point out that an efficient data access system and a long-term record are necessary for our success. The hiatus in remote sensing data now facing the scientific community represents a serious detriment to our ability to predict or observe global change on land systems. It is essential that at least the present data base be maintained through the years before EOS instruments come on line to develop the foundations of understanding the simulation models themselves, and for providing a data set with which to observe global change.

Current Impediments and Strategies for the Future

Discussions amongst the IGBP scientists have made it clear that international satellite observing capabilities currently existing and those likely to develop over the coming decade will be critical for the success of the IGBP (Fig. 2a-c). However, several impediments are currently limiting us from the most effective use of the satellite data.

Existing Data: 1980-1990

There are about half a dozen operational geostationary satellites which provide global data on cloud cover and temperatures on a near continuous basis. In the near earth polar orbits, there are a number of operational remote sensing satellites including LANDSAT, NOAA, and SPOT which collect a variety of remote sensing data in the visible and IR spectral regions providing more or less continuity of data already available over the last ten years or so including close to six years of global vegetation index. In addition, there are a number of research satellites like SMM/I, ERBE, and Nimbus, which provide data on many other parameters such as solar flux, sea surface temperature, atmospheric moisture, ocean chlorophyll, snow cover, sea ice extent, Earth radiation budget, and atmospheric ozone and stratospheric dust.

Together these data sets are of unique value for the WCRP and the IGBP provided they are quality controlled and are continuous over at least a decade. Only a few of the above mentioned parameters pass this test. These are the measurement of solar irradiance, stratospheric ozone, stratospheric dust and sea surface temperature. Efforts are now underway to reprocess the data and reassess the algorithms and consistent global data sets for ocean chlorophyll, vegetation index, radiation budget and snow and ice cover for the entire decade of the 1980s may become available. Eventual availability of these data will be of substantial benefit to the IGBP community and were given the highest priority in our deliberations. In order to achieve this we will have to give serious attention

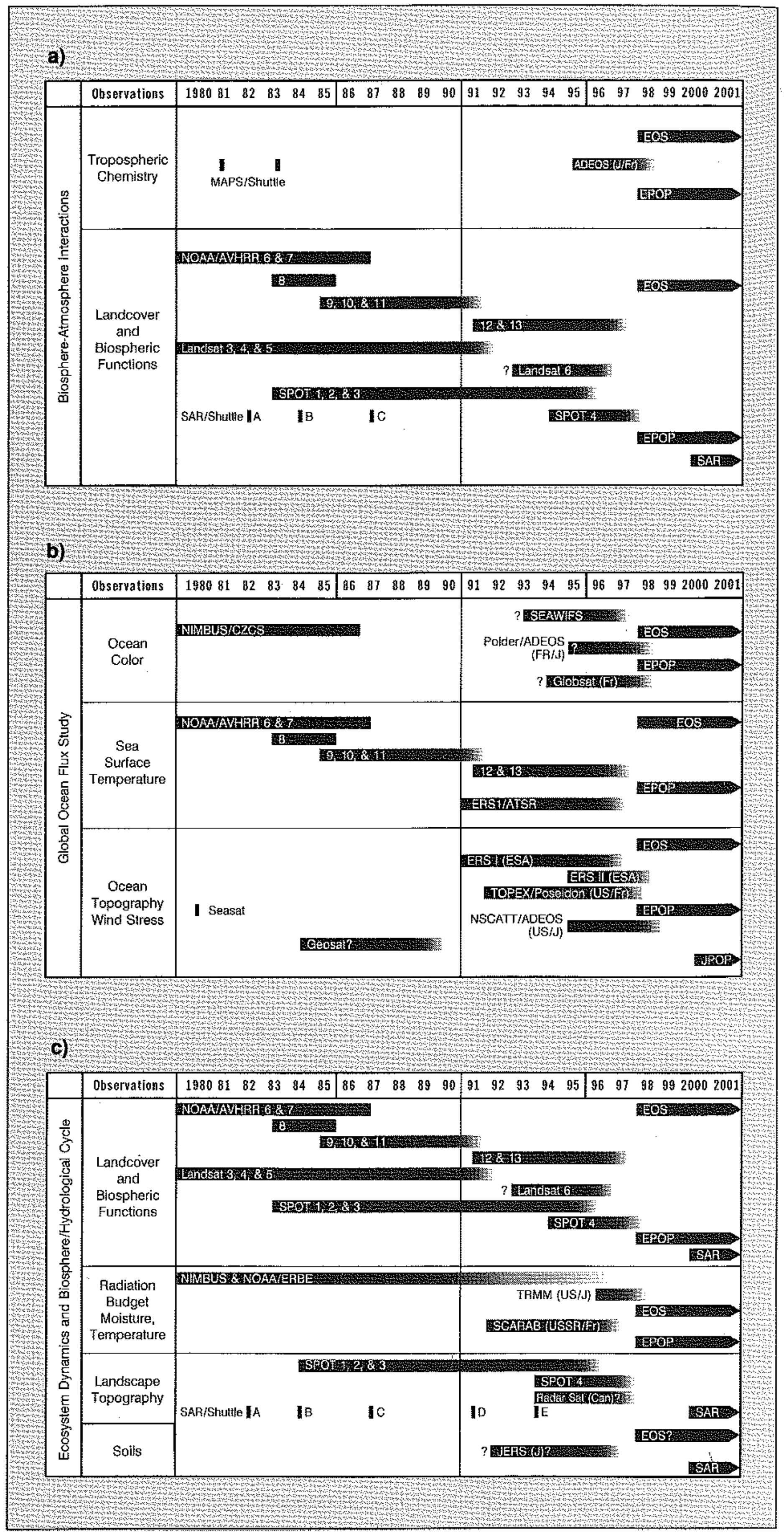


Figure 2. IGBP highest priority global data product continuity (satellite measurements).

to the problems related to spacecraft sensor calibration. A drift in sensor response and changing algorithm for atmospheric correction can easily be interpreted as an indication of global change on the surface of the Earth. Without a thorough evaluation of such discrepancies, satellite data is of practically no use to a student of global change.

Future Data 1990-1995

As we enter the decade of the 1990s, a number of new satellites with new sensors relevant to IGBP studies are planned by about a dozen countries. These are shown in Figure 2a-c. The challenge for the space agencies and for the IGBP community will be to assume that the data acquired in the 1980s and those acquired, on the same parameter but by different satellites, in the 1990s, are consistent with each other and can be used to derive an uninterrupted time series to document accurately long-term changes in the state of atmosphere, ocean and land. Some pitfalls loom on the horizon such as a 'data hole' of at least five years on ocean colour between the CZCS on Nimbus 7 (which stopped functioning in 1987) and SeaWIFS which still has an uncertain launch date.

For Global Change Studies, the challenge will be to combine data from several of these satellites to provide the global context for process studies. For example, ocean colour data from SeaWIFS combined with data on surface winds (from either ERS-I or NASA Scatterometer and sea surface temperature from ERS-I or NOAA type satellites) will be of essential for the large scale study of marine biosphere-atmosphere exchange.

An ocean colour monitoring instrument less sophisticated that SeaWiFS is planned for ADEOS mission in 1995. The international field campaigns of JGOFS, which began in 1989 and are scheduled through 1996, were planned to be coincident with the deployment of SeaWiFS. Unfortunately, it now appears as though ocean colour data may not be available until late in the field campaigns of JGOFS (Fig. 1). A concentrated effort by the space agencies to narrow the data gap in ocean colour measurements should receive the highest priority.

Beyond 1995

Simultaneity, accuracy, long-term consistency and continuity are the key requirements for IGBP for space observation of several parameters. These conditions are proposed to be met by the launch of polar platforms starting in 1997. While the payload combinations of these platforms are being defined, we would like to re-emphasize the IGBP requirements for data from the Earth Observing System. For the projects shown in Figures 1 and 2a-c, data on tropospheric chemistry, land, biospheric functions, ocean colour, temperature and wind stress, land topography and soil moisture are of critical importance.

One of the principal impediments in the use of space data by the international science community has been its non-availability in a usable format. It is therefore encouraging to note the plans for initiating an Earth Observing System Data Information System. For the IGBP scientists to benefit from the information and data archived in EOS-DIS, plans for establishing an IGBP-DIS are in progress (Chapter 9). The sooner the two systems are put in place and become functional, the more the global change scientific community will be able to investigate the Earth system in its totality.

References

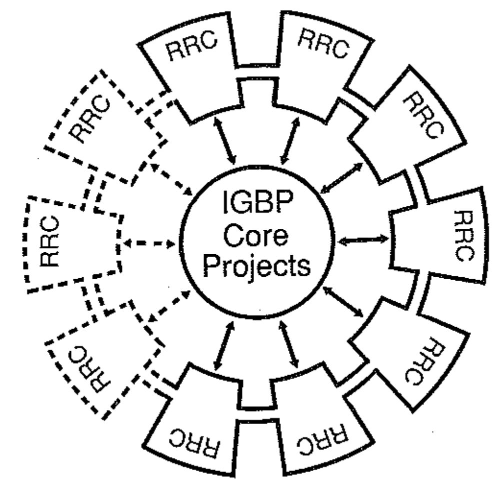
IGBP. 1988. The International Geosphere-Biosphere Programme: A Plan for Action. IGBP Report No. 4. IGBP Secretariat, Stockholm, Sweden.

IGBP. 1989. Pilot Studies for Remote Sensing and Data Management. IGBP Report No. 8. IGBP Secretariat, Stockholm, Sweden.

Mooney, H. A. and Hobbs, R. J. (eds). 1990. Remote Sensing of Biosphere Functioning. Springer-Verlag, New York.

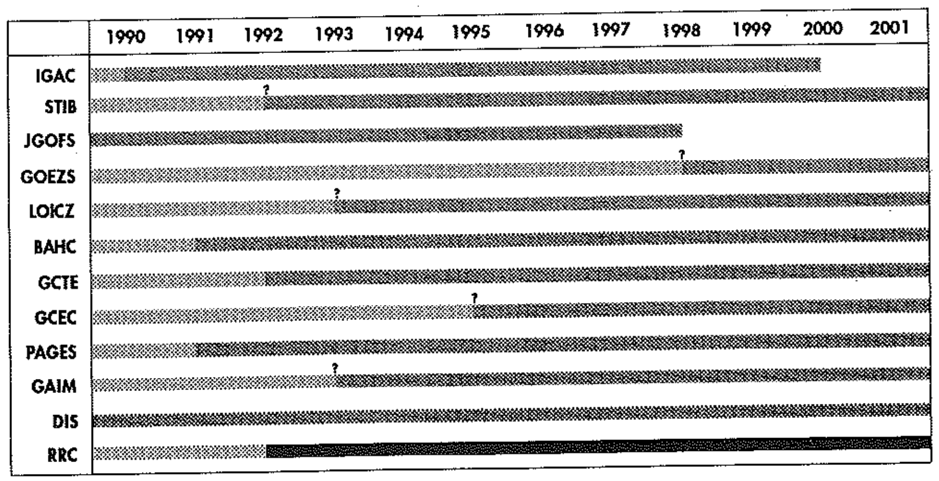
Rasool, S. I. (ed). 1987. Potential of Remote Sensing for the Study of Global Change. Advanced in Space Research. Vol. 7(1). Pergamon Press.

GLOBAL
I G B P
CHANGE



The IGBP Global Change Regional Research Centres (RRCs)

Contents


1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
IGAC
STIB
JGOFS
GOEZS
LOICZ
BAHC
GCTE
GCEC
PAGES
GAIM
DIS
RRC

11. The IGBP Global Change Regional Research Centres (RRCs)

The Need for RRCs

IGBP research must be carried out in all regions of the world in order to obtain the necessary understanding of global change processes. Likewise, scenarios of global change originating from modelling activities need to be interpreted in a regional context to guide both further research and policy decisions. Global change research to decrease present uncertainty is primarily the responsibility of the IGBP and WCRP, as acknowledged in a UN General Assembly resolution (December 1989). The need for the IGBP and WCRP to narrow uncertainties relating to climate change through research has also been recognized by the Intergovernmental Panel on Climate Change (IPCC).

The scientific understanding concerning global change processes and impacts is generally not well advanced in less-developed countries, where available scientific manpower and financial resources are especially limited. There is an urgent need for the IGBP to stimulate global change research in these regions and to ensure that their scientists are involved in all aspects of data collection, synthesis and global change predictions. In addition, outputs from climate and global Earth system models must be made available to the science community in less developed countries and interpreted in a national and regional context.

IGBP research requires an interdisciplinary approach and few, if any, academic institutions have the full suite of scientific expertise needed to address the synergetic aspects of the IGBP Core Projects. This is especially true for developing countries, where IGBP research needs to be enhanced and facilitated in an academically stimulating environment.

In order to achieve this, a number of IGBP Global Change Regional Research Centres (RRCs) should be established in developing countries. This will permit scientists from these countries to become intimately involved in all aspects of research related to global change. Unless RRCs are established, it is likely that developing country scientists will be solely involved in data collection and will be outside the mainstream of global change research including participation in data analysis, interpretation and modelling. It is important that these centres are established early in the implementation phase of the IGBP, so that the scientific competence in the less-developed countries is harnessed to the fullest extent.

Purposes of the RRCs

The purpose of an RRC is to facilitate regional interdisciplinary research within IGBP Core Projects, and to promote strong synthesis and modelling activities relating to regional priorities. The RRCs will be established in developing countries, but similar centres may also be set up in developed countries and will in such cases be affiliated to the IGBP-RRCs. The centres will establish networks to link existing scientific institutions in the regions that contribute to the IGBP Core Projects. They will be situated in a research environment involved in all facets of Core Project research including monitoring, field experimentation, integration, synthesis and modelling. The RRCs will play a major role as centres for regional data analysis and synthesis and analyses of global change scenarios in a regional setting. The network activities are important in this regard, since most of the Core Project research in the region will be conducted in affiliated laboratories and not at the centre itself.

The RRCs will:

- Promote cooperation among scientists of the region for the purposes of: (i) facilitating coordination of Core Project research; and (ii) defining regional research priorities and identifying regional questions that have global significance.

- Provide facilities for data management of regional and global data sets.
- Develop synthesis and modelling activities.
- Distribute research results to scientists within the region and establish mechanisms for sharing the results with scientists from other regions.
- Establish training and exchange programmes, especially in the use of new technologies and in the area of data analysis synthesis and modelling.

Regional workshops will evaluate regional priorities in relation to the IGBP Core Projects and discuss the establishment of networks of collaborating laboratories for the IGBP Core Projects. The first meeting was in South America (March 1990, Brazil), a second will be held in Asia (India, February 1991), and a third in Africa (Niger, January 1991). In addition, Southern Hemisphere collaboration is being supported through a series of meetings (Swaziland, December 1988; Chile, March 1991). Once established, the RRCs should take over responsibility for the regional meetings on a regular basis.

The management of regional and global data sets is a major responsibility of the RRCs in collaboration with IGBP-DIS (Chapter 9). This responsibility has many dimensions including: (i) banking of critical subsets of data from the region; (ii) quality assurance of those data sets; (iii) incorporation of appropriate data in regional geographic information systems that are in place at the RRCs; and (iv) providing scientists with access to global data sets as needed to interpret regional research results or to conduct data analysis and synthesis. Help should also be available from the RRCs to various research groups within the region concerning their data-management problems. Close links must be established with GRID (UNEP/GEMS) nodes.

The contents of the regional data bases must be available to all scientists as well as to decision makers. The RRCs will encourage the sharing of research results by establishing easy-to-use communications networks within and among the regions. Electronic networks, newsletters, and scientific meetings will be among the tools used to achieve this goal of data exchange.

One of the major purposes of the RRCs is to foster synthesis and modelling activities that will ultimately lead to predictions of the effects of global change.

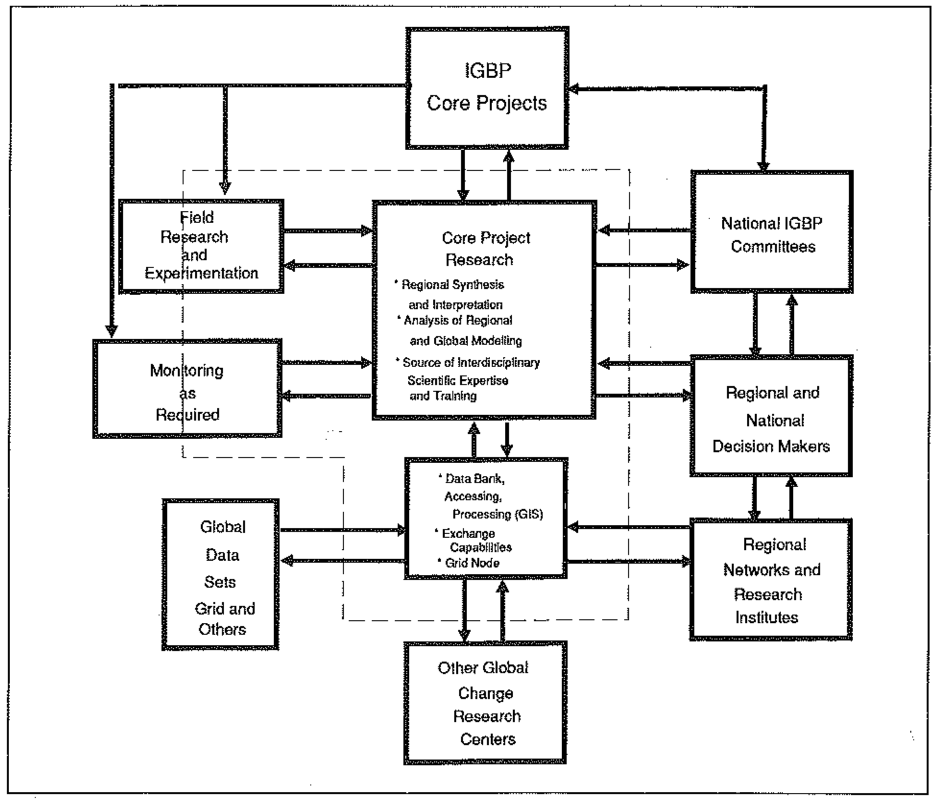


Figure 1. A schematic illustration of functional relations between a RRC (dashed line box) and other IGBP activities

Each RRC will have computer hardware and software needed for data management and processing. Links will be established with appropriate centres to ensure that LDC participants are fully involved in global modelling activities.

The training component of the RRCs will include the use of new technologies and techniques. The training will occur as short courses (weeks to a month), apprenticeship programmes (months to years), and exchange programmes between research centres within the region and to more specialized centres outside the region. Training will primarily be conducted in the network laboratories. Initiatives such as the recent establishment of the International Centre for Earth and the Environment at Trieste (Italy) could provide one focal point for training of scientists from the developing nations in General Circulation Modelling. The GCM facility at INPE (Brazil) may serve in a similar fashion for South America.

In order to meet the multiple functions of RRCs in a regional context, their institutional setup must be tailored to be politically neutral while at the same time having the support of the government of the country where they are established.

Finally, when the RRCs are fully developed, they will be able to communicate research results to regional resource managers and policy makers. This will be accomplished in a variety of ways according to the specific types of relationships between the scientific establishment, governments and non-governmental organizations within each region. Figure 1 illustrates the functional relation between RRCs and other IGBP activities.

Site Selection Criteria

The goals of the IGBP demand the active participation of scientists from all regions of the world, and the assurance that research results of the IGBP are brought effectively to the attention of national governments. These factors argue for distributing the RRCs in such a way that major biogeographic and geopolitical regions of the developing world are appropriately represented. The number of sites that will be selected for the RRCs in developing countries will probably be five to ten.

Site selection criteria will be guided by the scientific questions that the IGBP is addressing, as expressed in the research plans for Core Projects. Each RRC, apart from being a node in the regional network of collaborating institutions, also must have active IGBP research component and be an integrated part of the Core Project activities relevant to the region in question.

The selection of a specific site within a region should be judged according to four major criteria: (i) the existence of a scientific institution or "nucleus"; (ii) the interest of scientists and of national and regional governments; (iii) the availability of logistical support; and (iv) access to the RRC for visiting scientists and technicians.

An Existing Nucleus

Siting RRCs in existing institutions will save set-up costs and minimize the administrative infrastructure that each will require. In addition, ongoing research should be built upon the development of a strong input to IGBP Core Projects. For these reasons, RRCs should primarily be established in active research institutions which are interdisciplinary in nature or that have the potential of becoming interdisciplinary. These centres will serve as nuclei for further growth and for the establishment of networks of collaborating laboratories in the region.

Interest and Involvement of Scientists and of National and Regional Governments.

The proposal of potential sites for an RRC should originate within the region, on the basis of scientific and governmental interest. Governmental recognition is needed to assure stability and continuity in the host country.

Availability of Logistic Support

Certain logistic support is required for a proposed site. This should ideally include, for example, proximity to an international airport, convenient regional and international communications, adequate office space and housing for visiting scientists and technicians. Additional resources include: (i) a number of resident research scientists to provide an initial "critical mass" of talent; (ii) support personnel, including research assistants, clerical and maintenance staff; (iii) a scientific library adequate for initial research activities; (iv) computational facilities; (v) access to Geographical Information System (GIS); and (vi) the availability of a suitable conference facility in the area, for example for the regional research conferences that will be an outreach activity of each RRC.

It is recognized that some of these desired facilities might not be available in a proposed site, and they will need to be provided through additional funding.

Access to RRCs by Visiting Scientists and Technicians

RRCs are by definition regional and of necessity international. Access to the RRC by scientists and technicians from the region, who are not nationals of the host country, is a requirement of any ICSU activity.

Relationships of RRCs to Other Networks

The RRCs should foster the establishment of regional collaborative mechanisms specifically for the IGBP Core Projects. In doing so, the RRCs will need to build on regional networks, some of which are part of established national and international research networks, (e.g., the Unesco/MAB Biosphere Reserves). It is envisaged that the RRCs will play an important role in facilitating a wider use of data obtained from such networks for IGBP purposes.

Monitoring is an important component of global change research and there are many such existing programmes, both governmental and non-governmental. Monitoring networks should be an integral part of the regional RRC structure and hence the centres should help in ensuring long-term financial commitments to monitoring, both to detect global change and to ensure that the needs of the Core Projects are met. The IGBP-DIS Core Office should act as the coordination node for regional data directories. Special attention should be given to the development of appropriate links with programmes such as the GEMS/GRID of UNEP. Indeed, in some cases, the RRCs might be formally linked to regional GRID nodes.

Prior to the establishment of an RRC, an inventory of activities within the specific region should be commissioned. A first survey is presently being conducted for Africa with the help of the Commonwealth Science Council and the Association of African Universities.

Funding Strategy

A comprehensive funding strategy for the RRCs would be premature until their number, location, and specific facility needs are known. It is, however, important to proceed with the identification of potential RRC funding sources and to identify procedures necessary to mobilize those funds. A number of general objectives for funding approaches should be highlighted: (i) funding should be directed towards institutionalizing the functions of the RRCs within the regional setting; (ii) funding must be long-term and stable; (iii) funding should be IGBP directed rather than Core Project driven; (iv) funding should include both research and administration; and (v) the RRC activities should be directed by global change scientific concerns and IGBP Core Project needs as opposed to individual interests of funding bodies.

A critical responsibility of the RRC Standing Committee (see Chapter 12) will be to ensure that the scientific goals of the centre are focused on the IGBP objective even in the presence of changing funding-body interests, and specific demands of individual projects or institutions. Rigorous review procedures within funding cycles will be essential for both internal health of the RRC and external perception of the centre's activities. Mechanisms must be developed between the centre and funding agencies to fulfill these two needs, but not be made so complex and frequent that they interfere with RRC activities.

The context in the developing countries is such that the options of government and government-related funding for RRCs is generally absent. Many governments in the developing world may not have the resources to fund substantial global change related research, but it is necessary that governmental bodies specify global change research to be a national priority in order to attract major outside donors.

Plan for Action

To ensure the future development of the IGBP as a whole and to develop an implementation plan for the establishment of the RRCs, including appropriate fund raising activities, a first consultative meeting will be held in December 1990, with the support of the Rockefeller Foundation. The SC-IGBP will then appoint an RRC Advisory Committee to guide the further developments. An RRC Project Office should also be established to coordinate the early phases of RRC establishment.

At present, three initiatives to create RRCs in the developing world are being considered in consultation with governments and international agencies. The Regional IGBP Meeting for South America proposed that an RRC be set up in the Amazon region. The French proposal to create a Sahara-Sahel Observatory offers promise for collaboration and support for an RRC. In addition, a proposal to create an international centre in Indonesia for Equatorial Atmospheric Research with funds from Japan can be built-on to form an RRC.

Given the mission of these centres and the need for global participation in the IGBP, it is essential that the Regional Research Centres are in place as rapidly as possible. As the IGBP has profound implications for sustainable management of natural resources, the RRCs will play a major role in providing the necessary scientific base for evaluating global change scenarios for planning purposes in the developing regions of the world.

Implementation and Funding Strategy

Contents

12. IGBP Implementation and Funding Strategy

IGBP Implementation Structure and Organization

The organizational and implementation plans for the IGBP have been based in part on the experiences of other international collaborative research efforts such as the IGY, IBP and WCRP/GARP. The following have been the general tenets:

- Programme development is guided by a strong committee consisting of scientists from relevant disciplines.
- A minimum of new organizational machinery should be created, building where possible, on capabilities and infrastructures that already exist within and outside ICSU.
- The implementation of the programme will require full-time coordination at the level of individual Core Projects. The development of detailed science and implementation plans must be in the hands of active scientists.
- The national programmes of research, which make up the IGBP, will differ in emphasis among themselves and may be less comprehensive, in general, than the composite international programme.
- Since national participants in the IGBP will benefit from the international aspects of the programme, including the provision of data and shared facilities, they must equitably share in the costs of administering the programme internationally.

Based on these considerations, the overall structure illustrated in Figure 1 has been proposed.

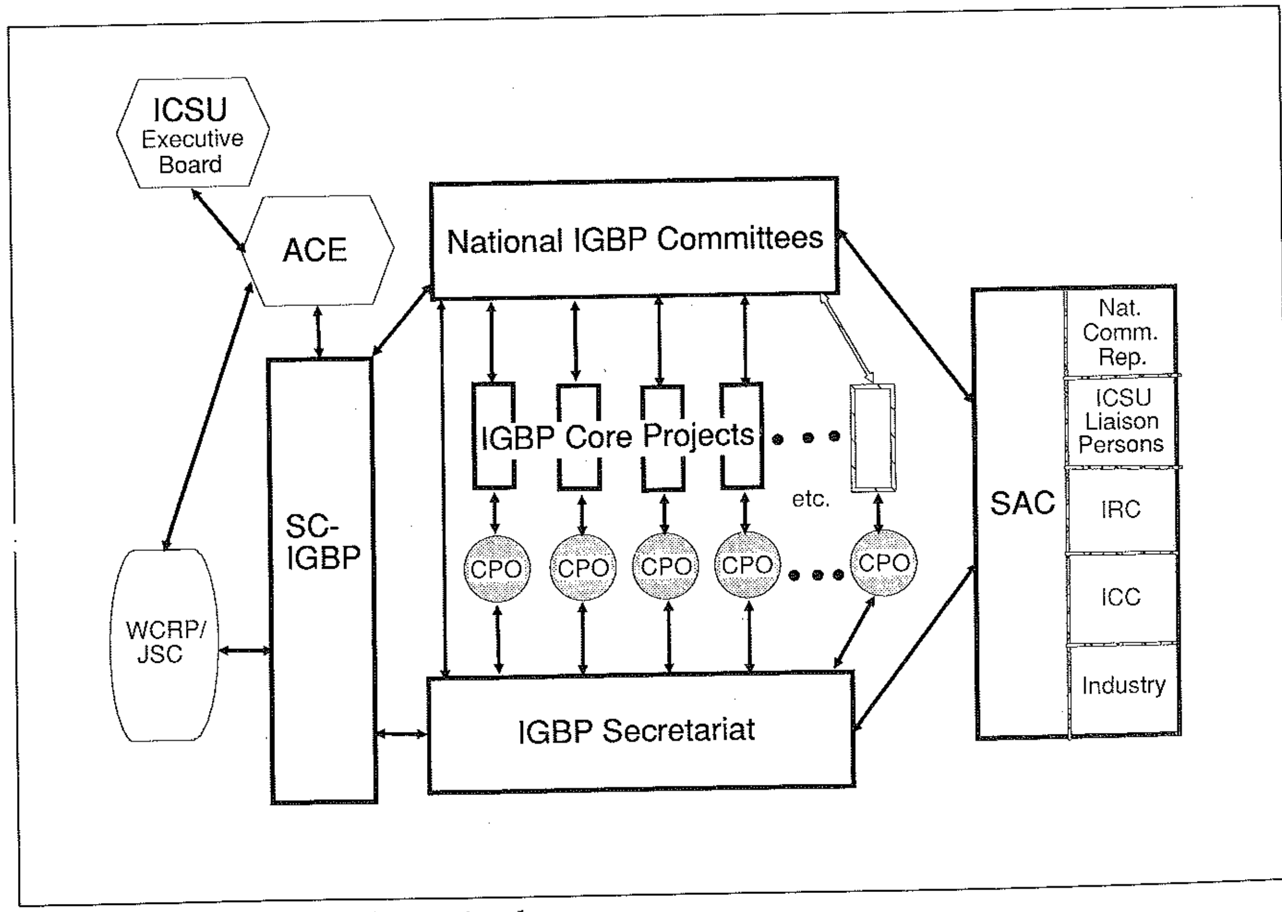


Figure 1. Structure of IGBP implementation phase.

Core Projects, Scientific Steering Committees and Standing Committees

The research efforts of the IGBP will be implemented through a set of Core Projects, which are defined by the Scientific Committee for the IGBP (SC-IGBP) on the basis of the programme objective, the four underlying themes of the IGBP, key scientific questions that are identified in the course of the definition and evolution of the programme, project feasibility, and readiness (see Chapter 1). For purposes of management and support, a maximum of about ten Core Projects will be ongoing at any one time (Fig. 2).

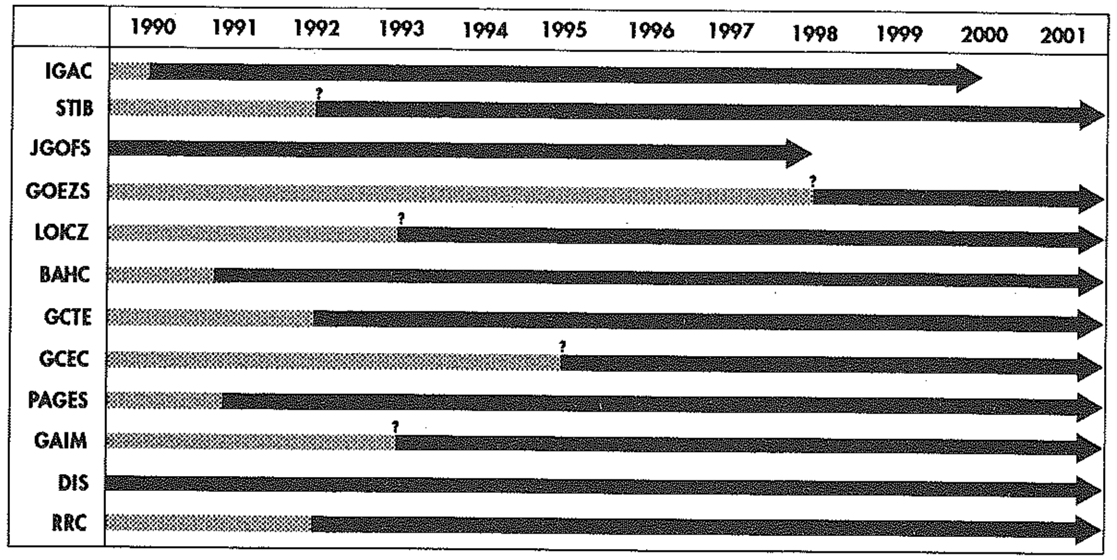


Figure 2. Tentative timelines for IGBP Core Projects and complementary activities.

Core Projects are considered by the SC-IGBP in three categories of planning and readiness:

1. Established Core Projects, for which a detailed science plan has been developed. The following projects have now been approved, and have begun developing implementation plans:
   - IGAC (International Global Atmospheric Chemistry Project), jointly coordinated with IUGG-IAMAP-CACGP
   - JGOFS (Joint Global Ocean Flux Study), coordinated by SCOR
   - PAGES (Past Global Changes)
   - BAHC (Biological Aspects of the Hydrological Cycle), jointly coordinated with WCRP/GEWEX
   - GCTE (Global Change and Terrestrial Ecosystems)
2. Proposed Core Projects, identified by the SC-IGBP as key to the objective and underlying themes of the IGBP, for which a detailed science plan is not yet developed or approved. The SC-IGBP will appoint ad hoc Planning Committees for proposed Core Projects to accomplish this task. The following are under consideration:
   - STIB (Stratosphere-Troposphere Interactions and the Biosphere) jointly proposed with IAMAP/IAGA/SCOSTEP
   - LOICZ (Land-Ocean Interactions in the Coastal Zone)
   - GAIM (Global Analysis, Interpretation and Modelling)

3. Potential Core Projects, which have direct relevance to the goal and underlying themes, but for which the SC-IGBP has not yet proceeded to develop a science plan. These are, at present:
   - GOEZS (Global Ocean Euphotic Zone Study), jointly discussed with SCOR
   - GCEC (Global Change and Ecological Complexity), evaluation being prepared by SCOPE/IUBS

For each established Core Project, the SC-IGBP appoints a Scientific Steering Committee (SSC). In the case of Core Projects established jointly with other organizations, the SSC is appointed by the SC-IGBP jointly with the co-sponsoring body. The Chairpersons of the SSC will be appointed by the SC-IGBP based on recommendations from the SSC. The SSC Chairpersons are full members of the SC-IGBP and participate fully in all deliberations and decisions regarding the IGBP.

Each SSC will organize an annual Open Meeting to which representatives from participating nations, ICSU scientific organizations, other relevant programmes and other IGBP Core Projects will be invited. These Open Meetings of IGBP Core Projects are intended to promote strong interactions between the organized international programme and contributing national efforts, and to ensure necessary interaction among the Core Projects of the programme as well as with other relevant international programmes.

The process of selection, organization, development of science plan and implementation of IGBP Core Projects will, in principle, follow the sequence of steps listed below:

- Designation as a potential Core Project by the SC-IGBP through recognition of relevance to the IGBP objectives and priorities.
- Designation as a proposed Core Project, when project feasibility and community readiness have been ascertained, and appointment of an ad hoc Planning Committee by the SC-IGBP.
- Presentation of a draft science plan by the ad hoc Planning Committee.
- Consultation with national committees, ICSU liaison persons, and other IGBP partners.
- Decision of the SC-IGBP to establish a Core Project and appointment of a Scientific Steering Committee by the SC-IGBP.
- Preparation of a detailed science plan by the SSC.
- Core Project Open Meeting to discuss and refine the science plan.
- Approval of the science plan by the SC-IGBP.
- Preparation of an implementation plan by the SSC.
- Invitation to participating nations to host and/or co-sponsor a Core Project office and establishment of a Core Project office.
- Core Project Open Meeting to discuss implementation plan.
- Project implementation begins.
- Annual Open Meetings to review progress, with subsequent reports to SC-IGBP and SAC.

IGBP Core Projects nominally will operate for about a decade and appropriate mechanisms will be developed to monitor their progress. Standing Committees will be established by the SC-IGBP to guide activities that cut across the Core Projects. Initially, two Standing Committees have been appointed for:

- IGBP Data and Information System (IGBP-DIS);
- IGBP Global Change Regional Research Centres (RRC)

The Chairpersons of these committees will also be members of the SC-IGBP.

Core Project Offices

IGBP Core Projects will be administered through a Core Project Office (CPO), established within the home institution of the chairperson of the SSC or at another suitable location. Funding for the operation of individual CPOs, including necessary salaries, will be sought from funding sources within the nation in which the office is sited, or jointly supported by two or more countries. The responsibility for securing support for establishing and operating a Core Project Office rests with the chairperson(s) of the SSC. Once a Core Project Office is established, support for the project through funds administered by the IGBP

Secretariat will probably be limited to the support of one meeting a year of the SSC. The Secretariat will, however, continue to help support especially cross-project initiatives that will promote the overall IGBP objective and other initiatives, depending on availability of funds. The functions of a Core Project Office include: (i) administering the project on a day-to-day basis, under the long-term guidance of the SSC; (ii) coordinating research efforts, and planning and coordinating research campaigns and field programmes; (iii) providing project advocacy and promotion, and enlisting wide international participation in the project; (iv) maintaining needed connections with relevant national projects; (v) ensuring effective coordination with other Core Projects of the IGBP; (vi) disseminating information and research results; and (vii) securing support for the operation of the office.

Table 1. List of established Core Projects, SSC and Standing Committee chairpersons, Core Project sites, and proposed Core Project Office national sponsors. The GOEZS project development will be facilitated by an International Planning Office.

Core Project	Chairperson(s)	CPO Site	Natl.Sponsor(s)
IGAC	R. Prinn (USA)	?	?
JGOFS	B. Zeitzschel (FRG)	Kiel	FRG
PAGES	H. Oeschger (Switzerland) J. Eddy (USA) (Co-Chairperson)	Bern	Switzerland/ USA (?)
BAHC	H.-J. Bolle (FRG) S. Dyck (GDR) (Co-Chairperson)	Berlin	FRG
GCTE	B. H. Walker (Australia)	?	?
IGBP-DIS	S. Rasool	Paris	France/USA
RRC	G. Golubev	?	?
GOEZS		Wormley	UK

Scientific Advisory Council

The Scientific Advisory Council (SAC-IGBP) is an advisory body composed of representatives of IGBP National Committees, ICSU national and scientific members, appropriate UN organizations and other international bodies. It is the highest policy discussion forum of the IGBP and it will be convened every two years to provide advice to the SC-IGBP and to allow full discussions on all aspects of IGBP plans and projects. Meetings of the SAC-IGBP will be chaired by the President of ICSU.

National participants in the SAC meetings should include representatives from each national IGBP committee as well as an appropriate national funding body. This dual national representation is necessary to ensure that both the scientific and funding communities are involved in the discussions regarding implementation of the IGBP Core Projects.

To allow these two types of national representatives ample opportunity to meet as a group, the SAC meeting programme will provide for parallel sessions: one for the representatives of national IGBP committees and the other for the representatives of national funding bodies (see below). Regional and international bodies funding IGBP research should also be invited to take part in the IRC meeting. Observers from national ICSU members, which have not yet established IGBP committees, will also be invited to the meetings of national committees.

ICSU scientific members are invited to SAC meetings. All ICSU scientific members have been invited to appoint liaison persons to the IGBP. These persons provide essential links between the IGBP and other ICSU projects. Representatives of ICSU scientific members at SAC meetings may also wish to meet in parallel sessions to national members meeting to discuss coordination and complementary/cooperative activities in relation to global change research in a context wider than that provided by the IGBP in an ICSU Global Change Forum.

In addition, relevant UN organizations; international social science organizations with research programmes in the human dimensions of global change; other international bodies and representatives of industry will also be invited to attend the SAC meetings.

Scientific and Executive Committees

The Scientific Committee for the IGBP (SC-IGBP), which replaces the Special Committee, has overall responsibility for the development of the IGBP including planning and implementation. It will meet at least once a year.

The SC-IGBP will be composed of:

- SC-IGBP Executive Committee, to direct ongoing affairs of the IGBP, consisting of no more than 15 persons: a Chairman, two or three Vice-Chairmen, Treasurer, Executive Director (the Officers) and up to nine additional members. Members of the Executive Committee are appointed by the ICSU Executive Board. A scheme for rotation of membership will be implemented when the new set of members are appointed in 1990. Members of the EC-IGBP are to be scientists active in research in areas that are particularly relevant to the present and future plans of the IGBP. The EC-IGBP is expected to meet twice a year.
- Additional members of the SC-IGBP will be chairpersons of Scientific Steering Committees and Standing Committees. Chairpersons of these Committees are appointed by the SC-IGBP upon recommendations from the SSC. In the case that a Core Project is organized in collaboration with another body, the SSC Chairperson(s) will be appointed in consultation with that body.
- Ex officio members of the SC-IGBP will be the chairman of WCRP/JSC and a designated representative of the ICSU Advisory Committee on the Environment (ACE).

The IGBP Secretariat

The IGBP Secretariat will be headed by an Executive Director, appointed by the ICSU Executive Board, and staff appointed by the Executive Director with the approval of the EC-IGBP. It is expected that the staff will include the Executive Director, a Deputy Executive Director, two Programme Officers with a PhD in a subject area of relevance to the IGBP, an Assistant to the Executive Director, a Finance Officer and two Secretaries. In addition to these persons, it is anticipated that a special officer will be hosted with responsibilities for promoting and establishing linkages to endeavours in the social sciences that address the human dimensions of global change research. This person will be selected and supported through mechanisms external to the IGBP and ICSU.

The Executive Director is responsible, under the guidance of the EC-IGBP, for the overall administration and coordination of the IGBP. The Deputy Executive Director is responsible for the general management of the Secretariat. These two persons together with the Programme Officers serve as contact persons between the Secretariat, the Core Projects and other external organizations.

IGBP Funding Mechanisms

The implementation of the IGBP will require the commitment of major resources to support the research activities of the Core Projects of the programme. Funding for IGBP research activities will be raised by two different mechanisms. The majority of the research activities of Core Projects will be funded through affiliated national research programmes, with a small fraction set aside for international planning, coordination and synthesis efforts managed by Core Project offices and the IGBP. In some instances, however, centralized funding will be needed for specific research activities. In such cases, arrangements will be made through IGBP for the appointment of a coordinating body, responsible for project management and funding. The financing of the IGBP Regional Research Centres is an example of this need.

The task of sustaining an international programme of research that is funded principally by national efforts with national research priorities is a major challenge of the IGBP. The need to coordinate observational campaigns and other implementation aspects of the IGBP (including satellite schedules, ship operation plans, coordination of short- and long-term budget development and planning) requires an effective coordinating mechanism among federal agencies. For this reason, an Interagency Resource Committee (IRC) with members from participating nations should be formed to coordinate national efforts. In view of the complementarity of the IGBP and WCRP, the IRC should address both programmes as well as certain global change initiatives. A first meeting of national funding agency representatives was held in Washington, January 1990 in parallel with the meeting of national IGBP committees. The IRC should meet annually and also in conjunction of SAC meetings. It is appropriate that this committee includes initially the nations that will provide major funds for the IGBP Core Projects and WCRP research programmes, with membership expanded in the future to include all participating nations.

Particular measures need to be taken to enlist the collaboration of scientists from developing countries. For this it will be necessary that governments of all nations identify global change research as a national priority, regardless of the size of expenditure that is allowed. If national priorities are set, it will be considerably easier to fund the research through bilateral or multilateral arrangements. The SAC and IRC meetings will constitute suitable fora for discussions of such funding.

The SC-IGBP and Secretariat will primarily be financed through national contributions. National Cmmittees for the IGBP need to convince their funding bodies of this necessity. Funding secured from private foundations and industry has aided considerably in the initial years of programme planning and administration. In the long run, the international coordination mechanism must operate on continuing commitments from the nations that participate in the IGBP.

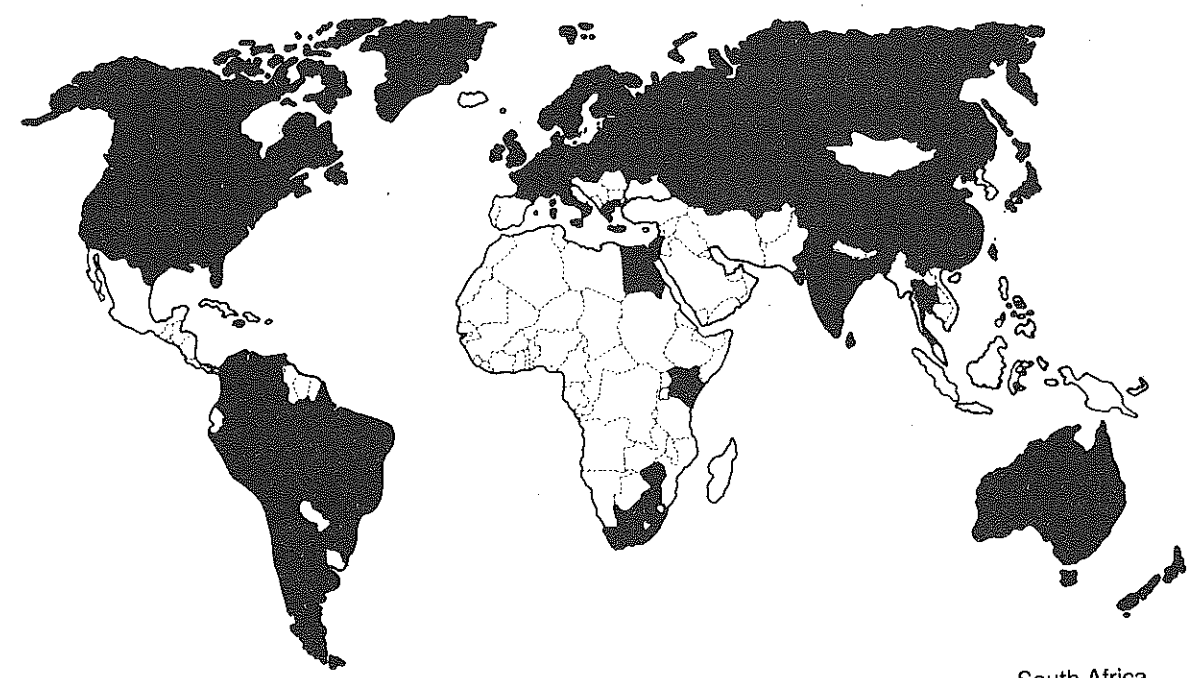
The costs for the international planning and coordination activities of the overall programme, excluding expenses of Core Project Offices, are expected to amount to USD 1.5 million per year administered by the IGBP Secretariat. It is anticipated that during the peak implementation phase, the total costs for coordination and synthesis efforts at the international level, including Core Project Office expenses, will be less than 1% of the total funding level for all affiliated national research programmes.

IGBP at the National Level

Core Projects of the IGBP will require the support of many participating nations if they are to be successfully implemented. Each participating nation, although subscribing to the overall priorities of the IGBP, will place differing degrees of emphasis on the various programme elements, consistent with its own needs and capabilities. National IGBP committees will constitute the crucial link between the national and international efforts. Many such committees have already been

established. It is a responsibility of the IGBP Secretariat to identify key contact persons in countries where national committees do not yet exist and to promote the establishment of such committees.

Present distribution of National IGBP Committees (May 1990).



Argentina
Australia
Austria
Bangladesh
Belgium
Bolivia
Brazil
Bulgaria
Canada
Chile
China (CAST)
China (Academy in Taipei)
Colombia
Czechoslovakia
Denmark
Egypt
Finland
France
German Democratic Republic
Federal Republic of Germany
Greece
Hungary
India
Ireland
Israel
Italy
Jamaica
Japan
Kenya
The Netherlands
New Zealand
Norway
Peru
Poland
South Africa
Sweden
Switzerland
Sri Lanka
Thailand
United Kingdom
U. S. A.
U. S. S. R.
Venezuela
Zimbabwe

Regional meetings constitute an important mechanism to create awareness of the scientific challenge of global change research, stimulate nations in the region to become involved in IGBP Core Projects, promote the establishment of national committees and foster increased regional collaboration within the IGBP and with other relevant research programmes. Such meetings have already been organized for the Southern Hemisphere (Swaziland, December 1988) and South America (Brazil, March 1990) and meetings are now planned for Asia (February 1991) and Africa (January 1991).

Annual meetings of representatives of national IGBP committees will be convened to coordinate national efforts that contribute to the international programme. The first such meeting was held in Washington at the invitation of the US National Committee in January 1990; the second is planned for the UK in early 1991. These meetings, attended by scientists from the national committees and national funding agency counterparts, will review the status of the international IGBP planning and operations in the context of planned and ongoing national research, analyze and discuss the commonality of national programme elements, design mechanisms for supporting critical programme elements, and develop multinational and regional programme linkages.

While these meetings of national members, as well as those of the IGBP Scientific Advisory Council, will provide input into the overall IGBP operations and strategic planning, specialized attention must be given to the individual Core Projects of the IGBP. For this purpose, periodic meetings of appropriate specialists from National Committees as well as appropriate ICSU Unions and Committees and other relevant organizations will be convened. These Core Project Open Meetings (see above) will provide the mechanism for coordinating the collaborative efforts of the scientists who will be active in the research components of individual projects.

It is essential that national funding agencies are involved in the international discussions on programme development and implementation. The IGBP implementation plan calls for a close partnership between national IGBP committees and the funding agencies, both in context of national planning and through meetings of the SAC.

IGBP in Relation to ICSU's Scientific Members

Many of the ICSU scientific members carry out substantial activities of their own that relate to studies of global change, efforts that lie outside the scope of the two major research programmes of ICSU, the IGBP and WCRP.

The Scientific Committee on Problems of the Environment (SCOPE) plays a special role through its charter "to advance knowledge of the influence of humans on their environment ... and to serve as a source of advice ... with respect to environmental problems." A fundamental difference between IGBP and SCOPE is that the former has been set up to conduct a research programme, while SCOPE focuses on interdisciplinary analyses of environmental problems that often lead to the identification of research needs. As two examples, SCOPE is now conducting surveys of our present state of knowledge on the effect of UV-B on organisms and ecosystems and the effect of global change on ecological complexity. In both instances, the IGBP will use the results from these studies when deciding on whether these research questions should be covered by IGBP Core Projects.

In developing plans for Core Projects under the guidance of the IGBP objective and underlying themes, the SC-IGBP has relied on planning efforts in other ICSU scientific bodies. The following merit special mention:

SCOR:	Responsible for planning and implementing JGOFS.
IUGG/IAMAP/ CACGP:	Responsible for planning the major proportion of IGAC and together with IGBP responsible for its implementation.
IUGS:	Has provided major inputs to the planning for PAGES and is, together with Unesco, making a feasibility study for a complementary programme.
SCOPE:	Apart from the two above mentioned activities, SCOPE has made a major contribution to the development of the biological component of IGAC; it has initiated, together with Unesco, the discussions on needs for Geosphere-Biosphere Observatories (now developed into the RRC concept); it is developing generic simulation models for primary production/decomposition in boreal forests and grasslands, which will be important inputs to GCTE; it has addressed the issue of large-scale ecological experiments, which has guided the development of certain core activities in GCTE; and it has addressed the need for long-term ecological research, which is of special interest to the development of RRC networks.
WDC:	A major component in the development of IGBP-DIS.
IUGG-IAGA, IAMAP/SCOSTEP:	Contributed to the plans for STIB
IUBS:	Collaborating with SCOPE on GCEC and together with Unesco it is addressing how soil biological processes, and the TSBF programme, can contribute to GCTE as well as surveying how current simulation models for the savanna can be used to GCTE.
SCAR:	Published a report on the role of Antarctica in global change research, which is an important source for the development of IGBP Core Project PAGES.
COSPAR:	Serves together with IGBP as ICSU's focal points with SAFISY. Involved in developing the report which identifies IGBP remote sensing needs (Chapter 10).

Many other ICSU bodies have developed important research programmes of relevance to global change research, although they fall outside the specific objective and priorities of the IGBP (e.g., STEP of SCOSTEP).

It is essential that the IGBP maintains close contacts with the scientific members of ICSU. To this end ICSU scientific members with activities relevant to global change research have been invited to appoint liaison representatives to the IGBP. Their role is to foster efficient communications between their parent body and the IGBP. The IGBP Secretariat will ensure that they are kept informed of current developments within the programme.

The scientific member liaison persons and other representatives of ICSU scientific members are invited to the SAC meetings. In addition, they will be invited to the Core Project Open Meetings, where further discussions can develop plans for specific collaborative activities.

Discussions between ICSU scientific members and the IGBP will also be possible at the annual ICSU meetings (General Assembly or General Committee). In addition, the ICSU Global Change Forum offers a platform for discussions of additional global change activities, which are not explicitly included in IGBP Core Projects.

IGBP in Relation to the UN System and Other International Organizations

Three United Nations bodies are essential for the implementation of an international programme of global change research: the World Meteorological Organization (WMO); the United Nations Educational, Scientific and Cultural Organization (Unesco) and the United Nations Environment Programme (UNEP). Of special relevance in this context is the Intergovernmental Panel on Climate Change (IPCC). Cooperation with other bodies of the United Nations system, such as FAO, will be needed to facilitate the implementation of certain IGBP projects.

It is important to identify those activities of intergovernmental bodies, which relate directly to the IGBP and to define mechanisms through which the IGBP can be strengthened by collaboration with focused research projects of intergovernmental bodies. A key component of an international global change research effort and a close counterpart to the IGBP is the World Climate Research Programme (WCRP) of ICSU and WMO. The Intergovernmental Oceanographic Commission (IOC), the Man and Biosphere Programme (MAB), the International Hydrological Programme (IHP), the International Geological Correlation Programme (IGCP) and other Unesco programmes have great potential to contribute to the overall global change research effort. The Global Environmental Monitoring System (GEMS), the Global Resource Information Database (GRID), and other UNEP programmes can also make important contributions.

These organizations also provide a vehicle for multinational coordination. This could be particularly useful in developing the active interest and involvement of developing countries in the IGBP. Thus, Unesco has supported the IGBP regional meeting in South America and a planning meeting for Africa. For this group of countries, but also in general, IGBP will need to work together with the relevant intergovernmental institutions with extensive experience in coordination, environmental education and scientific training activities. The intergovernmental bodies can help to communicate IGBP and other global change research results to governments and their agencies. The UN bodies can be instrumental in formulating internationally agreed upon response measures and legal agreements to deal with global change. For this reason, close links have already been developed between IPCC and IGBP/WCRP, who have jointly developed the chapter on research needs for the IPCC report to the 2nd World Climate Conference.

An Interagency Coordinating Committee (ICC) for the IGBP has been set up to facilitate exchanges between the UN system and IGBP. This body has comprised the Executive Committee of the IGBP and representatives from UNEP, Unesco and WMO. The ICC is now under review to determine how it can provide the most efficient mechanism for such interaction between IGBP and the UN bodies with major interests in global change research.

The IGBP now collaborates with several bodies outside the ICSU and UN system and hopes to further develop such links. IIASA has, for example, cosponsored a meeting on RRCs and activities within their environment programme have directly influenced the planning for GCTE. SC-IGBP also serves as one of ICSU's two focal points with SAFISY. IGBP will continue to maintain close contacts with IUCN in questions related to conservation issues.

IGBP and Industry

In recent years private industry has become more involved in the analysis of environmental issues, including global change. In the next decades, with possibly great environmental changes, industry will need to be fully apprised of the best available scientific knowledge concerning environmental changes and the research that is planned to increase our understanding and predictive ability. Industry must know, on global as well as regional scales, the anticipated impacts of environmental change.

The IGBP and WCRP endeavours, to carry out major research programmes and to provide a focus for global change studies, should be of service to the private as well as the public sector. At present, few people directing these industries are sufficiently aware of ICSU's plans for global change research in general and the IGBP in particular. There is a large potential interest in industries that could be harnessed to aid the IGBP research effort. The IGBP Secretariat should make efforts to develop closer links to industry.

It is in the interest of both parties, the natural sciences represented by IGBP and the increasing group of large industrial companies much affected by global changes, to consider the mutual advantages of collaboration. In this regard, industry can contribute in kind to the IGBP effort with their expertise in data management and model development, provide access to large computers and instruments, advise on public affairs aspects, fund raising and management, and contribute to needed technological development.

Members of the Special and Executive Committee for the IGBP

Appendix 1

Executive Committee

Chairman
Prof. J. J. McCarthy

Museum of Comparative Zoology, Harvard University, Cambridge, MA 02138, USA. Tel: (+1-617) 495 23 30, Telex: (23) 7402058 MCZL UR, Telefax: (+1-617) 495 05 06, Telemail: J.McCarthy (Omnet).

Vice Chairman
Prof. R. Herrera

Centre for Ecology and Environmental Science, IVIC, Apartado 21827, Caracas 1020A, Venezuela. Tel: (+58-2) 69 19 49, Telex: (31) 21657 IVICB VC, Telefax: (+58-2) 571 31 43.

Executive Director
Prof. T. Rosswall

IGBP Secretariat, Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden. Tel: (+46-8) 15 04 30 (exch.), 16 64 48 (direct), Telex: 17509 IGBP S, Telefax: (+46-8) 16 64 05, Telemail: T.Rosswall (Omnet)

Treasurer
Prof. W. S. Fyfe

Dean of Science, University of Western Ontario, London, Ontario N6A 5B7, Canada. Tel: (+1-519) 661 30 41, Telex: (21) 0647134 UWO LIB LDN, Telefax: (+1-519) 661 32 92, fax-phone 661 34 86.

EC Members at large

Prof. P. J. Crutzen

Max-Planck-Institute for Chemistry, PO Box 3060, D-6500 Mainz, FRG. Tel: (+49-6131) 30 54 58/9, Telex: (41) 4187674 MPCH D, Telefax: (+49-6131) 30 53 88

Prof. V. M. Kotlyakov

Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109017, USSR. Tel: (+7-095) 238 86 10, Telex: (64) 411781 GLOBE, Telefax: (+7-095) 230 20 90.

Special Committee

Prof. B. Bolin

Kvarnåsvägen 6, 184 51 Österskär, Sweden. Tel: (+46-8) 15 77 31 (university), Telex: 15959 MISU S, Telefax (+46-8) 15 71 85.

Dr. M.-L. Chanin

Service d'Aeronomie du CNRS, B.P. 3, F-91371 Verrières-le-Buisson Cedex, France. Tel: (+33-1) 69 20 07 94, Telex: (42) 602400 AERONO F, Telefax: (+33-1) 69 20 29 99, Telemail: M.L.Chanin (Omnet).

Dr. E. S. Diop

PO Box 3311, (Street address: 12 Avenue Roume), UNESCO/BREDA, Dakar, Senegal, Tel: (+221) 23 87 17, 23 46 14, Telex: (+906) 21735, 51410 UNESCO.

Prof. S. Dyck	Division of Hydrology and Meteorology, Dresden Technical University, Mommsenstrasse 13, DDR-8027 Dresden, German Democratic Republic. Tel: (+37-51) 463 39 31, Telex: (69) 2278MZ TEUNI DD.
Dr. J. A. Eddy	Office for Interdisciplinary Earth Studies, UCAR, PO Box 3000, Boulder, CO, 80307, USA. Tel: (+1-303) 497 16 80, Telex: (230) 989764 NCAR BDR UD, Telefax: (+1-303) 497 16 79, Telemail: J.Eddy (Omnet).
Prof. T. Nemoto	Ocean Research Institute. University of Tokyo, 1-15-1 Minamidai, Nakano-ku, Tokyo 164, Japan. Tel: (+81-3) 376 12 51, Telex: (72) 25607, ORIUT J, Telefax: (+81-3) 375 67 16, Telemail: ORI.Tokyo (Omnet)
Prof. H. Oeschger	Institute of Physics, University of Berne, Sidlerstrasse 5, CH-3012 Bern, Switzerland. Tel: (+41-31) 65 44 62, Telex: (45) 912643 PIBE CH, Telefax: (+41-31) 65 44 05,.
Dr. S. I. Rasool	Office of Space Science and Applications, Code E, NASA, Washington, DC 20546, USA. Tel: (+1-202) 453 14 20, Telex: (23) 4979843 NASA, WSH, Telefax: (+1-202) 755 92 34, 755 92 35, Telemail: I.Rasool (Omnet).
Prof. J. S. Singh	Department of Botany, Banaras Hindu University, Varanasi 221 005. India. Tel: (+91-542) 542 91 ext 352, Telex: (81) 545304 BHU IN, Telefax: (+91-542) 451 76.
Prof. V. A. Troitskaya	8692 Brae Brook Drive, Lanham, Maryland 20706, USA. Tel: +(1-301) 522 95 66.
Dr. B. H. Walker	Division of Wildlife and Ecology, CSIRO, PO Box 84, Lyneham, ACT 2602, Australia. Tel: (+61-62) 42 17 42, Telex: (71) 62284 WLR AA, Telefax: (+61-62) 41 33 43, Telemail: B.Walker (Omnet).
Dr. J. D. Woods	Natural Environment Research Council, Marine Sciences Directorate, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU, UK. Tel: (+44-793) 41 15 00 ext 1637, Telex: (51) 444293 ENVRE G, Telefax: (+44-793) 41 15 01, Telemail: J.Woods/Science (Omnet).
Prof. Ye Duzheng	Academia Sinica, 52 Sanlihe Road, Beijing, China. Tel: (+86-1) 86 83 61 ext. 843, Telex: (850) 22474 ASCHI CN, Telefax: (+86-1) 801 10 95.

Ex-officio members

Prof. G. A. McBean	Joint Scientific Committee, Atmospheric Sciences Programme, University of British Columbia, Department of Geography, Vancouver, B.C V6T 1W5, Canada. Tel: (+1-604) 228 5940, Telex: 04-51233, Telefax: (+1-604) 228 6150, Telemail: G.McBean (Omnet).

Prof. R. G. Prinn	International Global Atmospheric Chemistry Project, Room 54-1824, Massachusetts Institute of Technology, Cambidge, MA 02139, USA. Tel: (+1-617) 253 2452, Telex: (23) 921 473 MIT CAM, Fax:(+1-617) 253 6208.
Prof. B. Zeitzschel	JGOFS, Institut für Meereskunde, Universität Kiel, Düsternbrooker Weg, 20, D-2300 Kiel, FRG. Tel: (+49-431) 597 38 60, Telex: 0292619 JFMK D, Telefax: (+49-431) 56 58 76, Telemail: B.Zeitzschel (Omnet).

Appendix 2

IGBP Staff at the Stockholm Secretariat

Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden. Tel: (+46-8) 15 04 30, Telex: 17509 IGBP S, Telefax: (+46-8) 16 64 05, Telemail: igbp.secretariat t.rosswall, h.virji, d.ojima (Omnet)

Prof. Thomas Rosswall, Executive Director, Member EC-IGBP and SC-IGBP

Dr. Hassan Virji, Deputy Executive Director

Dr. Gunilla Björklund, Programme Officer (until January 1990)

Dr. Dennis Ojima, Programme Officer

Ms. Elise Wännman, Finance Officer

Ms. Hildburg Berglund, Assistant to the Executive Director (until September 1989)

Ms. Suzanne Nash, Assistant to the Executive Director (from September 1989)

Ms. Cecilia Edlund, Secretary

Ms. Lisa Wanrooy-Cronquist, Secretary

IGBP Senior Research Fellows, 1989-1990

Wissenschaftskolleg zu Berlin, Wallotstrasse 29, Berlin (West).

Lorius, Dr. Claude. Laboratoire de Glaciologie et Géophysique de l'Environnement, BP. 96, F-38402 Saint-Martin-d'Hères Cédex, France. Tel: (+33-76) 42 58 72, Telex: 80131 lgge, Telefax: (+33-76) 51 32 48.

Molion, Prof. Luiz C. Instituto de Pesquisas Espaciaias, Caixa Postal 515, 12201 São José dos Campos SP, Brazil. Tel: (+55-123) 22 99 77, Telex: (38) 3530 INPE BR, Telefax: (+55-123) 21 87 43, Telemail: Inpe.met (Omnet).

Reiners, Prof. William A. Department of Botany, University of Wyoming, Aven Nelson Building, Laramie, Wyoming 82071, USA. Tel: (+1-307) 766 23 60, Telefax: (+1-307) 766 22 71. Telemail: W.Reiners (Omnet).

Rutter, Prof. Nat. Department of Geology, University of Alberta, 1-26 Earth Sciences Building, Edmonton, Alberta T6G 2E3, Canada. Tel: (+1-403) 492 30 85, 3265, Telefax: (+1-403) 492 20 30.

Schiff, Dr. Harold I. Canadian Institute for Research in Atmospheric Chemistry, York University, 4700 Keele Street, North York, Ontario M3J 1P3, Canada. Tel: (+1-416) 739 48 68, Telefax: (+1-416) 739 45 21.

Steward, Prof. John W. B. Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, S7N OWO Canada. Tel: (+1-306) 966 68 27, Telemail: [jwbstewart/USDA] TM11/USA Attn: Holm Tiessen.

Virji, Dr. Hassan. US National Science Foundation, 1800 G Street NW, Washington DC, 20550, USA. Tel: (+1-202) 357 98 92, Telefax: (+1-202) 357 77 45, Telemail: H.Virji (Omnet)

IGBP Post-Doctoral Fellows, 1989-1990

Arino, Dr. Olivier. LERTS, 18 Avenue Edouard Belin, 31055 Toulouse CEDEX, France. Tel: (+33-61) 27 36 30, Telefax: (+33-61) 28 14 10.

Arquit, Dr. Anne. c/o Prof. Hans Oeschger, Institute of Physics, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland. Tel: (+41-31) 65 48 71, Telex: (45) 912643 PIBE CH, Telefax: (+41-31) 65 44 05, Telemail: A.Arquit (Omnet).

Baumert, Dr. Helmut. Institute of Mathematics, GDR Academy of Sciences, DDR-1086 Berlin, German Democratic Republic. Tel: (+49-30) 541 24 65, Telex: (+69) 114427 ADW DD

Turner, Dr. Sandra. CSIRO Div, Wildlife and Ecology, PO Box 84, Canberra ACT 2602, Australia. Tel: (+61-62) 42 17 70, Telex: 62284, Telefax: (+61-62) 41 33 43, Telemail: S.Turner (Omnet) /or/ SJturner@sevilleta.unm.Edu (internet) /or/ SJturner@UNMB (bitnet).

Appendix 3

Members of IGBP Coordinating Panels, Working Groups and Scientific Steering Committee

CP 1: Coordinating Panel on Terrestrial Biosphere - Atmospheric Chemistry Interactions

Crutzen, Prof. Paul J. Max-Planck-Institute for Chemistry, PO Box 3060, D-6500 Mainz, Federal Republic of Germany. Tel: (+49-6131) 30 54 58/9, Telex: (41) 4187674 MPCH D, Telefax: (+49- 6131) 30 53 88. *Chairman (Member SC-IGBP)*

Chanin, Dr. Marie-Lise. Service d'Aeronomie du CNRS, BP 3, F-91371 Verrières-le-Buisson Cedex, France. Tel: (+33-1) 69 20 07 94, Telex: (42) 602400 AERONO F, Telefax: (+33-1) 69 20 29 99, Telemail: M.L.Chanin (Omnet). *(Member SC-IGBP)*

Cicerone, Dr. Ralph J. Department of Geoscience, School of Physical Sciences, University of California, Irvine, California 92717, USA. Tel: (+1-714) 725 21 57, Telefax: (+1-714) 725 22 61.

Freney, Dr. John. CSIRO, Division of Plant Industry, PO Box 1600, Canberra, ACT 2601, Australia, Tel: (+61-62) 46 54 22, Telex: AA 62351, Telefax: (+61-62) 47 37 85.

Harriss, Dr. Robert C. Institute for the Study of Earth, Oceans and Space, Science and Engineering Research Building, University of New Hampshire, Durham, NH 03824, USA. Tel: (+1-603) 862 38 75, Telefax: (+1-603) 862 19 15, Telemail: CSRC (Omnet).

Malingreau, Dr. Jean-Paul. Commission of the European Communities, Joint Research Centre, Building 44, I-21020 Ispra (Varese), Italy. Tel: (+39-332) 78 98 30, Telex: 380042 EUR 1, Telefax: (+39-332) 78 90 01.

Matson, Dr. Pamela. NASA, Ames Research Center, Mail Stop 239-12, Moffett Field, CA 94035, USA. Tel: (+1-415) 694 68 84, Telefax: (+1-415) 694 46 80.

Melillo, Prof. Jerry M. Marine Biological Laboratory, Woods Hole, MA 02543, USA. Tel: (+1-508) 548 37 05, Telex: 951679, Telefax: (+1-508) 540 69 02, Telemail: J.Melillo (Omnet).

Prinn, Prof. Ronald. Department of Earth, Atmospheric and Planetary Science, M.I.T., Cambridge, MA 02139, USA. Tel: (+1-617) 253 24 52, Telex: 921473 MIT CAM, Telefax: (+1-617) 253 62 08.

Reeburgh, Dr. William S. Institute of Marine Science, University of Alaska, Fairbanks, Alaska 99775- 1080, USA. Tel: (+1-907) 474 78 30, Telex: 740 2055 SFOS, Telefax: (+1-907) 474 72 04, Telemail: w.reeburgh GTETLM.

Rodhe, Prof. Henning. Department of Meteorology, Stockholm University, S-106 91 Stockholm, Sweden, Tel: (+46-8) 16 36 96, Telex: 15950 MISU S, Telefax: (+46-8) 15 71 85, Telemail: misu.imi (Omnet).

Schiff, Dr. Harold I. Canadian Institute for Research in Atmospheric Chemistry, York University, 4700 Keele Street, North York, Ontario M3J 1P3, Canada. Tel: (+1-416) 739 4868, Telefax: (+1-416) 739 4521.

Tuck, Dr. Adrian. Aeronomy Laboratory of NOAA, Broadway, Boulder, CO 80303, USA. Tel: (+1-303) 497 54 85, Telefax: (+1-303) 497 5373.

Zavarzin, Dr. George A. Institute of Microbiology, USSR Academy of Sciences, Prosp. 60 - letija Octjabrja 7, Moscow 117812, USSR. Telex: 411 634 INMAN.

CP 2: Coordinating Panel on Marine Biosphere-Atmosphere Interactions

Nemoto, Prof. Takahisa. Ocean Research Institute, University of Tokyo, 1-15-1 Minamidai, Nakano -ku, Tokyo 164, Japan. Tel: (+81-3) 376 12 51, Telex: (72) 25607 ORIUT J, Telefax: (+81-3) 375 67 16, Telemail: ORI.TOKYO (Omnet). *Chairman (Member SC-IGBP).*

Abbott, Dr. Mark. College of Oceanography, Oregon State University, Oceanography Admin. Bldg. 104, Corvallis, Oregon 97331-5503, USA. Telemail: M.Abbott (Omnet).

Bolin, Prof. Bert. *(Corresponding Member, Member SC-IGBP)* (see CP 5)

Harris, Dr. Graham P. CSIRO Office of Space and Science Applications, Industry House, National Circut, Dickson, ACT 2602, Australia. Tel: (+61-62) 70 18 11, Telex: 61371 AA, Telefax: (+61-62) 73 39 58, Telemail: G.Harris (Omnet).
Holligan, Dr. Patrick. Plymouth Marine Laboratory, Prospect Place, West Hoe, Plymouth PL1 3DH, UK. Tel: (+44-752) 22 27 72, Telefax: (+44-752) 67 06 37.
Liss, Dr. Peter. University of East Anglia, School of Environmental Sciences, Norwich NR4 7TJ, UK. Tel: (+44-603) 56 161, Telex: 975197, Telefax: (+44-603) 507 719.
Laserre, Dr. Pierre. Directeur de la Station Marine de Roscoff, Place Georges Teissier, F-29211, Roscoff, France. Tel: (+33) 98 69 72 30, Telex: 940374, Telefax: (+33) 98 61 26 55.
Shannon, Dr. L. Vere. Director, Sea Fisheries Research Institute, Private Bag X2, Rogge Bay, Cape Town 8012, South Africa. Tel: (+27-21) 25 39 00; 25 29 20, Telex: 5-20796.
Tsunogai, Prof. Shizuo. Department of Chemistry, Faculty of Fisheries, Hokkaido University, Minatomachi 3-1-1, Hakodate 041, Japan. Tel: (+81-138) 53 27 98.
Vinogradov, Prof. M. Academy of Sciences of the USSR, 1, Letnaya (Ljublina), Moskva 109387, USSR. Tel: (+7-095) 124 61 49, Telex: 411968 Okean SU.
Woods, Dr. John. Natural Environment Research Council, Marine Sciences Directorate, Polaris House, Swindon, Wiltshire SN1 1EU, UK. Tel: (+44-793) 41 15 01, Telex: (51) 444293 ENVRE G, Telefax: (+44-793) 41 15 01, Telemail: J.Woods/Science. *(Member SC-IGBP)*
Zeitzschel, Prof. Bernt. Institut für Meereskunde, Universität Kiel, Düsternbrooker Weg 20, D-2300 Kiel, Federal Republic of Germany. Tel: (+49-431) 597 38 60, Telex: 0292619, JFMK D, Telefax: (+49-431) 565 876, Telemail: B.Zeitzschel (Omnet). *(JGOFS, ex officio)*

CP 3: Coordinating Panel on Biospheric Aspects of the Hydrological Cycle

Dyck, Professor Siegfried. Division of Hydrology and Meteorology, Dresden Technical University, Mommsenstrasse 13, DDR-8027 Dresden, German Democratic Republic. Tel: (+37-51) 463 39 31, Telex: (69) 2278MZ TEUNI DD. *Chairman (Member SC-IGBP)*
André, Dr. Jean-Claude. Direction de la Météorologie Nationale, Etablissement d'Etudes et de Recherches de la Météorologie, Centre National de Recherche Météorologique, 42, avenue G. Coriolis, F-31057 Toulouse Cedex, France. Tel: (+33-61) 07 90 90, Telex: 521 990 f (MTOJD), Telefax: (+33-61) 07 96 00, Telemail: J.Andre (Omnet).
Bolle, Prof. Hans-Jürgen. Institut fr Meteorologie, Freie Universität Berlin, Dietrich-Schäfer-Weg 6-10, D-1000 Berlin 41, Federal Republic of Germany. Tel: (+49-30) 838 39 61, Telex: (2627) 308740 FUSAT, Telefax: (+49-30) 791 90 02.
Chahine, Dr. Moustafa. Jet Propulsion Laboratory, Mail Stop 180-904, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA. Tel: (+1-818) 354 60 57, Telex: 675429, Telefax: (+1-818) 354 31 22, Telemail: M.Chahine (Omnet).
Dickinson, Dr. Robert. National Centre for Atmospheric Research, PO Box 3000, Boulder, CO 80307, USA. Tel: (+1-303) 497 89 98, Telex: 258 658 IAMP U12, Telemail: R.Dickinson (Omnet).
Farquhar, Dr. Grahame. Research School of Biological Sciences, Australian National University, PO Box 4, Canberra, ACT 2601, Australia. Tel: (+61-62) 49 37 43, Telex: 62219, Telefax: (+61-62) 48 99 95.
Harrison, Dr. Sandy. Department of Physical Geography, Uppsala University, Box 554, S-751 22, Uppsala, Sweden. Tel: (+46-18) 18 25 00.
Khublaryan, Prof. M. G. Institute of Water Problems, USSR Academy of Sciences, Sadovo-Chernogryazskaya str. 13/3, Moscow 103064, USSR. Tel: 208 45 64, Telex: 411478 sgc su (to: s.ferronsky).
Kienitz, Dr. Gabor. Director, Budapest Postgraduate Unesco Course, VITUKI Research Centre for Water Resources Development, Kvassay Jenoe ut. 1, 27, H-1453 Budapest 92, Hungary.
Körner, Prof. Christian. Botanisches Institut, Universität Basel, Schönbeinstrasse 1, CH-4056 Basel, Switzerland. Tel: (+41-61) 29 35 10/29 35 00, Telefax: (+41-61) 29 35 04, Telemail: C.Korner (Omnet).
Molion, Prof. Luiz C. Instituto de Pesquisas Espaciaias, Caixa Postal 515, 12201 São José dos Campos, SP, Brazil. Tel: (+55-123) 22 99 77, Telex: (38) 3530 INPE BR, Telefax: (+55-123) 21 87 43, Telemail: Inpe.met (Omnet).
Running, Dr. Stephen W. School of Forestry, University of Montana, Missoula, MT 59812, USA. Tel: (+1-406) 243 63 11, Telefax: (+1-406) 243 45 10, Telemail: [s.running/nasa] nasa.mail/usa.
Targulian, Prof. Victor. IIASA, Schlossplatz 1, A-2361 Laxenburg, Austria. Tel: (+43-2236) 71 52 10, Telex: 079137 IIASA A, Telefax: (+43-2236) 71 3 13.

CP 3: Joint IGBP/WCRP Working Group on Land-Surface Experiments

André, Dr. Jean-Claude. *Chairman.* (see CP 3)
Bolle, Dr. Hans-Jürgen. (see CP 3)
Jarvis, Dr. Paul. Department of Forestry and Natural Resources, Darwin Building, Mayfield Road, Edinburgh EH9 3JU, UK. Telefax: (+44-31) 668 38 70.
Molion, Dr. Luiz. (see CP 3)
Running, Dr. Stephen. (see CP 3)
Sellers, Dr. Piers. Corresponding Member. (see CP 4)
Shuttleworth, Dr. W. J. Institute of Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, UK. Tel: (+44-491) 388 00, Telefax: (+44-491) 380 97.

CP 4: Coordinating Panel on Effects of Climate Change on Terrestrial Ecosystems.

Walker, Dr. Brian H. Division of Wildlife and Ecology, CSIRO, PO Box 84, Lyneham, ACT 2602, Australia. Tel: (+61-62) 42 17 42; 42 17 73, Telex: (71) 62284 WLR AA, Telefax: (+61-62) 41 1742. Telemail: B.Walker (Omnet). *Chairman. (Member SC-IGBP)*
Fu, Prof. Congbin. Institute of Atmospheric Physics, Academia Sinica, Beijing 100011, China. Tel: (+86-1) 256 24 58, Telex: (850) 22474 ASCHI CN, Telefax: (+86-1) 801 10 95 Attn: Fu Congbin.
MacMahon, Dr. J. Department of Biology, Utah State University, Logan, UT 84322, USA. Tel: (+1-801) 750 24 85, Telefax: (+1-801) 750 15 75.
Nix, Prof. Henry. Centre for Resource & Environmental Studies, A.N.U., PO Box 4, Canberra, ACT 2600, Australia. Tel: (+61-62) 49 42 77/49 45 88, Telex: NATUNI AA 62760, Telefax: (+61-62) 49 07 57.
Prentice, Dr. Colin. Department of Ecological Botany, Uppsala University, Box 559, S-751 22 Uppsala, Sweden. Tel: (+46-18) 18 28 56 / (+46-293) 512 13, Telemail: Colin@PAX.UU.SE.
Reiners, Prof. William A. Department of Botany, University of Wyoming, Aven Nelson Building, Laramie, Wyoming 82071, USA. Tel: (+1-307) 766 23 60, Telefax: (+1-307) 766 22 71. Telemail: W.Reiners (Omnet).
Sellers, Dr. Piers. NASA/GSFC, Code 624, Hydrological Sciences Branch, Greenbelt, MD 20771 USA. Tel: (+1-301) 286 41 73, Telefax: (+1-301) 286 92 00.
Steward, Prof. John W. B. Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, S7N OWO Canada. Tel: (1-306) 966 6827, Telemail: [jwbstewart/USDA] TM11/USA Attn: Holm Tiessen.
Shugart, Dr. H. H. Department of Environmental Sciences, University of Virginia, Clark Hall, Charlottesville, VA 22903, USA. Tel: (+1-804) 924 76 42, Telefax: (+1-804) 982 21 37.
Tiessen, Dr. Holm. Institute of Pedology, University of Saskatchewan, Saskatoon S7N 0W0 Canada. Tel: (+1-306) 966 68 41, Telex: 0742659 UOGSASK, Telemail: [jwbstewart/USDA] TM11/USA Attn: Holm Tiessen.
Uchijima, Dr. Zenbei. Faculty of Science, Ochanomizu University, Otsuka 2-1-1,

Bunkyoku, Tokyo 112, Japan. Tel: (+81-3) 943 31 51.
Vitousek, Prof. Peter M. Department of Biological Sciences, Stanford University, Stanford, CA 943015, USA. Tel: (+1-415) 725 18 66, Telefax: (+1-415) 723 92 53.
Woodward, Dr. Ian. University of Cambridge, Department of Botany, Botany School, Downing Street, Cambridge CB2 3EA, UK. Tel: (+44-223) 33 39 00, Telefax: (+44-223) 33 39 53.
Zlotin, Dr. R. Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109017, USSR. Telex: 411478 SGC SU.

CP 5: Coordinating Panel on Global Analysis, Interpretation and Modelling.

Bolin, Prof. Bert. Department of Meteorology, Stockholm University, S-106 91 Stockholm, Sweden. Tel: (+46-8) 16 20 00 (exch.), 15 77 31 (direct), 16 26 64 (secr.) 753 12 28 (home) Telex: 15959 MISU S, Telefax (+46-8) 15 71 85, Telemail: MISU.IMI (Omnet). Chairman *(Member SC-IGBP)*
Bretherton, Dr. Francis P. Space Science and Engineering Center, University of Wisconsin, 1225 West Dayton Street, Madison, WI 53706, USA. Tel: (+1-608) 266 74 97, Telex: 265452, UNOFWISC MDS, Telefax: (+1-608) 262 59 74, Telemail: F.Bretherton (Omnet).
Crutzen, Dr. Paul J. (see CP 1)
Dickinson, Dr. Robert. (see CP 3)
Fung, Dr. Inez. NASA Goddard Space Flight Center, Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA. Tel: (+1-212) 678 55 90, Telefax: (+1-212) 678 55 52, Telemail: [IFUNG/NASA] NASAMAIL/USA. *(Corresponding Member)*
Hasselmann, Dr. Klaus. Max-Planck-Institute for Meteorology, Bundesstrasse 55, D-2000 Hamburg 13, Federal Republic of Germany. Tel: (+49-40) 41 17 30, Telex: 221092 MPIMED, Telefax: (+49-40) 41 17 32 89, Telemail: mp1.meteorology (Omnet).
Kondratyev, Academician K. Ya. Counsellor of Directorate Institute for Lake Research, USSR Academy of Sciences, Sevastyanov Street 9, Leningrad 196199, USSR.
Kutzbach, Prof. John E. Center for Climatic Research, University of Wisconsin, 1225 West Dayton Street, 1135 Meteorology and Space Science, Madison, WI 53706, USA. Telemail: J.Kutzbach (Omnet).
Nobre, Dr. Carlos A. INPE, Caixa Postal 515, 12201 São José dos Campos, SP, Brazil. Tel: (+55-123) 22 99 77, Telex: (38) 3530 INPE BR, Telefax: (+55-123) 21 87 43, Telemail: inpe.met (Omnet).
Pearman, Dr. Graeme. CSIRO, Division of Atmospheric Research, Private Bag 1, Mordialloc, VIC 3195, Australia. Tel: (+61-3) 586 76 66, Telex: 344 63 AA, Telefax: (+61-3) 586 76 00, Telemail: G.Pearman (Omnet).
Prather, Dr. Michael. NASA Goddard Space Flight Center, Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA. Tel: (+1-212) 678 55 90, Telefax: (+1-212) 678 55 Telemail: [ifung/nasa] nasamail/usa - Attn: michael prather.
Schimel, Dr. David S. Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523, USA. Tel: (+1-303) 491 19 78, Telefax: (+1-303) 491 19 65, Telemail: [d.schimel/usa] tm11/usa.
Sellers, Dr. Piers. (see CP 4)
Siegenthaler, Dr. Uli. Physikalisches Institut, Universität Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland. Tel: (+41-31) 65 44 71, Telefax: (41-31) 65 44 05.
Woods, Dr. John D. (see CP 2)

WG 1: Working Group on Data and Infromation Systems

Rasool, Dr. S. Ichtiaque. Office of Space Science and Applications, Code E, NASA, Washington, DC 20546, USA. Tel: (+1-202) 453 14 20, Telex: (23) 4979843 NASA WSH, Telefax: (+1-202) 755 92 34, 755 92 35, Telemail: I.Rasool (Omnet). Chairman *(Member SC-IGBP)*

Becker, Dr. Franois. Université Louis Pasteur, Ecole Nationale Superieure de Physique, 7 rue de l'Université, F-6700 Strasbourg, France. Tel: (+33-88) 355 150, Telefax: (+33-88) 607 550.
Boldirev, Dr. V. WMO, World Climate Programme Office, CP 5, CH-1211 Geneva, Switzerland. Tel: (+41-22) 34 64 00, Telex: 23260. *(Liaison member with WMO)*
Cihlar, Dr. Josef. Application Development Section, Canada Centre for Remote Sensing, 2464 Sheffield Road, Ottawa, Ontario K1A OY7, Canada. Tel: (+1-613) 952 27 34, Telefax: (+1-613) 952 73 53, Telemail: [cihlar@ccrs.cdn].
Croze, Dr. Harvey. UNEP, PO Box 30552, Nairobi, Kenya. Tel: (+254-2) 33 39 30, Telex: 22068/22173, Telemail: H.Croze (Omnet).
da Cunha, Dr. Roberto Pereira. Director of Remote Sensing, INPE, Brazilian Institute of Space Research, PO Box 515, 12201 São José dos Campos - SP, Brazil. Tel: (+55-123) 22 99 77, Telex: (38) 3530 INPE BR, Telefax: (+55-123) 21 87 43, Telemail: inpe.met (Omnet) Attn: Roberto da Cunha.
Kullenberg, Dr. Gunnar. IOC, Unesco, 7, place de Fontenoy, F-75700 Paris, France. Tel: (+33-1) 45 68 39 83, Telefax: (+33-1) 40 65 98 97. *(Liaison member with Unesco)*
Ruttenberg, Dr. Stan. University Corporation for Atmospheric Research (UCAR), PO Box 3000, Boulder, CO 80307, USA. Tel: (+1-303) 497 89 98, Telex: 258 658 IAMP, Telemail: S.Ruttenberg (Omnet) stan@sh.cs.net.arpa
Skole, Dr. David. Institute for the Study of Earth, Oceans and Space, Science and Engineering Building, University of New Hampshire, Durham, NH 03824, USA. Tel: (+1-603) 862 17 92, Telefax: (+1-603) 862 19 15, Telemail: D.Skole (Omnet).
Sombroek, Dr. Wim. International Soil Reference and Information Centre (ISRIC), PO Box 353, 6700 AJ Wageningen, The Netherlands. Tel: (+31-8370) 190 63, Telex: 45888 intus-nl, Telefax: (+31- 8370) 244 60.
Viskov, Dr. Volodya. Academy of Sciences of the USSR, Soviet Geophysical Committee, Molodezhnaya 3, Moscow GSP-1, 117296, USSR.
Withee, Dr. Gregory. NOAA/NESDIS/NODC, 1825 Connecticut Avenue, NW, Washington, DC 20235, USA. Tel: (+1-202) 673 55 94, Telefax: (+1-202) 673 55 86.

WG 2: Working Group on Reginal Research Centres

Herrera, Prof. Rafael. Centre for Ecology and Environmental Sciences, IVIC, Apartado 21827, Caracas 1020A, Venezuela. Tel: (+58-2) 69 19 49, Telex: (31) 21657 IVICB VC, Telefax: (+58-2) 571 31 43. Chairman *(Member SC-IGBP)*
Diop, Dr. E. S. UNESCO/BREDA, PO Box 3311, Dakar, Senegal. Tel: (+221) 23 87 17/23 46 14, Telex: (906) 21735, 51410 UNESCO SG. *(Member SC-IGBP)*
Fyfe, Prof. William S. Dean of Science, University of Western Ontario, London, Ontario N6A 5B7, Canada. Tel: (+1-519) 661 30 41, Telex: (21) 0647134 UWO LIB LDN, Telefax: (+1-519) 661 32 92. *(Member SC-IGBP)*
Kotlyakov, Prof. Vladimir M. Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109017, USSR. Tel: (+8-095) 238 86 10, Telex: (64) 411478 SGC SU, Telefax: (+7- 095) 230 30 90. *(Member SC-IGBP)*

SSC: Scientific Steering Committee on Global Changes of the Past

Oeschger, Prof. Hans. Institute of Physics, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland, Tel: (+41-31) 65 44 62, Telex: (45) 912643 PIBE CH, Telefax: (+41-31) 65 44 05, Telemail: via A.Arquit (Omnet). Chairman *(Member SC-IGBP)*
Eddy, Dr. John A. Office for Interdisciplinary Earth Studies, UCAR, PO Box 3000, Boulder, CO 80307, USA. Tel: (+1-303) 497 16 80, Telex: (230) 989764 NCAR BDR UD, Telefax: (+1-303) 497 16 79, Telemail: J.Eddy (Omnet). Co-Chairman *(Member SC-IGBP)*
Berger, Dr. A. L. Institute of Astronomy and Geophysics, 2 Chemin du Cyclotron,

B-1348 Louvain-la-Neuve, Belgium. Tel: (+32-10) 43 33 03, Telex: 59065 IPLB.

Berglund, Prof. Björn. Department of Quaternary Geology, Lund University, Tornavägen 13, S-223 63 Lund, Sweden. Tel: (+46-46) 10 78 86, Telefax: (+46-46) 10 48 30.

Frenzel, Dr. Burkhard. Universität Hohenheim, Institut für Botanik -210-, Garbenstrasse 30, D-7000 Stuttgart 70, Federal Republic of Germany.

Hammen, Prof. Thomas van der. Hugo de Vries Laboratorium, Vakgroep Bijzondere Plantkunde, Kruislaan 318, NL-1089 SM Amsterdam, The Netherlands. Tel: (+31-20) 525, Telex: 16460 facwn.nl.

Imbrie, Dr. John. Department of Geological Sciences, Brown University, Providence, RI 02912-1846, USA. Tel: (+1-401) 863 31 96.

Liu, Dr. Tungshen. Institute of Geology, Academia Sinica, PO Box 634, Beijing 100011, China. Tel: (+86-1) 401 40 31.

Lorius, Dr. Claude. Laboratoire de Glaciologie et Géophysique de l'Environnement, BP 96, F-38402 Saint-Martin-d'Hères Cédex, France. Tel: (+33-76) 42 58 72, Telex: 80131 lgge, Telefax: (+33-76) 51 32 48.

Pfister, Dr. Christian. Historisches Institut, Universität Bern, Engehaldenstrasse 4, CH-3012 Bern, Switzerland. Tel: (+41-31) 65 83 84.

Rutter, Prof. Nat. Department of Geology, University of Alberta, 1-26 Earth Sciences Building, Edmonton, Alberta T6G 2E3, Canada. Tel: (+1-403) 492 3085, 3265, Telefax: (+1-403) 492 2030.

Schweingruber, Dr. Fritz. Eidg. Anstalt fr das forstliche Versuchswesen (EAFV), CH-8903 Birmensdorf, Switzerland. Tel: (+41-01) 739 21 11, Telex: 827203 eafv ch, Telefax: (+41-01) 739 22 15.

Shackleton, Dr. N. L. Sub-Department of Quaternary Research, The Godwin Laboratory, Free School Lane, Cambridge CB2 3RS, UK. Tel: (+44-223) 33 68 71, Telefax: (+44-223) 33 47 48.

Stuiver, Dr. Minzie. Quaternary Research Center, University of Washington, Seattle, WA 98195 USA. Tel: (+1-206) 545 17 35.

Velitchko, Dr. A. A. Department of Palaeogeography, Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109017, USSR. Tel: (+70-95) 238 86 10, Telex: (64) 411478 SGC SU.

Liaison Persons for the IGBP from ICSU Scientific Members — Appendix 4

CASAFA	Dr. F. W. G. Baker, Scientific Secretary, CASAFA, Lacombe de Sauve, F-26110 Venterol, France.
CODATA	Mrs. P. Glaeser, Executive Secretary, CODATA, 51 Boulevard de Montmorency, F-75016 Paris, France.
COSPAR	Prof. G. Ohring, Chief, Satellite Research Laboratory, National Oceanic and Atmospheric Administration, NESDIS (E/RAI), World Weather Building, Room 712, 5200 Auth Road, Camp Springs, Washington, DC 20233, USA.
IGU	Prof. V. M. Kotlyakov, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109017, USSR.
IMU	Dr. J.-L. Lions, International Mathematical Union, C.N.E.S., 2, Place Maurice Quentin, F-75039 Paris Cedex 01, France.
ISSS	Dr. H.-W. Scharpenseel, Institute für Bodenkunde, Universität Hamburg, Allende-Platz 2, D-2000 Hamburg 13, FRG.
IUB	Dr. H. Kornberg, President Elect, IUB, Department of Biochemistry, University of Cambridge, Tennis Court Road, Cambridge CB2 1QW, UK.
IUFRO	Dr. E. Tessier du Cros, Institut National de la Recherche Agronomique, Departement des Recherches Forrestières, F-45160 Ardon, France.
IUGG	Prof. J. C. I. Dooge, Belgrave Road, Monksdown, Co. Dublin, Republic of Ireland.
IUGS	Dr. K. Hsü, Geological Institute, ETH, Sonneggstrasse 5, CH-8006 Zürich, Switzerland.
IUHPS	Prof. B. Hansson, Filosofiska Instutionen, Kungshuset i Lundgård, S-223 50 Lund, Sweden.
IUPAC	Dr. M. Williams, Executive Secretary, IUPAC, 2-3 Pound Way, Cowley Centre, Oxford OX4 3YF, UK.
IUPHAR	Dr. K. J. Netter, Institut für Pharmakologie der Universität Fachbereich Humanmedizin, D-3500 Marburg, FRG.
IUPsyS	Dr. K Pawlik, Secretary General, IUPsyS, University of Hamburg, Von-Melle-Park 11, D-2000 Hamburg 13, FRG.
SCOPE	Dr. F. di Castri, President, SCOPE, C.N.R.S., Centre d'Etudes Phytosociologiques et Ecologiques Louis Emberger, Route de Mende, BP 5051, F-34033 Montpellier, France.
SCOR	Dr. E. Tidmarsh, Executive Secretary, Scientific Committee on Oceanic Research, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia B3H 4J, Canada.
SCOSTEP	Dr. J. G. Roederer, Chairman, SCOSTEP, Geophysical Institute, University of Alaska, Fairbanks, AK 99775-0800, USA.
TWAS	Dr. C. Ponnamperuma, Institute of Fundamental Studies, 380/72 Bauddhaloka Mawatha, Colombo 7, Sri Lanka.
URSI	Prof. Dr. G. Brussaard, Eindhoven University of Technology, Faculty of Electrical Engineering, EH 12.33, PO Box 513, NL-5600 MB Eindhoven, The Netherlands.

Chairmen of National Committees for the IGBP **Appendix 5**

Argentina	Dr. M. N. Nuñes, Co-Chairman, National Committee for the IGBP, Departamento de Meteorologia, Universidad de Buenos Aires, Pabellon 2 - Ciudad Universitaria, Buenos Aires 1428. Tel:(+54-1) 782 65 28, Telex: (33) 18694 IBUBA AR, Fax:(+54-1) 311 05 16.
	Dr. O. E. Sala, Co-Chairman, National Committee for the IGBP, Departamento de Ecologia, Universidat de Buenos Aires, Facultad de Agronomia, Av. San Martin 4453, Buenos Aires 1417. Tel:(+54-1) 52 09 03, Fax: (+54-1) 34 54 37, E-mail: DELPHI USERNAME SALA.
Australia	Prof. B. G. Thom, Acting Chairman, National Committee for the IGBP, Department of Geography, Institute Building HO 3, University of Sidney, Sidney, New South Wales. Tel:(+61-2) 692 2886, Fax: (+61-2) 692 3644.
Austria	Prof. S. J. Bauer, Chairman, Ad hoc National Committee for the IGBP, Institut für Meteorologie und Geophysik, Universität Graz, Halbärthgasse 1, A-8010 Graz. Tel:(+43-316) 380 52 56/55/61, Telex:(47) 31662 UBGRAZ A, Fax:(+43-316) 355 66.
Bangladesh	Dr. S. D. Chaudhuri, Chairman, National Committee for the IGBP, Bangladesh Academy of Sciences, 3/8 Asad Avenue, Muhammadpur, Dhaka 1207. Tel:(+880-2) 31 04 25/60 68 68, Telex: (780) 64 22144 SRSBJ.
Belgium	Dr. O. Vanderborcht, Chairman, National Committee for the IGBP, Study Centre for Atomic Energy/UIA, Kraaibossen 24, B-2440 Geel. Tel: (+32-14) 31 18 01. Telefax: (+32-14) 31 50 21.
Bolivia	Dr. J. Argollo, Chairman, *ad hoc* National Committee for the IGBP, Facultad de Ciencias Geológicas, Universidad Mayor de San Andrés, Casilla de Correo 355, La Paz. Tel:(+591-2) 37 44 64, Telex:(355) 3438 UMSA BU; 3514 ORSTOM BU, Telefax:(+591-2) 35 94 91.
Brazil	Prof. A. Azevedo Pacheco Leão, Chairman, National Committee for the IGBP, Academia Brasileira de Ciencias, Cx. Postal 229, Rua Alfilófio de Carvalho 29. 3o, Rio de Janeiro 20000. Tel:(+55-21) 220 47 94/220 57 94.
Canada	Prof. W. R. Peltier, Chairman, National Committee for the IGBP, Department of Physics, University of Toronto, Toronto, Ontario M5S 1A. Tel:(+1-416) 978 29 38, Fax:(+1-416) 978 89 05, Telemail: (bitnet) PELT @ ATMOSP.PHYSICS.UTORONTO.EDU.
Chile	Prof. H. A. Fuenzalida, Chairman, National Committee for the IGBP, Departamento de Geofisica, Universidad de Chile, Casilla 2777, Santiago de Chile. Tel:(+56-2) 696 87 90, Telex: (34) 243302 INGEN CL, Fax: (+56-2) 71 27 99.
China (CAST)	Professor Duzheng Ye, Chairman, IGBP Committee, Chinese Academy of Sciences, 52, Sanlihe Road, Beijing. Tel: (+86-1) 86 83 61, ext. 843, Telex: (850) 22474 ASCHI CN, Fax: (+86-1) 801 10 95.

China (Academy in Taipei)	Professor Jong-Ching Su, Chairman, IGBP Committee, Department of Agricultural Chemistry, National Taiwan University, Taipei, Taiwan 10764. Tel: (+886-2) 363 17 44 (fax mode in off-office hours), Telex: (859) 28164 ROCNSC, Fax: (+886-2) 737 76 07.
Colombia	Dr. J. Carrizosa Umaña, Chairman, National Committee for the IGBP, Apartado 60.076, Calle 10 no. 1-87, Bogota DE, Tel: (+57-1) 241 19 22, Fax: (+57-1) 283 85 52.
Czechoslovakia	Prof. V. Bucha, Chairman, National Committee for the IGBP, Vice- President, Czechoslovak Academy of Sciences, Národni tr. 3, 111 42 Praha 1. Tel: (+42-2) 26 66 71, Telex: (66) 121040 AKAD CS.
Denmark	Dr. C. Hammer, Chairman, National Committee for the IGBP, Geofysisk Institut, Haraldsgade 6, D-2200 Copenhagen. Tel: (+45) 31 83 39 92, Fax: (+45) 31 82 25 65.
Egypt	Prof. M. A. Ayyad, Chairman, National Committee for the IGBP, Botany Department, Faculty of Science, University of Alexandria, Moharran Bey, Alexandria.
Finland	Prof. E. Leppäkoski, Chairman, National Committee for the IGBP, Åbo Akademi University, Department of Biology, SF-20500 TURKU, Tel: (+358-21) 65 43 55, Telex: (57) 62301 AABIB SF, Fax: (+358-21) 65 47 48.
France	Dr. J.-C. Duplessy, Chairman, National Committee for the IGBP, CNRS Centre des Faibles Radioactivités, Avenue de la Terrasse, F- 91190 Gif-sur-Yvette. Tel: (+33-1) 69 82 35 86, Telex: (42) 214627 F, Fax: (+33-1) 69 82 35 68.
German Democratic Republic	Prof. S. Dyck, Chairman, National Committee for the IGBP, Division of Hydrology and Meteorology, Dresden Technical University, Mommsenstrasse 13, DDR-8027 Dresden. Tel: (+37-51) 463 39 31, Telex: (69) 2278MZ TEUNI DD.
Federal Republic of Germany	Prof. H.-J. Bolle, Chairman, National Committee for the IGBP, Institut für Meteorologie, Freie Universität Berlin, Dietrich-Schäfer- Weg 6-10, D-1000 Berlin 41. Tel: (49-30) 838 39 61, Telex: (41) 183 188 FUMET D, Fax: (+49-30) 791 90 02.
Greece	Prof. J. Xanthakis, Chairman, National Committee for the IGBP, Research Center for Astronomy and Applied Mathematics, Academy of Athens, 14, Anagnostopoulou Street, GR-10673 Athens. Tel: (+30-1) 361 35 89.
Hungary	Prof. J. Tigyi, Chairman, National Committee for the IGBP, Biophysical Institute of the Medical University, PO Box 99, H-7643 Pécs. Tel: (+36-72) 14 017, Telex: (61) 12500 POTE H, Fax: (+36-72) 262 44.
India	Prof. R. R. Daniel, Chairman, National Committee for the IGBP, COSTED, Asia Regional Office, 24, Gandhi Mandap Road, Guindy, Madras 600 025. Tel: (+91-44) 41 94 66, Telex: (81) 41 210 14 CLRI IN, Fax: (+91-44) 94 44 44.
Ireland	Prof. G. F. Imbusch, Chairman, National Committee for the IGBP, Science Secretary, Royal Irish Academy, 19 Dawson Street, Dublin 2. Tel: (+353-1) 762 570, 764 222, Fax: (+353-1) 762 346.

Israel	Prof. D. H. Yaalon, Chairman, National Committee for the IGBP, Institute of Earth Sciences, Hebrew University of Jerusalem, Givat Ram Campus, Jerusalem 91904. Tel: (+972-2) 58 42 48/58 46 86, Telex: (606) 2539 HU IL, Fax:(+972-2) 66 68 04.
Jamaica	Dr. G. V. Taylor, Chairman, National Committee for the iGBP, Executive Director, Scientific Research Council, PO Box 350, Kingston, Tel: (+1-809) 927 17 71/4 or 927 19 12, Telex: (291) 3631 SRCSTIN JA, Fax: (+1-809) 927 54 37.
Japan	Prof. Yasuyki Oshima, Chairman, National Committee for the IGBP, Department of Basic Human Science, School of Human Sciences, Waseda University, Mikajima 2-579-15, Tokorozawa, Saitama 359, Tel: (+81-3) 203 41 41, ext. 76-3535, Telex:(72) 1212180 J WASEDA, Fax: (+81) 429 48 43.
Kenya	Prof. S. O. Wandiga, Deputy Vice Chancellor (A & F), University of Nairobi, PO Box 30197, Nairobi, Tel:(+254-2) 33 61 09, Telex: (987) 22095 KE, Fax: (+254-2) 33 68 85.
The Netherlands	Prof. H. Postma, Chairman, Dutch MAB/SCOPE/IGBP Committee, K.N.A.W., Kloveniersburgwal 29, NL-1011 JV Amsterdam, Tel: (+31-20) 22 29 02, Fax: (+31-20) 20 49 41.
New Zealand	Professor J. Soons, Convener, National Committee for the IGBP, Royal Society of New Zealand, PO Box 598, Wellington. Tel: (+64-4) 72 74 21, Cable: Royal Soc., Fax: (+64-4) 73 18 41.
Norway	Prof. I. S. A. Isaksen, Chairman, National Committee for the IGBP, Institute of Geophysics, University of Oslo, PO Box 1022 Blindern, N- 0315 Oslo 3. Tel: (+47-2) 45 58 22, Fax: (+47-2) 45 43 74.
Peru	Dr. A. A. Giesecke M., Chirman, National *ad hoc* Committee for the IGBP, Director, Centro Regional de Sismología, Apartado 14-0363, Lima. Tel: (+51-14) 24 74 21, Telex: (36) 20053 PE PB LIMTC, Fax: (+51-14) 31 92 66.
Poland	Academician Prof. L. Starkel, Chairman, National Committee for the IGBP, Polish Academy of Sciences, Palac Kultury i Nauki, Pok 2603, PL-00-901 Warszawa. Tel: (+48-2) 22 40 85, Telex: (63) 815414.
South Africa	Prof. P. Tyson, Chairman, National Committee for the IGBP, Deputy Vice-Chancellor, University of the Witwatersrand, Wits 2050. Tel: (+27- 21) 716 34 00, Telex: (95) 4-50937 VCWITS, Fax: (+27-11) 339 82 15.
Sweden	Prof. B. Bolin, Chairman, National Committee for the IGBP, Department of Meteorology, University of Stockholm, S-106 91 Stockholm. Tel: (+46-8) 16 20 00, direct 15 77 31, Fax: (+46-8) 15 71 85.
Switzerland	Prof. H. R. Thierstein, Chairman, National Committee for the IGBP, Geologisches Institut, ETH-Zentrum, CH-8092 Zürich. Tel: (+41-1) 256 36 66, Telex: (48) 817379 EHHG CH, Fax: (+41-1) 252 70 08.
Sri Lanka	Prof. I. Balasooriya, National Committee for the IGBP,

	Central Environmental Authority, PO Box 2205, Parisara Mawatha, Maligawate New Town, Colombo 10, Tel: (+94-1) 54 67 49.
Thailand	Dr. T. Piyakanchana, National Committee for IGBP, c/o Research Project and Coordination Division, National Research Council of Thailand, 196 Phahonyothin Road, Bangkhen, Bangkok 10900. Tel: (+66-2) 579 13 77/9, ext 439; 579 22 84, Telex: (86) 82213 NARECOU TH, Fax: (+66-2) 579 34 92.
United Kingdom	Prof. P. Liss, Chairman, National Committee for the IGBP, c/o The Executive Secretary, The Royal Society, 6 Carlton House Terrace, London SW1Y 5AG, Tel: (+44-1) 839 55 61, Telex: (51) 917 876, Fax: (+44-1) 930 21 70.
USA	Prof. H. A. Mooney, Chairman, National Committee for the IGBP, Department of Biological Sciences, Stanford University, Stanford, CA 94305. Tel: (+1-415) 723 11 79, Telex: (23) 348402 STANFRD STNU, Fax: (+1-719) 576 47 11, E-mail: H.Mooney (Omnet).
USSR	Academician Prof. G. I. Marchuk, Chairman, National Committee for the IGPB, Academy of Sciences of the USSR, Leninsky Prospekt 14, 117901 Moskva B-71, Tel: (+7-095) 232 29 10, Telex: (64) 411964 ANS SU, Fax: (+7-095) 230 27 41.
Venezuela	Prof. F. Pannier, Chairman, National Committee for the IGBP, Academia de Ciencias Físicas, Matematicas y Naturales, Apartado 1421, Caracas 1010A, Tel: (+58-2) 41 66 11/483 41 33, Telex: (31) 25205 CNIT VC.
Zimbabwe	Dr. G. R. Chimonyo, Chairman, National Committee for IGBP, Department of Geography, University of Zimbabwe, PO Box MP 167, Mount Pleasant, Harare, Tel: (+263-4) 30 32 21, ext. 1265, Telex: (907) 26580 UNIVZ ZW, Fax: (+263-4) 30 32 92.

List of IGBP Meetings and Participants 1987-1990 — Appendix 6

Special Committee for the IGBP (SC-IGBP)

1st SC-IGBP	Paris (France) 16-19 July, 1987
2nd SC-IGBP	Cambridge, MA (USA) 8-11 February, 1988
3rd SC-IGBP	Stockholm (Sweden) 23, 29-30 October, 1988
4th SC-IGBP	Brussels (Belgium) 13-16 June, 1989
5th SC-IGBP	Berlin (West) 6-11 November, 1989
6th SC-IGBP	Moscow (USSR) 21-24 March, 1990

Executive Committee for the IGBP (EC-IGBP)

1st EC-IGBP	Cambridge, MA (USA) 4-5 December, 1987
2nd EC-IGBP	Budapest (Hungary) 4-5 June, 1988
3rd EC-IGBP	London (UK) 12-13 January, 1989
4th EC-IGBP	Lisbon (UK) 15 October, 1989

Interagency Coordinating Committee (ICC)

1st ICC	London (UK) 11 January, 1989
2nd ICC	Lisbon (Portugal) 14 October, 1989

Chairmen of National Committees for the IGBP

1st	Washington, D.C.(USA) 22-24 January, 1990

Strategy Planning

1st	Washington, D.C. (USA) 4-5 May, 1989
2nd	Lisbon (Portugal) 12-13 October, 1989

Regional Meetings for the IGBP

Southern Hemisphere	Swaziland, 11-16 December, 1988
South America	São José dos Campos (Brazil), 5-9 March, 1990
Africa (planning)	Lomé (Togo) 13-14 March, 1990

CP1: Terrestrial Biosphere-Atmospheric Chemistry Interactions

CP1	Snowmass (USA) 13-14, 20-21 August, 1988
IGAC	Dookie (Australia) 7-11 November, 1988
CP1	Mainz (FRG) 26 February-1 March, 1989
CP1	Woods Hole, Mass. (USA) 25-27 October, 1989
Joint CP1/SCOPE	Sigtuna (Sweden) 19-25 February, 1990

CP2: Marine Biosphere-Atmosphere Interactions

CP2	Tokyo (Japan) 19-21 September, 1989
JGOFS/IGAC	San Francisco (USA) 6 December, 1989 JGOFS
	London (UK) 12-13 March, 1990

CP3: Biospheric Aspects of the Hydrological Cycle

CP3	Cambridge (USA) 12-13 February, 1988
CP3	Potsdam (DDR) 7-9 June, 1988

Joint CP3/CP4/CP5/WG1	Brussels (Belgium) 7-12 June, 1989
CP3	Paris (France) 23-26 October, 1989
CP3/IGBP/IAHS/IHP	Vadstena (Sweden) 5-10 June, 1990

CP4: Effects of Climate Change on Terrestrial Ecosystems

CP4	Canberra (Australia) 29 February-2 March, 1988
CP4	Woods Hole, Mass. (USA) 15-17 April, 1989
Joint CP3/CP4/CP5/WG1	Brussels (Belgium) 7-12 June, 1989
CP4	Canberra (Australia) 29-31 August, 1989
CP4	Yaoundé (Cameroon) 27 November-1 December, 1989
CP4	Cambridge (UK) 2-4 February, 1990

CP5: Global Analysis, Interpretation and Modelling

Joint CP3/CP4/CP5/WG1	Brussels (Belgium) 7-12 June, 1989
CP5	Hinterzarten (FRG) 21-22 October, 1989

WG1: Data and Information Systems

WG1	Moscow (USSR) 9-13 August, 1988
WG1	Geneva (Switzerland) 11-13 January, 1989
WG1/IGBP Remote Sensing	Boston (USA 19-29 April, 1989
Joint CP3/CP4/CP5/WG1	Brussels (USA) 7-12 June, 1989
WG1	Washington (USA) 29 January-2 February, 1990

WG2: Regional Research Centres

WG2	Caracas (Venezuela) 2-4 May, 1988
WG2	New York (USA) 10-20 May, 1989
WG2/IISA/Unesco	Warsaw (Poland) 25-29 September, 1989

SSC: Global Changes of the Past

SSC	Bern (Switzerland) 6-8 July, 1988
SSC	Bern (Switzerland) 4-7 April, 1989
SSC	Villach (Austria), 23-26 January, 1990

Other IGBP Scientific Planning Meetings

Land-Ocean Interactions in the Coastal Zone	London (UK) 11-12 December, 1989
IGBP/WCRP Group on Land Surface Experiments	Wallingford (UK), 25-26 January, 1990

Meetings of the Editorial Committee for the SAC II Report

1st	Berlin (West), 5-7 February, 1990
2nd	Bålsta and Stockholm (Sweden) 17-21 April, 1990

Participants in IGBP Planning Meetings

Abbott, M., College of Oceanography, Oregon State University, Oceanography Administration Building 104, Corvallis, Oregon 97331-5503, USA.

Abid, G., WDC-A for R & S, Code 692, NASA CSFC, Greenbelt, MD 20771, USA. Abston, C. C., NOAA/NCDC, E/Gc, 325 Broadway, Boulder, CO 80303 USA.

Aceituno, P., Departamento Geologia y Geofisica, Facultad de Ciencias Fisicas y Matematicas, Blanco Encalada 2085, Casilla 2777, Santiago, Chile.

Acevedo, M., Escuela de Ingenieria de Sistemas, Universidad de los Andes, Apartado 72 Mérida 5101-A, Venezuela.

Affaton, P., Department of Geology, Faculty of Sciences, University of Benin, BP 30389, Lomé, Togo.

Agardy, T., Woods Hole Oceanographic Institite, Woods Hole, MA 02543, USA. Ainsworth, M., Plymouth Marine Laboratory, Prospect Place, West Hoe, Plymouth PL1 3DH, UK.

Akimoto, H., National Institute for Environmental Studies, 16-2 Ongawa, Tsukuba, Ibaraki 305, Japan.

Albritton, D. L., Aeronomy Laboratory, NOAA, 325 Broadway, Boulder, Colorado 80303, USA.

Allan, T. D., Space Department R.16 Bldg, Royal Aircraft Establishment, Farnborough, Hampshire GU14 6TD, UK.

Allard, B., Department of Water and Environmental Studies, Linkoping University, 581 83, Sweden. Allen, J.H., WDC-A for STP / NOAA, E/GC2, Boulder, CO 80303, USA.

Alperin, M., 12-5 Venable Hall, University of North Carolina, Chapel Hill, North Carolina 27599-3300, USA.

Ameho, M. E., SCAFT, BP 1284, Lomé, Togo. Andersen, V., Station Zoologique, BP 28 La Darse, F-06230 Villefranche-sur-Mer, France.

Anderson, J. M., Department of Biological Sciences, Prince of Wales Road, Hatherley Laboratories, University of Exeter, Exeter EX4 4PS, UK.

Anderson, T. R., IOSDL, Wormley, Godalming, UK. Andersson, J., Kangwane Parks Corporation, PO Box 1990, Nelspruit 1200, South Africa.

André, J.-C., Direction de la Météorologie Nationale, Etablissement d'Etudes et de Recherches de la Météorologie, Centre Nationale de Recherche Météorologique, 42 avenue G. Coriolis, F-31057 Toulouse Cedex, France.

Andreae, M. O., Max-Planck-Institut für Chemie, Abt. Biogeochemie, Postfach 3060, D-6500 Mainz, FRG.

Angel, M. V., IOSDL, Wormley, Godalming, UK. Angulo, A., Centre for Ecology and Environmental Sciences, IVIC, Apartado 21827, Caracas 1020A, Venezuela.

Anisimow, S., Institute of Physics of the Earth, USSR Academy of Sciences, Bolshaya Gruzinskaya 10, Moscow 123242, USSR.

Annenkov, V. V., Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109117, USSR.

Argollo, J., Faculdad de Ciencias Geológicas, Universidad Mayor de San Andrés, Casilla de Correo 11152, La Paz, Bolivia.

Arino, O., LERTS, 18 Avenue Edouard Belin, F-31055 Toulouse Cedex, France. Arnold, R. J., NASA Headquarters, Code EC, Washington, DC 20546, USA.

Arquit, A., Institute of Physics, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland.

Arshinov, B. M., Institute of Hydrometeorology Koroleva ul. 6, Obninsk 249020, USSR. Atkinson, R., Bureau of Meteorology, CGP Box 1289K, Melbourne, Victoria, 30001, Australia.

Augstein, E., Alfred Wegner Institute for Polar Research, Columbus Center, D-2850 Bremmerhaven, FRG.

Austin, M., CSIRO, Division of Wildlife and Ecology, PO Box 84, Canberra, ACT 2602, Australia.

Ayers, G., CSIRO Div. of Atmospheric Research, Private Bag No. 1, Mordialloc, Victoria, 3195 Australia.

Ayoade, J. O., Department of Geography, Faculty of the Social Sciences, Univer-

sity of Ibadan, Ibadan, Nigeria.
Ayyad, M. A., Botany Department, Faculty of Science, University of Alexandria, Moharran Bay, Alexandria, Egypt.
Bacastow, D., Scrips Institution of Oceanography, La Jolla, California 92093, USA. Badenkov, Y. P., Institute of Geography, USSR Academy Sciences, Staronomonetny 29, Moscow 109017, USSR.
Baer, M., Institut für Meteorologie und Klimaforschung, Kernforschungszentrum, Karlsruhe, Postfach 3640, D-7500 Karlsruhe, FRG.
Baker, F. W. G., CASAFA, Lacombe de Sauve, F-26110 Venterol, France. Baker, D. J., Joint Oceanographic Institutions Inc., 1755 Massachusetts Avenue NW, Washington, DC 20036, USA.
Baldocchi, D., NOAA/ERL/Atmosperic Turbulence and Diffusion Division, PO Box 2456, Oak Ridge, TN 37831, USA.
Balek, J., UNEP, Water and Litosphere, PO Box 47074, Nairobi, Kenya. Ball, M., The Australian National University, RSBS, PO Box 475, Canberra, ACT 2601, Australia.
Banage, W. B., Department of Biology, University of Lusaka, PO Box 32379, Lusaka, Zambia.
Band, L., Department of Geography, University of Toronto, 100 Saint George Street, Toronto, Ontario MSS 1A1, Canada.
Bardossy, A., Institut für Hydrologie und Wasserwirtschaft, Universität Karlsruhe, Kaiserstrasse 12, D.7500 Karlsruhe, FRG.
Barkmann, W., Department of Oceanography, The University, Southampton, UK. Barrie, L., Atmospheric Environment Service, Environment Canada, 4905 Dufferin St., Downsview, Ontario M3H 5T4, Canada.
Barry, R., World Data Center-A, CIRES, University of Colorado, Campus Box 449, Boulder, CO 80309, USA.
Barson, M., Bureau of Rural Resources, GPO Box 858, Canberra, ACT 2601, Australia. Bassa, G., Cartographia II, A'fonya u.l, H-1025 Budapest, Hungary.
Basso, E., Technical Co-operation Department, WHO, Case Postale No. 5, CH-1211 Geneva 20, SWITZERLAND
Batista, G., INPE - DPA, Caixa Postal 515, 12201 São José dos Campos, SP, Brazil.
Bauer, S. J., Institut für Meteorologie und Geophysik, Universität Graz, Halbärthgasse 1, A-8010 Graz, Austria.
Baumert, H., Akademie der Wissenschaften der DDR, Otto-Nuschke-Strasse 22/23, DDR-1086 Berlin, GDR.
Becker, F., Université Louis Pasteur, Ecole Nationale Superieure de Physique, 7 rue de l'Université, F-6700 Strasbourg, France.
Belchansky, G.I., Institute of Evolutionary Morphology and Ecology of Animals, USSR Academy of Science, Leninsky prospect 33, Moscow 117071, USSR.
Beloussov, V.V., Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117292, USSR.
Beran, M., Institute of Hydrology, Crowmarsh Gifford, Wallingford, Oxon OX1O 8BB, UK.
Berg, B., Department of Ecology and Environmental Research, Swedish University of Agricultural Sciences, S-750 07 Uppsala, Sweden.
Berger, A. L., Institute of Astronomy and Geophysics, 2 Chemin du Cyclotron, B-1348 Louvain-la-Neuve, Belgium.
Berglund, B., Department of Quaternary Geology, Lund University, Tornavägen 13, 223 63 Lund, Sweden.
Bernal, P., BIOTECMAR, Universidad Catolica de Chile, Talcahuauo, Chile. Bezuneh, T., OAC/STRC-SAFGRAD, Coordination Office, BP 1783, Ougadougou, Burkina Faso.
Bhandari, N., Physical Research Laboratory, Navrangapura, Ahmedabad 38009, India. Bigg, G. R., School of Environmental Sciences, University of East Anglia, Norwich, UK.
Birkenmajer, K., Committee on Polar Research, Polish Academy of Sciences, Palac Kultury i Nauki, 00-901 Warsaw, Poland.
Björklund, G., IGBP Secretariat, Royal Swedish Academy of Sciences, Box 50005, 10405 Stockholm, Sweden.
Blanar, F. Institute of Atmospheric Physics, Acadademy of Sciences, Bocni 11, 140 00 Praha 4 Czechoslovakia.

Bogner, J. E., Argonne National Laboratory, EES-362 9700 S, Cass Avenue, Argonne, Illinois 60439, USA.
Boichenko, V. A., Institute of Problems of Management, Profsojuznaja 65, Moscow, USSR.
Boldirev, V., WMO, World Climate Programme Office, Case Postale No. 5, CH-1211, Geneva, Switzerland.
Bolin, B., Kvarnåsvägen 6, S-184 51 Österskär, Sweden; Department of Meteorology, Arrhenius Laboratory, University of Stockholm S-106 91, Stockholm, Sweden.
Bolle, H.-J., Institut fr Meteorologie, Freie Universität Berlin, Dietrich-Schäfer-Weg 6-10, D-1000 Berlin 41, FRG.
Boryczka, J., Department of Geography, University of Warsaw, Krakowskie Przedmiescie 30, 00-927 Warsaw, Poland.
Boubacher, B., CODESRIA, BP 3304, Dakar, Senegal. Bourdeau, P., Commission of European Communities, DG XII, Rue de la Loi 200, B-1049 Brussels, Belgium.
Bouwman, A. F., National Institute of Public, Health and Environmental Protection, PO Box 1, 3720 BA Bilthoven, The Netherlands.
Bowman, G., CSIRO, Division of Soils, GPO Box 639, Canberra, ACT 2601, Australia. Bradley, R. S., Department of Geology and Geography, Morill Science Centre, University of Massachusetts, Amherst, MA 01003, USA.
Bretherton, F. P., Space Science and Engineering Center, University of Wisconsin, 1225 West Dayton Street, Madison, WI 53706, USA.
Brewer, P., Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA.
Breymeyer, A., Institut of Geography and Spatial Organization, Polish Academy of Sciences, Krakowskie Przedmiescie 30, 00-927 Warsaw, Poland.
Broecker, W. S., Lamont-Doherty Geological Observatory and Department of Geological Sciences,Columbia University,Palisades, NY 10964, USA.
Bruce, J. P., World Meteorological Organization, Case Postale 5, CH-1211 Geneva 20, Switzerland.
Brussard, G., Eindhoven University of Technology, Faculty of Electrical Engineering, EH 12.33, PO Box 513, NL-5600 MB Eindhoven, The Netherlands.
Buat-Menard, P., Centre des Faibles Radioactivités, CNRS-CEA, 91190 Gif-sur-Yvette, France.
Bucher, E. H., Department of Biology, Colorado State University, Fort Collins, CO 80523, USA.
Budd, W., Department of Meteorology, University of Melbourne, Grattan Street, Parkville, Victoria 3052, Australia.
Buessler, K. O., Woods Hole Oceanographic Institute, Woods Hole MA, USA. Burch, G., Bureau of Rural Resources, GPO Box 858, Canberra, ACT 2601, Australia.
Burgos, J. J., Centro de Investigaciones, Biometeorologicas, Caja Postal 5233, Corneo Central, 1000 Buenos Aires, Argentina.
Burren, C., Department of Oceanography, The University, Southampton, UK. Buttle, E., Natural Environment Research Coucil, Swindon, UK.
Cadet, A., Centre National de la Recherche Scientifique, Paris, France.
Carrizosa Umaña, J., Apartado 60.076, Calle 10 no. 1-87, Bogota DE, Colombia.
Carvalho, J.C.M, Museau Nacional, Quinta Boa Vista, Rio de Janeiro, RJ 20940 Brazil.
Caspary, H.-J., Institut für Hydrologie und Wasserwirtschaft, Universität Karlsruhe, Kaiserstrasse 12, D-7500 Karlsruhe, FRG.
Caughley, G., CSIRO, Division of Wildlife & Ecology, PO Box 84, Canberra, ACT 2602, Australia.
Celecia, John F., Division of Ecology, Unesco, 7 Place de Fontenoy, F-75700 Paris, France.
Chahine, M., Jet Propulsion Laboratory, Mail Stop 180-904, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA.
Chaloner, W. G., Royal Holloway and Bedford New College, Egham, Surrey, UK. Chanin, M. L., Service d'Aeronomie du CNRS, BP 3, F-91371 Verrières-le-Buisson, France.
Chapin, F. S., Institute of Arctic Biology, University of Alaska, Fairbanks, Alaska 99775, USA.

Charleson, R. J., Department of Civil Engineering, University of Washington, Seattle, Washington 98195, USA.
Charnock, H., Oceanography, Southampton University, UK. Chaudhuri, S. D., Bangladesh Academy of Sciences, 3/8 Asad Avenue, Muhammadpur, Dhaka 1207, Bangladesh.
Chavarria, P. L., Universidad de Costa Rica, San Jose, Costa Rica.
Chavez, E., CINVESTAV-IPN, Unidat Merida, Mexico.
Chen, P., Bureau of Resources & Environmental Sciences, Chinese Academy of Sciences, 52 San Lihe Lu, 100864 Beijing, China.
Chimonyo, R., Department of Geography, University of Zimbabwe, PO Box MP 167, Mount Pleasant, Harare, Zimbabwe.
Chinnery, M. A., NOAA/NGDC, E/GC, 325 Broadway, Boulder, CO 80303, USA.
Chorbadze, N. B., Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR.
Chuchkalov, V. S., Department of World Weather Analysis, Moscow, USSR.
Chuikova, R. N. Publishing House "Znaniye", proezd Serova 4, Moscow 101835, USSR.
Cicerone, R. J., National Center for Atmospheric Research, PO Box 3000, Boulder, CO 80307, USA.
Cihlar, J., Application Development Section, Canada Centre for Remote Sensing, 2464 Sheffield Road, Ottawa, Ontario, Candada K1A OY7.
Ciolkosz, A., Institute of Geodesy and Cartography, ul. Jasna 2/4, 00-950 Warsaw, Poland.
Clarke, A., BAS, Cambridge, UK. Clarkson, B., Botany Division DSIR, c/- Forest Research Institute, Private Bag, Rotorua, New Zealand.
Clegg, S., Plymouth Marine Laboratory, Prospect Place, West Hoe, Plymouth PL1 3DH, UK.
Comerma, J. A., CENIAP-FONIAP, Apdo Postal 4653, Maracay 2101, Venezuela. Conrad, R., Fakultät für Biologie, Universität Konstanz, Postfach 5560, D-7750 Konstanz, FRG.
Cook, Sir Alan, Selwyn College, Cambridge, UK. Cooper, K., Wildlife Society of South Africa, 100 Brand Street, Durban 4001, South Africa.
Cordani, U. G., Instituto de Geociencias - USP, Ciudade Universitaria Armando Salles de Oliveira, Rua do Lago 562 - 211.2847, Caixa Postal 20899, CEP 05508 Butantan SP, Brazil.
Corell, R. W., National Science Foundation, 1800 G St. NW, Room 510, Washington, DC 20550, USA.
Correal, G., Colombian Academy of Sciences, PO Box 52514, Bogota 2, DE, Colombia.
Cottenie, J. H., Rijksuniversiteit te Gent, De Campagen 23, B-9910 Gent, Belgium.
Coughenhour, M., Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, Colorado 80523, USA.
Coward, A., IOSDL, Wormley, UK. Crawford, R., Sea Fisheries Research Institute, Private Bag X2, 0812 Rogge Bay, South Africa.
Crease, J., Marine Physics Group, Institute of Oceanographic Sciences, Brook Road, Wormley, Godalming, Surrey GU8 5UB, UK
Crome, F., CSIRO, Division of Wildlife & Ecology, PO Box 780, Atherton QLD 4883, Australia.
Croze, H., UNEP, PO Box 30552, Nairobi, Kenya. Crutzen, P. J., Max-Planck-Institute for Chemistry, PO Box 3060, D-6500 Mainz, FRG.
Cubasch, U., Max-Planck Institut für Meteorologie, Bundesstrasse 55, D-2000 Hamburg 13, FRG.
Cushing, D. H., Lowestoft, Suffolk, UK. Czank, N., Event Dynamics Pty. Ltd., PO Box 32730, Braamfontein 2017, South Africa.
da Cunha, R., INPE, Brazilian Institute of Space Research, PO Box 515, 12201 SMo José dos Campos - S.P., Brazil.
Daniel, R. R., COSTED, Asia Regional Office, 24 Gandhi Mandap Road, Guindy, Madras 600 025, India.
Datye, K. R., Rehem Mansion No. 2, 44 S Bhagat Singh Rd, Colab, Bombay 400 039, India.
Davidson, E. A., National Research Council Associate, NASA Ames Research Center, Mail Stop 239-12, Moffett Field, CA 94035, USA.

Davidson, K., World Meteorological Organization, CP No. 5, CH-1211 Geneva 20, Switzerland.
de Bisbal, E. C., CENIAP-FONAIAP, Apdo Postal 4653, Maracay 2101, Venezuela. de Cuevas, B., IOSDL, Wormley, UK.
de Haan, B., RIVM, Bilthoven, The Netherlands.
de Mesquita, A. R., Instituto Oceanografio, Universidade de Sao Paulo, Caixa Postal 9075, Sao Paulo, Brazil.
de Pury, D., RSBS, The Australian National University, PO Box 475, Canberra, ACT 2601, Australia.
Delmas, R. J., Laboratoire de Glaciologie de l'Atmosphere, Faculté des Sciences, BP 96, 3842 St Martin d'Heres Cedex, France.
Denman, K., Institute of Ocean Sciences, Sidney, BC, Canada. Denmead, O. T., CSIRO, Centre for Environmental Mechanics, GPO Box 821, Canberra, ACT, 2601, Australia.
Desjardins, R. L., Agrometeorology Section, Land Resource Research Institute, Central Experimental Farm, Bldg. 74, Ottawa, Ontario, Canada KIA OC6.
Detling, J., Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523, USA.
Diawara, A., E.N.I, BP 242, Bamako, Mali. Dickinson, R., National Centre for Atmospheric Research, PO Box 3000, Boulder, CO 80307, USA.
Diop, E. S., Unesco/BREDA, PO Box 3311, Dakar, Senegal.
Dobrowolski, K., Institute of Ecology, Polish Academy of Sciences, Dziekanów Lesny, P-05150 Lomianki, Poland.
Domergue, J.-L., Ministère de la Coopération, 20 rue Monsieur, F-75700 Paris, France. Dooge, J. C. I., Belgrave Road, Monksdown, Co. Dublin, Republic of Ireland.
Dorman, L. I., IZMIRAN, Troitsk, Moscow Region 142092, USSR.
Drozdov, A. V., Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29. Moscow 109017, USSR.
Duce, R. A., Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island 02881, USA.
Ducklow, H., Point Laboratory, Cambridge, Md., USA.
Dueñas, H., Colombian Academy of Sciences, PO Box 52514, Bogota 2, DE, Colombia.
Dumitrescu, S., Unesco, 7 Place Fontenoy, F-75007 Paris, France.
Dunxin, Hu, Institute of Oceanology, Quingdao, China.
Duplessy, J.-C., CNRS Centre des Faibles Radioactivités, Avenue de la Terrasse, F-91190 Gif-sur-Yvette, France.
Duyzer, J. M., MT TNO PO Box 217, NL-2600 AE Delft, The Netherlands.
Dwivedi, S. N., Department of Ocean Development, Mahasagar Bhavan, Block 12, CGO Complex, Lodi Road, New Delhi 110003, India.
Dyck, S., Division of Hydrology and Meteorology, Dresden Technical University, Mommsenstrasse 13, DDR-8027 Dresden, GDR.
Dyer, M.I., Division of Ecology, Unesco, 7 place de Fontenoy, F-75700 Paris, France.
Dyke, P. P. G., Department of Maths, Polytechnic South West, Plymouth, UK.
Dziewonski, A., Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138, USA.
Eddy, J. A., Office for Interdisciplinary Earth Studies, UCAR, PO Box 3000, Boulder, CO 80307, USA.
Edjame, K. S., Faculty of Sciences, University of Benin, BP 1515, Lomé, Togo.
Edwards, A., Dunstaffnage Marine Laboratory, PO Box 3, Oban, UK.
Efremov, S.A., Institute of Oceanography, USSR Academy of Sciences, Moscow, USSR.
Eglinton, G., The Royal Society, 6 Carlton House Terrace, London SW1Y 5A9, UK.
Egorov, V.I., Laboratory of Monitoring the Environment and Climate, Moscow, USSR.
Ehhalt, D. H., Institut für Atmosphärische Chemie, Kernforschungsanlage Jülich, D-5170 Jülich, FRG.
Ekpo, I. J., Department of Geography, University of Birmingham, Birmingham B15 2TJ, UK.
Ellis, J., National Resource Ecology Laboratory, Colorado State University, Fort

Collins, CO 80523, USA.
Elman, R.I., All-Union Association "Lesproekt", Moscow, USSR
Elutin, A.V., Institute of the Earth Physics, B. Gruzinskaya 10, Moscow 123810, USSR.
Eroshenko, E.A., IZIRAN, Troitsk, Moscow region 142092 USSR.
Evans, G., Institut für Meereskunde, Universität Kiel, Düsternbrooker Weg 20, D-2300 Kiel, FRG.
Evteev, S., UNEP, PO Box 30552, Nairobi, Kenya.
Faith, D. P., CSIRO, Division of Wildlife & Ecology, PO Box 84, Lyneham, ACT 2602, Australia.
Falkenmark, M., Swedish Natural Science Research Council, Wennergren Centre, Box 6711, S-113 85 Stockholm, Sweden.
Farmer, G., 1611 North Kent Street, Suite 201, Arlington, VA 22209, USA. Farquhar, G., RSBS, The Australian National University, PO Box 475, Canberra, ACT 2601, Australia.
Fasham, M., Institute of Oceanographic Sciences, Wormley, Godalming, Surrey GU8 5UB, UK.
Faustin, G., AGRHYMET Centre, PO Box 11011, Niamey, Niger.
Feddes, R. A., Agricultural University Wageningen, Department of Hydrology, Soil Physics and Hydraulics, Nieuwe kanaal 11, The Netherlands.
Fehsenfeld, F. C., Aeronomy Laboratory, NOAA/ERL, 325 Broadway, Mail code R/E/AL7, Boulder, CO. 80303, USA.
Fichefet, T., Institut d'Astronomie et de Géophysique, Université Catholoque de Louvain, 2 Chemin de Cyclotron,B-1348 Louvain-la-Neuve, Belgium.
Field, J. G., Zoology Department, University of Capetown, Rondebosch, South Africa.
Finch, M., Department of Oceanography, The University, Southampton, UK.
Fischer, H., Institut fur Meteorologie and Klimatforschung, Kernforschungszentrum, Karlsruhe, Postfact 3640, D.7500 Karlsruhe 1, FRG.
Fitzjarrald, D., Atmospheric Sciences Research Center, State University of New York at Albany, 100 Fuller Road, Albany, NY 12205, USA.
Fonseca, F., Evironement Department, Cia Vale do Rio Doce, Av. Presidente Wilson 231-21, Rio de Janeiro, Brazil.
Fonseca, T., Departamento de Geofisica, Universidad de Chile, Blanco Encalada 2085 Casilla 2777, Santiago, Chile.
Forgan, B., BMRC, GPO Box 1289K, Melbourne, Victoria, 3001, Australia.
Forman, J. M. A., Industrias Núcleares do Brasil SA, Av Presidente Wilson, 231-11o Pav., Rio de Janeiro 20.030, Brazil.
Fowler, D., Institute of Terrestrial Ecology, Edinburgh Research Station, Bush Estate, Penicuik, Midlothian EH26 0QB, Scotland, UK.
Francey, R., CSIRO Div of Atmospheric Research, Private Mail Bag No. 1, Mordialloc, Victoria, 3195, Australia.
Franz, E., ICRAF, PO Box 30677, Nairobi, Kenya. Franz, H. G. NIOZ, Den Burg, Texel, The Netherlands.
Fraser, P., CSIRO Div. of Atmospheric Research, Private Mail Bag No. 1, Mordialloc, Victoria 3195, Australia.
Freney, J., CSIRO, Division of Plant Industry, PO Box 1600, Canberra, ACT 2601, Australia.
Frenzel, B., Universität Hohenheim, Institut für Botanik 210, Garbenstrasse 30, D-7000 Stuttgart 70, GDR.
Froehlich, W., Institute of Geography and Spatial Organization, Polish Academy of Sciences, ul. Sw. Jana 22, 31-018 Cracow, Poland.
Fu, C., Institute of Atmospheric Physics, Academia Sinica, Beijing 100011, China.
Fuentes, E. R., Laboratorio de Ecologia, Facultad de Ciencias Biológicas, Universidad Catolica de Chile, Casilla 114-D, Santiago, Chile.
Fuenzalida, H., Facultad de Ciencias Fisicas y Matematicas, Blanco Encalada 2085, Casilla 2777, Santiago, Chile.
Fung, I., NASA Goddard Space Flight Center, Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA.
Ferguson, H. L., Atmospheric Environment Services, Environment Canada, Terrasses de la Chaudière, Ottawa K1A OH3, Canada.
Fyfe, W. S., University of Western Ontario, London, Ontario, Canada N6A 5B7.
Gaidukov, V. Y., Institute of Applied Geophysics, Glebovskaya 20b, Moscow, USSR.
Galbally, I., CSIRO, Division of Atmospheric Physics, Private Bag No. 1, Mordialloc, VIC 3195, Australia.
Galchenko, V., Institute of Microbiology, Academy of Sciences USSR, Prosp. 60-letija, Octjabrja 7, 117811 Moscow, USSR.
Galeev, R., Academy of Sciences of the USSR, 14 Leninsky Prospekt, 117901 Moskva V-71, USSR.
Gammon, R., NOAA/Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE, Seattle WA, USA.
Garside, J., Bigelow Laboratory for Ocean Sciences, West Boothbay Harbor, Maine, USA.
Garside, C., Bigelow Laboratory for Ocean Sciences, West Boothbay Harbor, Maine, USA.
Gifford, R., CSIRO, Division of Plant Industry, GPO Box 1600, Canberra, ACT 2601, Australia.
Gill, M., CSIRO, Division of Wildlife & Ecology, PO Box 84, Canberra, ACT 2602, Australia.
Gille, J.C., NCAR, PO Box 3000, Boulder, CO 80307, USA
Guill, M. Division of Plant Industry, CSIRO, GPO Box 1600, Canberra, ACT 2601, Australia.
Gladwell, J., Division of Water Sciences, Unesco, 7, Place de Fontenoy, F-75700 Paris France.
Glaser, G., Focal Point for Environmental Affairs, Science Sector, Unesco, 7 Place Fontenoy, F-75700 Paris, France.
Gleick, P., Pacific Institute for Studies in Development, Environment and Security, 1681 Shattuck Avenue, Suite H, Berkeley CA, USA.
Glooschenko, W. A., CIRAC, York University, 4700 Keele Street, North York, Ontario, M3J IP3 Canada.
Godwin, D., IFDC, PO Box 2040, Muscle Shoals, Alabama 35662, USA.
Goldstein, G., Laboratory of Biomedical and Environmental Sciences, University of California Los Angeles, CA 90024, USA.
Golitsyn, G.S., Institute of Atmospheric Physics, USSR Academy of Sciences, Moscow, USSR.
Golovkov, V.P, IZMIRAN, Troitsk, Moscow Region 142092, USSR.
Golubev, G. N., Faculty of Geography, Moscow State University GSP-3, Moscow 119899, USSR.
Gorchakov, E.V. Research Institute of Nucclear Physics, Moscow University, Moscow 119899, USSR.
Gordon, C., Meteorological Office, Eastern Road, Bracknell, Berks, UK.
Gordon, W. E., National Academy of Science, 2101 Constitution Avenue NW, Washington, DC 20418, USA.
Gosz, J., Biology Department, University of New Mexico, Albuquerque, New Mexico 87131, USA.
Goyet, C., Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA.
Graetz, D., CSIRO, Division of Wildlife & Ecology, PO Box 84, Canberra, ACT 2602, Australia.
Gray, J. S., Department of Biology, University of Oslo, Norway.
Green, J.L. National Space Science Data Centre, NASA/GSFC, Code 630, Greenbelt, MD 20771, USA.
Green, A. W. Jr., US Geological Survey, Mail Stop 946 DFC, Denver, CO 80225, USA.
Groffman, P., University of Rhode Island, Department of Natural Resources Sciences, Kingston, RI 02881, USA.
Gruza, G.V. Hydrometeocenter, Moscow, USSR.
Guljaeva, T.L., IZMIRAN, Troitsk, Moscow Region 142092, USSR.
Gutry-Korycka, M., Department of Geography, University of Warsaw, Krakowskie Przedmiescie 30, 00-927 Warsaw, Poland.
Gwynne, M.W., UNEP/GEMS, PO Box 30552, Nairobi, Kenya. Gvishiani, A.D. Institute of the Earth Physics, B. Gruzinskaya 10, Moscow 123810, USSR.
Hadeen, K., NOAA/NCDC, Federal Building, Asheville, NC 28801, USAHALEM, M Goddard Space Flight Center, NASA Code 630, Greenbelt Road, Greenbelt, MD 20771, USA.

Haider, K., Institut für Pflanzenernährung und Bodenkunde, Bundesforschungsanstalt für Landwirtschaft (FAL), Bundesallee 50, D-3300 Brunschweig, FRG.
Hall, D., Department of Biology, King's College London, Campden Hill Road, London W87 AH, UK.
Hall, F.G., Goodard Space Flight Center, Greenbelt Road, Greenbelt, MD 20771, USA.
Halldin, S., Department of Hydrology, University of Uppsala, Västra Ågatan 24, 75220 Uppsala, Sweden.
Halliwell, J., Natural Sciences and Engineering Research Council of Canada, 200 Kent Street, Ottawa, Canada K1A 1H5.
Hardjasoemantri, K. Gadjah Mada University, Bulaksumur, Yogyakarta, Indonesia.
Harris, G., CSIRO, Office of Space Science and Applications, PO Box 225 Dickson, Canberra, ACT 2601, Australia.
Harris, G., Max-Planck-Institut für Chemie, Abt. Luftchemie, Postfach 3060, D-6500 Mainz, FRG.
Harrison, S., Department of Physical Geography, Uppsala University, Box 554, 751 22 Uppsala, Sweden.
Harriss, R. C., Institute for the Study of Earth, Oceans and Space, Science & Engineering Research Building, University of New Hampshire, Durham, NH 03824, USA.
Hart, P.J. WDC-A Coordination Office, 2101 Constitution Ave, NW, Washington, DC 20418, USA.
Harvey, V., Event Dynamics Pty. Ltd., PO Box 32730, Braamfontein 2017, South Africa.
Hasegawa, Y., Bureau of Scientific and International Affairs, Ministry of Education, Tokyo, Japan.
Hasselmann, K., Max-Planck-Institute for Meteorology, Bundesstrasse 55, D-2000 Hamburg 13, FRG.
Haugan, P. M., Nansen Remote Sensing Center, Solheimsvik, Norway.
Hayward, R. B., British Antarctic Survey, Cambridge, UK.
Hayward, T., Scripps Institution of Oceanography, University of California, La Jolla, CA 92038, USA.
Hempel, G., Alfred-Wegener-Institut für Polar- und Meeresforschung, Columbusstrasse, Postfach 12 01 61, D-2850 Bremmerhaven, FRG.
Henderson-Sellers, A., School of Earth Sciences, Macquarie University, North Ryde, NSW 2109, Australia.
Herrera, R., Centre for Ecology and Environmental Sciences, IVIC, Apartado 21827, Caracas 1020A, Venezuela.
Hicks, B., NOAA/Atmospheric Turbulence Diffusion Labs., PO Box 2456, Oak Ridge, Tennessee 37831, USA.
Holligan, P. M., Plymouth Marine Laboratory, Prospect Place, West Hoe, Plymouth PL1 3DH, UK.
Hong, G. H., Korea Ocean Reearch & Development Institute, An San, P.O. Box 29, Seoul 425-600, Korea.
Hopkins, C. Norwegian College of Fisheries Science, Tromso, Norway.
Hsu, K. J. Geologisches Institut der ETH Zürich, Sonneggstrasse 5, CH-8092 Zürich, Switzerland.
Hu, Z. H. International Cooperative Bureau, Chinese Academy of Science, 52 San Lihe Rd, Beijing, China.
Huebert, B., Graduate School of Oceanography, University of Rhode Island, Kingston, RI 02881, USA.
Hughes, B. C. UJO Division, ARE Southwell, Portland, UK.
Hughes. M. K. Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ 85721, USA
Huntley, B., FRD, CSIR, PO Box 395, Pretoria 0001, South Africa.
Ikishi, M. J. Ocean Research Institute, Tokyo, Japan.
Ilyas, M., School of Physics, University of Science of Malaysia, Minden, Pulau Pinang, Malaysia.
Imbamba, S., Department of Botany, University of Nairobi, Nairobi, Kenya.
Isaksen, I. S. A., Institute of Geophysics, University of Oslo, PO Box 1022 Blindern, N-0315 Oslo 3, Norway.

Isidorov, V. A., Chemical Department, Leningrad State University, 198904 Leningrad, USSR.
Ivanov, M. V. Institute of Microbiology, USSR Academy of Sciences, propojurnaja 7a, Moscow 117811, USSR.
Jackson, G. C. UJO Division ARE Southwell, Portland, UK.
Jackson, G. A. Texas A & M University, College Station, TX, USA.
Jacob, D. J., Pierce Hall, 29 Oxford Street, Harvard University, Cambridge, MA 02138, USA.
Jagtap, S., IITA, Oyo Road, PMB 5320, Ibadan, Nigeria.
Jahn, B.-U., Embassy of the Federal Reublic of Germany, 4645 Reservoir Road, Washington, DC, USA.
Jakeman, T., CRES, The Australian National University, GPO Box 4, Canberra, ACT 2601, Australia.
Jankowski, A., Institute of Physical Geography, Silesian University, ul. Meilczarskiego 60, 41-200 Sosnowiec, Poland.
Jaramillo, V. J., Centro de Ecologia, Universidad Nacional Autonoma de Mexico, Apartado Postal 70-275, CP 04510, Mexico, DF.
Jarvis, P., Department of Forestry and Natural Resources, Darwin Building, Mayfield Road, Edinburgh EH9 3JU, UK.
Jenne, R., NCAR, P.O. Box 3000, Boulder, CO 80307, USA.
Jia Yanli, Southampton University, UK.
Jian, H.Y, Bureau of Resources and Environment, Chinese Academy of Sciences, 52 San Lihe Road, Beijing, China.
Johansson, C., Department of Meteorology, University of Stockholm, S-106 91 Stockholm, Sweden.
Johansson, I., Swedish Natural Science Research Council, Box 7611, S-113 85 Stockholm, Sweden.
Johnston, C., Physics and Engineering Lab, Lauder, DSIR, Private Bag, Omakau, C. Otago, New Zealand.
Jones, J., University of Florida, Gainesville, Florida, USA.
Jouzel, J., LGI/DPC, Centre d'Etudes Nucléaires de Saclay, BP 1, F-91191 Gif sur Yvette Cedex, France.
Kalma, J. D., CISRO Division of Water Reosurces, Institute of Natural Resources and Environment, GPO Box 1666, Canberra, ACT 2601, Australia.
Kamara, S. I., University of Sierra Leone, Njala University College, Private Mail Bag, Freetown, Sierra Leone.
Kamei, T., WDC-C2 for Geomagnetism, Data Analysis Centre for Geomagnetism and Space Magnetism, Hyoto University, Kyoto 606, Japan.
Kaneshige, T., WMO, C.P. T, Ch-1211 Geneva, Switzerland.
Kanninen, M., The Academy of Finland, PO Box 57, SF-00551 Helsinki, Finland.
Karasev, A. B., Hydrometeocenter, ul. Bolshevistskaya 9-13, Moscow 123376, USSR.
Kasomekere, Z., Department of Agriculture, Bunda College, University of Malawi, PO Box 219, Lilongwe, Malawi.
Kazantsev, N. N., Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109017, USSR.
Keating, B., CSIRO/ACIAR Dryland Project, PO Box 41567, Nairobi, Kenya.
Keilis-Borok, V. I., Institute of Physics of the Earth, USSR Academy of Sciences, USSR.
Kekeh, K. A., Faculty of Science, University of Benin, BP 1515, Lomé, Togo.
Keller, M., National Center for Atmospheric Research, PO Box 3000 Boulder, CO 80307, USA.
Kelts, K., EAWAG, Überlandstrasse 133, CH-8600 Dübendorf, Switzerland.
Kennedy, J. P., Institue for Remote Sensing Applications, Joint Research Center, CEC, I-21020 Ispra, Varese, Italy.
Kharin, E.P., Soviet Geophysical Committee, WDC B2, Molodezhnaya 3, Moscow 117296, USSR.
Khublaryan, M. G., Institute of Water Problems, USSR Academy of Sciences, Sadovo Chernogryazskaya str. 13/3, Moscow 103064, USSR.
Kienitz, G., Budapest Postgraduate Unesco Course, VITUKI, Research Centre for Water Resources Development, Kvassay Jenoe ut. 1-27, H-1453 Budapest 92, Hungary.
Kijko, A., Institute of Geophysics, Polish Academy of Sciences, ul. Ksiecia

Janusza 64, 01-452 Warsaw, Poland.
Killworth, P. D. Hooke Institute, Clarendon Labs, Oxford, UK.
Kirchman, D., College of Marine Studies, University of delaware, Lewes, DE, USA.
Kirillin, G. B. Institute of Space Researche, Profsojuznaya 84/32, Moscow, USSR
Klemes, V., 4383 Fieldmont Place, Victoria, BC V8N 4Z4, Canada.
Klug, M. J., Kellog Biological Station, Hickory Corners, Michigan 49060, USA.
Knapp, A. Bermuda Biological Station, Bermuda.
Kondratyev, K. Y., Institute of Limnology, USSR Academy of Sciences, 9 Sesastyanou Str., 196199 Leningrad, USSR.
Körner, C., Botanisches Institut, Universität Basel, Schönbeinstrasse 1, CH-4056 Basel, Switzerland.
Koropalov, V. M., Institute of Applied Geophysics, USSR Academy of Sciences, Moscow 107258, USSR.
Korotkov, V. E., All-Union Institute of Hydrometeoinformation, Obninsk 249020, USSR.
Koshkarev, A. V., Institute of Geography, USSR Academy of Sciences, Staromonetny per 29, Moscow 109017, USSR.
Kostrzewski, A., Institute of Quaternary Research, Adam Mickiewicz University, ul. Fredry 10, 61-701 Poznan, Poland.
Kotlyakov, V. M., Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109017, USSR.
Koulekey, K., School of Engineering, University of Benin, BP 1515, Lomé, Togo.
Kozoderov, V. V., Department of Computers, Gorky Street 11, Moscow 103009, USSR.
Krenke, A., Garibaldi Street 15, Block 3, Flat 36, Moscow, 117335, USSR.
Kruger, F., South African Forestry Research Institute, PO Box 727, Pretoria 0001, South Africa.
Kullenberg, G., Intergovernmental Oceanographic Commission, Unesco, 7 place de Fontenoy, F-75700 Paris, France.
la Rivière, J. W. M., ICSU, International Institute for Hydraulic and Environmental Engineering, PO Box 3015, Oude Delft 95, The Netherlands.
Lagos, P., RSMAS, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149 - 1099, USA.
Lal, D. R., Geological Research Division, University of California, San Diego, Mailcode: A-020, La Jolla, CA 92093, USA.
Lambert, C. E. Centre des Faibles Radioactivités, Gif-sur-Yvette, France.
Landsberg, J., CSIRO, Division of Wildlife & Ecology, PO Box 84, Canberra, ACT 2602, Australia.
Lassey, K., DSIR, Institute of Nuclear Sciences, PO Box 31312, Lower Hutt, New Zealand.
Lassiter, R., Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia 30605, USA.
Leishman, M., School of Biological Sciences, Macquarie University, Sydney, NSW 2109, Australia.
Lenschow, D. H., NCAR, PO Box 3000, Boulder CO 80307, USA.
Levine, J., Atmospheric Sciences Division, NASA Langley Research Center, Hampton, Virginia 23665-5225, USA.
Lewis, M., Earth Sciences and Application Division, NASA, Code EEC, 600 Independence Avenue SW, Washington, DC 10546, USA.
Li, W. H., MAB Programme, Chinese Academy of Sciences, 52 San Lihe Road, Beijing, China.
Lin, C. Department of Meteorology, McGill University, Montreal, Canada.
Liss, P., University of East Anglia, School of Environmental Sciences, Norwich NR4 7TJ, UK.
Liu, T., Institute of Geology, Academia Sinica, PO Box 634, Beijing 100011, China.
Livingston, W., National Solar Observatory, PO Box 26732, Tucson, Arizona 85719, USA.
Llerena, C. A., Facultad de Ciencias Forestales, Universidad Nacional Agraria La Molina, Apartado 456, Lima, Peru.
Loiko, P.F., Institute of Land Resources, Moscow, USSR.
Lorius, C., CNRS, Laboratoire de Glaciologie et Géophysique de l'Environnement, BP 96, F-38402 Saint-Martin-d'Hères Cédex, France.

Lucas, M. I., Zoology Department, University of Capetown, Rondenbosch, SouthAfric a.
Lundberg, H., Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden.
Lutjeharms, J., CSIR, PO Box 320, Stellenbosch 7600, South Africa.
Maass, J. M., Centro de Ecologia, Universidad Nacional, Autonoma de Mexico, Apartado Postal 70-275, CP 04510, Ciudad Universitaria, UNAM Mexico.
MacDonald, I., Percy Fitzpatrick Institute of African Ornithology, University of Capetown, Rondebosch 7700, South Africa.
Macharé, J., Instituto Geofisico del Peru, Los Alamos 241, San Isidro, Lima, Peru.
MacMahon, J., Department of Biology College of Science, Utah State University, Logan, Utah 84322-5305, USA.
Magazda, C. H. D., University of Zimbabwe, Kariba Research Station, Mount Pleasant, Harare, Zimbabwe.
Malakova, R. Y. VINITI, Baltijskaya 14, Moscow 125219, USSR.
Malingreau, J., Commission of the European Communities, Joint Research Centre, Building 44, I-21020 Ispra (Varese), Italy.
Malone, T. F., Scholar in Residence, St Joseph College, 1678 Asylum Avenue, West Hartford, CT 06117, USA.
Mandych, A. F., Institute of Geography, USSR Academy of Sciences, Staromonetny 29, Moscow 109017, USSR.
Manton, M., BMRC, CPO Box 1289K, Melbourne, Victoria 3001, Australia.
Margules, R., CSIRO, Division of Wildlife & Ecology, PO Box 84, Lyneham, ACT 2602, Australia.
Martin, J. H., Moss Landing Marine Laboratories, PO Box 450, Moss Landing CA, USA.
Mascarenhas, A., University of Dar-es-Salaam, PO Box 35097, Dar es Salaam, Tanzania.
Masson, J. R., Swaziland Milling, PO Box 158, Manzini, Swaziland. Matson, P., NASA, Ames Research Center, Mail Stop 239-12, Moffett Field, CA 94035, USA.
Matsumoto, E., Water Research Institute, Nagoya University, Nagoya 464-01, Japan.
McBean, G. A., Department of Geography, University of Colombia, 1984 West Mall, Vancouver, Canada V6T 1W5.
McCarthy, J. J., Museum of Comparative Zoology, Harvard University, Cambridge, MA 02138, USA.
McFarlane, F., CSIRO, Division of Wildlife & Ecology, PO Box 84, Canberra, ACT 2602, Australia.
McGillicuddy, D., Harvard University, Cambridge, MA, USA.
McMurtrie, R., CSIRO Division of Forestry and Forest Products, PO Box 4008, Queen Victoria Terrace, Parkes ACT 2600, Australia.
Medina, E., Centro de Ecologia, IVIC, Apartado 21827, Caracas 1020-A, Venezuela.
Melillo, J. M., The Ecosystem Centre, Marine Biological Laboratory, Woods Hole, MA 02543, USA.
Menaut, J.-C., Ecole Normale Supérieure, CNRS-VA 258, Laboratoire d'Ecologie, 46 rue d'Ulm, F-75230 Paris Cedex 05, France.
Mendes, R. Q., Dusternbrooker Weg 148, D-2300 Kiel 1, FRG.
Menon, M. G. K., Ministry of Science and Technology, Anusandan Bhavan, Rafi Marg, New Delhi 110001, India.
Messerli, B., Institute of Geography, University of Berne, CH-3012 Berne, Switzerland.
Michaels, A., Bermuda Biological Station, Fery Reach, Bermuda.
Mikhailovsky, G. E., Institute of Oceanology, ul. Krasikova 23, Moscow 117218, USSR.
Miller, J., Air Rsouerces Laboratory, NOAA, 8060 13th Street, Silver Spring, Maryland 20910, USA.
Minami, K., National Institute of Agro-Environmental Sciences, Tsukuba Norin Kenkyu Danchi-Nai, PO Box 2, Ibaraki 305, Japan.
Minister, J.-F., CNES/GRGS, 18 Avenue Edouard Belin, F-31055 Toulouse Cedex, France.
Mkhwanazi, H., Department of Physics, Universtity of Swaziland, Private Bag,

Kwaluseni, Swaziland.
Mohanty, P. K., Berhampur University, Ganjam, Orissa, India.
Mohnen, V., Department of Earth Sciences, SUNY, 1400 Washington Ave., Albany, NY 12222, USA.
Moldan, B., Geological Survey, Malostranske nam. 19, 118 21 Praha, Czechoslovakia.
Molion, L. C., INPE - Instituto de Pesquisas Espaciaias, Caixa Postal 515, 12201São José dos Campos, Brazil.
Mooers, C. N. K., Institute of Naval Oceanography, Room 311, Building 1100, NSTL, Mississippi 39529, USA,
Mooney, H. A., Department of Biological Sciences, Stanford University, Stanford, CA 94305-5020, USA.
Moore, B., University of New Hampshire, Complex system Research Center, Durham, NH 03924, USA.
Moore, T., Department of Geography, McGill University, Burnside Hall, 805 Sherbrooke Street West, Montreal, Québec, Canada H3A 2K6.
Morel, A., Laboratorie de Physique et Chimie Marines Universite Pierre et Marie Curie, B.P. 8, F-06230 Villefranche-sur-Mer, France.
Morel, P., WCRP, c/o WMO, Case postale No. 5, CH-1211 Geneva 20, Switzerland.
Morello, J., Direcccion a Parques Nationales, Av. Santa Fe 690, 1059 Buenos Aires, Argentina.
Morton, F. I., Department of Enineering Hydrology, Uniersity College, Galaway, Ireland.
Mosier, A., USDA-ARS, PO Box E, Fort Collins, CO 80523, USA.
Mostinsky, A.Z., Institute of the Earths Physics, B. Gruzinskaya 10, Moscow 123810, USSR.
Mugica, R., Universidad de Piura, Piura, Peru.
Muller, K., Univeristy College Wales, Bangor, UK.
Mundt, W., Heinrich-Hertz Institute for Atmospheric Research & Geomagnetism, Radower-Chaussee 5, DDR-1199, GDR.
Mungai, D., Department of Geography, University of Nairobi, PO Box 30197, Nairobi, Kenya.
Murphy, R., NASA Headquarters, Code EEL, 600 Independent Avenue SW, Washington, DC 20546, USA.
Murphy, A. G., Department of Oceanography, The University, Southampton, UK.
Musin, M. M., First Moscow Medical Institute, B. Pirogovskaya 2/6, Moscow 119435, USSR.
Naborov, I.V. First Moscow Medical Institute, B. Pirogovskaya 2/6, Moscow 119435, USSR.
Najjar, R. Atmosphere and Ocean Science Program, Princeton University, Princeton, USA.
Ndiaye, A., Centre for Ecology Studies, Dakar, Senegal.
Nechitailenko, V. A. Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR.
Needler, G. IOSDL, Wormley, UK. Nemoto, T., Ocean Research Institute, University of Tokyo, 1-15-1 Minamidai, Nakano- ku, Tokyo 164, Japan.
Neue, H. U., International Rice Research Institute, Division of Soil and Water Sciences, PO Box 933, 1099 Manila, Phillipines.
New, A., IOSDL, Wormley, Godalming, UK. Newsome, A., Division of Wildlife and Ecology, CSIRO, P.O. Box 84 Lyneham, ACT 2602, Australia.
Nicholls, N., Bureau of Meteorology Research Centre, GPO Box 1289K, Melbourne, Victoria 3001, Australia.
Nicholson, S., Department of Meteorology, Florida State University, Tallahassee, Florida 32306, USA.
Niewiadomski, J., Institute of Geophysics, Polish Academy of Sciences, ul. Ksiecia Janusza 64, 01-452 Warsaw, Poland.
Nisbet, E. G. Department of Geology, University of Saskatchewan, Saskatoon S7N OWO, Canada.
Nival, P., Station Zoologique, BP 28 La Darse, F-06230 Villefranche-sur-Mer, France.
Nix, H., Centre for Resource & Environmental Studies, ANU, PO Box 4, Canberra, ACT 2600, Australia.

Njoku, E., NASA Headquarters, Code EEC, Washington, DC 20546, USA.
Noble, I., Research School of Biological Sciences, The Australian National University, PO Box 475, Canberra, ACT 2601, Australia.
Nobre, C. A., INPE, Caixa Postal 515, 12201 São José dos Campos, SP, Brazil.
Nuñez, L. H., Coordenadoria da Pesquisa de Resursos Naturais, Instituto Geológico, Avenida Miguel Stefano No. 3900, CEP 04301, Agua Funda SP, Brazil.
Nuñez, M. N., Departamento de Meteorologia, Universidad de Buenos Aires, Pabellon 2 - Ciudad Universitaria, 1428 Buenos Aires, Argentina.
Nyambok, I. V., University of Nairobi, PO Box 30197, Nairobi, Kenya.
O'Laughlin, E., CSIRO Division of Water Resources, GPO Box 1666, Canberra A.C.T., Australia.
Obridko, V. N., IZMIRAN, Tsoitsk, Moscow Region 142092, USSR.
Octavio, K. H., Intevep SA, Filial de Petróleos de Venezuela SA, Apartado 76343, Caracas 1070A, Venezuela.
Oeschger, H., Institute of Physics, University of Berne, Sidlerstrasse 5, CH-3012 Bern, Switzerland.
Ogallo, L. J., Department of Meteorology, University of Nairobi, PO Box 30197, Nairobi, Kenya.
Ogawa, T., Geophysics Research Laboratory, University of Tokyo, Bunkyo-ku, Tokyo 113, Japan.
Ojima, D., IGBP Secretariat, The Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden.
Oshima, Y., Department of Basic Human Science, School of Human Sciences, Waseda University, Mikajima 2-579-15, Tokorozawa, Saitama 359, Japan.
Osmond, B., Botany Department, Duke University, Durham NC 27706, USA.
Ouakam, M., Ministère de l'Enseignement Supériure, BP 4742, Yaoundé, Cameroon.
Paltridge, G., Division of Atmospheric Research, CSIRO Privare Bag No. 1, Mordialloc, VIC 3195, Australia.
Panikov, N. S., Institute of Microbiology, Academy of Sciences USSR, Prosp. 60-letija, Octjabrja 7, 117811 Moscow, USSR.
Pannier, F., Academia de Ciencias Fisicas Mathematicas y Naturales Apartado 1421, Caracas 1010A, VENEZUELA
Papitashvili, V. O., IZMIRAN, Troitsk, Moscow Region 142092, USSR. Papitashvili, N. E., Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR.
Parry, M. L., Atmospheric Impact Research Group, University of Birmingham, PO Box 363, Birmingham B15 2TT, UK.
Parton, W. J., Natural Resource Ecology Laboratory, Colorado State University, Fort Collins CO 80523, USA.
Partridge, T., Department of Palaeontology and Palaeoenvironmental Studies, Transvaal Museum, Pretoria, South Africa.
Pearman, G. I., CSIRO, Division of Atmospheric Research, Private Bag No. 1, Mordialloc, VIC 3195, Australia.
Peck, R., General Motors Research Laboratories, Environemntal Science Department, 30500 Mound Road, Warren, MI 48090-9055, USA.
Peltier, R., Department of Physics, University of Toronto, Toronto, Canada M5S 1A1.
Peltzer, E. T., Woods Hole Oceanographic Institution, Woods Hole, USA.
Peng, T. H., Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA:
Penkett, S. A., School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK.
Pereira, J. R., Faculty of Agricultural Studies, University of Eduardo Mondland, CP 257, Maputo, Mozambique.
Perry, J., National Research Council, 2101 Constitution Avenue, NW (HA 594), Washington, DC, 20418, USA.
Peters, J., US Geological Survey, WRD, 6481-B Peachtree Undustrial Boulevard, Doraville, GA, USA.
Peterson, J., NOAA/ERL, R/E/AR4, GMCC, 325 Broadway, Boulder, Colorado 80303, USA.
Pfister, C., Historisches Institut, Universität Bern, Engehaldenstrasse 4, CH-3012

Bern, Switzerland.
Pilcher, J., Paleo Ecology Laboratory, Queens University, Belfast, Northern Ireland, UK.
Pittock, B., CSIRO, Division of Atmospheric Research, Private Bag No. 1, Mordialloc, Victoria 3195, Australia.
Piyakanchana, T., c/o Research Project and Coordination Division, National Research Council of Thailand, 196 Phahonyothin Road, Bangkhen, Bangkok 10900, Thailand.
Platt, T., Bedford Institute of Oceanography, Dartmouth, NS, Canada.
Pollard, R. T., IOSDL, Wormley, Godalming, UK.
Porter, S., Quaternary Research Centre 5, University of Washington, Seattle, WA 98195, USA.
Posson, D., U.S. Geological Survey, 801 National Center, Reston, VA 22092, USA.
Postma, H., KNAW, Kloveniersburgwal 29, NL-1011 JV Amsterdam, The Netherlands.
Povsner, A.D., Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR.
Praderie, F., Ministère de la Recherche et de la Département des Sciences de l'Univers, 21 rue Descartes, F-75231 Paris Cedex 05, France.
Prado, C., Ecole Normale Supérieure/URA 258 CNRS, Laboratoire d'Ecologie, 46 rue d'Ulm, F-75230 Paris Cedex 05, France.
Prather, M., NASA Goddard Space Flight Center, Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA.
Prentice, C., Department of Ecological Botany, Uppsala University, Box 559, S-751 22 Uppsala, Sweden.
Priddle, J., BAS, Cambridge, UK. Prinn, R. G., Department of Earth, Atmospheric and Planetary Science, MIT, Room 54-1824, Cambridge, MA 02139, USA.
Prinsley, R., CSC, Commonwealth Secretariat, Marlborough House, Pall Mall, London SW1Y 5HX, UK.
Prospero, J., RSMAS, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149, USA.
Pugacheva, G.I. Institute of Nuclear Physics, Moscow State University, Moscow 119899, USSR.
Pugh, D. T., Institute of Oceanographic Sciences, Bidston Observatory, Birkenhead, Merseyside, L43 7R4, UK.
Purdie, D. A., Department of Oceanography, The University, Southampton, UK.
Puzachenko, Y. G., Institute of Evolutionary Morphology and Ecology of Animals USSR Academy of Sciences, Leninsky prosp. 33, Moscow 117312, USSR.
Quinn, P., Division of Environmental Science, Lancaster University, Lancaster LA1 4YQ, UL.
Rabassa, J., CADIC - Centro Austral de Investigaciones Cientificas, CC92 (9410) Ushuaia, Tierra del Fuego, Argentina.
Radach, G., Institut für Meereskunde, Troplowitzstr 7, D-2000 Hamburg 54, FRG.
Radstetter, E., The Ecosystems Center, Mrine Biological Laboratory, Woods Hole, Mass. 02543, USA.
Rahm, L., SMHI, Norrköping, Sweden. Rakusa-Suszczewski, S., Institute of Ecology, Polish Academy of Sciences, Dziekanów Lesny, 05-150 Lomianki, Poland.
Ralska-Jasiewiczowa, M., Institute of Botany, Polish Academy of Sciences, ul. Lubicz 46, 31-512 Cracow, Poland.
Rapoport, S. I., All-Union Cardiocentre, ul. Cherepkova 5, Moscow, USSR.
Rasool, S. I., Office of Space Science and Applications, Code E, NASA, Washington, DC 20546, USA.
Raupach, M., CSIRO, Centre for Environmental Mechanics, GPO Box 821, Canberra, Australia.
Ravina, N. B., VNIGMI-WDC B1, ul. Lenina 102-27, Obninsk 249020, USSR.
Reboucas, A., Instituto de Geociencias - USP, Ciudade Universitaria Armando Salles de Oliveira, Rua do Lago 562 - 211.2847, Caixa Postal 20899, CEP 05508 Butantan SP, Brazil.
Reeburgh, W. S., Institute of Marine Science, University of Alaska, Fairbanks, Alaska 99775-1080, USA.

Reiners, W. A., Department of Botany, The University of Wyoming, Aven Nelson Building, Laramie, Wyoming 82071, USA.
Reitenbakh, R. G, All-Union Research Institute of Hydrometeorological Info., WDC-B1, Obninsk 249020, USSR.
Rennenburg, H., Frunhofer-Institut für Atmosphärische, Umweltforschung, Kreuzeckbahnstrasse 19, D-8100 Garmsich-Partenkirchen, FRG.
Rhind, D. H., Department of Geography, Birkbeck College, 7-15 Gresse Street, London WIP 1PA, UK.
Richards, K., Department of Oceanography, The University, Southampton, UK.
Richey, J., School of Oceanography, University of Washington, Seattle, WA 98195, USA.
Risser, P. G., University of New Mexico, Scholes Hall, Room 108, Albuquerque, NM 87131, USA.
Robert-Bradley, P., Office of the Secretary and General Counsel, IDRC,
Robertson, J., Plymouth Marine Laboratory, Plymouth, Devon, UK. Robertson, J., Division of Ecological Sciences, Unesco, 7 place de Fontenoy, F-75700 Paris, France.
Robertson, G. P., WK Kellog Biological Station, Michigan State University, Hickory Corners, MI 49060, USA.
Robertsson, K., Department of Water and Environmental Studies, Linköping University, S-581 83 Linköping, Sweden.
Robinson, R., National Parks Board, PO Box 774, George 6530, South Africa.
Rodhe, H., Department of Meteorology, University of Stockholm, S-106 91 Stockholm, Sweden.
Rodkin, M. V., Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR.
Roederer, J. G., Geophysical Institute, University of Alaska, Fairbanks, AK 99775- 0800, USA.
Rong, W., Institute of Oceanology, Academia Sinica, 7 Nan-Hai Road, Qingdao, Shantung, China.
Rosswall, T., IGBP Secretariat, The Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden.
Roulet, N. T., Department of Geography, York University, 4700 Keele Street, North York, Ontario, Canada M3J 1P3.
Rowland, F. S., Department of Chemistry, University of California at Irvine, Irvine, CA 92717, USA.
Rozanov, B. G., Soil Department Moscow State University, Moscow 117234, USSR
Running, S. W., School of Forestry, University of Montana, Missoula, MT 59812, USA.
Rutllant, J., Facultad de Ciencias Fisicas y Matematicas, Blanco Encalada 2085, Casilla 2777, Santiago, Chile.
Ruttenberg, S., University Corporation for Atmospheric Research (UCAR), PO Box 3000, Boulder, CO 80307, USA.
Rutter, N., Department of Geology, University of Alberta, 1-26 Earth Sciences Building, Edmonton, Alberta, Canada T6G 2E3.
Ryzhykh, E. P., All-Union Research Institute of Hydrometeoinformation, ul. Koroleva 6, Obninsk 249020, USSR
Saint, G., LERTS/CNES, 18 Av. Edouard Belin, F-31055 Toulouse Cedex, France.
Sala, O. E., Departamento de Ecologia, Universidad de Buenos Aires, Facultad de Agronomia, Av. San Martin 4453, 1417 Buenos Aires, Argentina.
Salinger, J., New Zealand Meteorological Service, PO Box 722, Wellington 1, New Zealand.
Salomonson, V. V., Space and Earth Sciences Directorate, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA.
Sands, D. Division of Entomology, CSIRO, Indooroopilly Qld 4068, Australia.
Sanhueza, E., IVIC, Apartado 21827, Caracas 1020-A, Venezuela.
Sarmiento, J., Program in Atmospheric and Oceanic Sciences, University of Princeton, PO Box 308, Princeton, NJ 08542, USA.
Sass, R. L., Biology Department, Rice University, Houston, TX 77251, USA.
Saugier, B., Ecologie Végétale, Univeristy de Paris Sud, Bat. 362, F-91405 Orsay Cedex, France.
Schaffer, G., Department of Oceanography, University of Göteborg, PO Box

4038, S-400 40 Göteborg, Sweden.
Schiff, H. I., Canadian Institute for Research in Atmospheric Chemistry, York University, 4700 Keele Street, North York, Ontario, Canada M3J IP3.
Schimel, D. S., National Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523, USA.
Schimel, J. P., Institute of Arctic Biology, University of Alaska, Fairbanks, AK 99775, USA.
Schlüchter, C., Institut für Grundund Bodenmechanik, ETH Hönggerberg, CH-8093 Zürich, Switzerland.
Schnack, E. J., Laboratorio de Oceanografia Costera, Casilla de Correo 45, 1900 La Plata, Argentina.
Schubert, C. Centro de Ecologiá y Ciencias Ambientales IVIC, Apartado 21827, Caracas 1020A, Venezuela.
Schulze, R., Department of Agricultural Engineering, University of Natal, PO Box 375, Pietermaritzburg 3200, South Africa.
Schweigruber, F., Eidg. Anstalt für das Forstliche, Versuchwesen (EAFV), CH-89 Birmendsorf, Switzerland.
Seddoh, K. F., University of Benin, BP 1515, Lomé, Togo. Sellers, P., NASA/GSFC, Code 624, Hydrological Sciences Branch, Greenbelt, MD 20771, USA.
Semenova, T. Yu., Deptartment of Environtal Protection, VINITI, Moscow 125 219, USSR.
Sergeeva, N. A. Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR.
Setzer, A., INPE - Instituto de Pesquisas Espaciaias, Caixa Postal 515, 12201 SMo José dos Campos - SP, Brazil.
Shackleton, N. J., Sub-Department of Quaternary Research, The Godwin Laboratory, Free School Lane, Cambridge CB2 3RS, UK.
Shapley, A. H., NOAA, 325 Broadway, Boulder, CO 80303, USA
Shcherbakov, A. I., State Research Institute of Land Resources, ul. Novaya 30, Moscow Region 123810, USSR
Shebalin, P. N., Institute of Earth Physics, B. Gruzinskaya 10, Moscow 123810, USSR
Shugart, H. H., Department of Environmental Studies, The University of Virginia, Charlottesville VI 22903, USA.
Shumbera, A. L., NOAA/NCDC, Federal Building, Asheville, NC 28801, USA.
Shuttleworth, W. J., Institute of Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, UK.
Sibrava, V., Division of Earth Sciences, Unesco, 7 place de Fontenoy, F-75700 Paris France.
Siegenthaler, U., Physikalisches Institut, Universität Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland.
Siegfried, R., Percy Fitzpatrick Institute of African Ornithology, University of Capetown, Rondebosch 7700, South Africa.
Simeland, N., Department of Geography, University of Swaziland, Private Bag, Kwaluseni, Swaziland.
Simonett, D., Geography Department, University of California at Santa Barbara, Santa Barbara, CA, USA.
Singh, J. S., Department of Botany, Banaras Hindu University, Varanasi 221 005, India.
Singh, G., Research School of Pacific Studies, Australian National University, P.O.Box 4, Canberra, ACT 2601 Australia.
Sivakumar, M. V. K., ICRISAT Sahelian Centre, PO Box 12404, Niamey, Niger.
Skole, D., Institute for the Study of Earth, Oceans and Space, Science & Engineering Building, University of New Hampshire, Durham, NH 03824, USA.
Slater, R., Program in Atmospheric and Oceanic Sciences, University of Princeton, PO Box 308, Princeton NJ 08542, USA.
Slatyer, R., Office of Chief Scientist, Department of Prime Minister and Cabinet, Canberra, ACT 2600, Australia.
Smayda, T. J., The University of Rhode Island, Graduate School of Oceanography, Narragansett Bay Campus, Narragansett, RI 02882-1197, USA.
Smirnov, B. I., All-Union Research Institute of Hydrometeoinformation, ul. Koroleva 6, Obninsk 249020, USSR.

Smith, T., Department of Environmental Science, University of Virginia, Charlottesville VI 22903, USA.
Smith, K. A., The Edinburgh School of Agriculture, West Mains Road, Edinburgh EH9 3JG, UK.
Smuts, B., Anglo American Corporation, 44 Main Street, Johannesburg 2000, South Africa.
Soegiarto, A., Center for Oceanological Research and Development, Jlan Pasir Putih No. 1, Ancol Timur, Kotak Pos 580, Dak, Jakarta 11001, Indonesia.
Solomon, A., International Institute for Applied Systems Analysis, A-2361 Laxenburg, Austria.
Sombroek, W., ISRIC, PO Box 353, NL-6700 AJ Wageningen, The Netherlands.
Soons, J., Royal Society of New Zealand, PO Box 598, Wellington, New Zealand.
Specht, R., Botany Department, University of Queensland, St. Lucia, QLD 4067, Australia.
Stafford-Smith, M., CSIRO, Division of Wildlife & Ecology, PO Box 2111, Alice Springs NT, Australia.
Stanton, B., DSIR, Oceanographic Institute, Private Bag, Kilbirnie, Wellington 3, New Zealand.
Starkel, L., Institute of Geography and Spatial Organization, Polish Academy of Sciences, ul. Sw. Jana 22, 31-018 Cracow, Poland.
Stewart, J., Department of Soil Science, University of Saskatchewan, Saskatoon, SN7 0W0 Canada.
Stewart, R., 4249 Thornhill Crescent, Victoria, BC V8N, Canada.
Stoll, M. H. C., NOIZ, Den Burg, Texel, The Netherlands.
Strassinopoulos, E., Radiation Physics Office, Mail Code 600, NASA GSFC, Greenbelt, MD 20771, USA.
Strömberg, J.-O., Kristineberg Marine Biological Station, S-45034 Fiskebackskil, Sweden.
Stuart, W.F., Geomagnetism Research Group, Murchinson House, West Mains Road, Edinburgh EH9 3LA, UK.
Stuiver, M., Quaternary Research Center, University of Washington, Seattle, WA 98195, USA.
Su, W. H., Laboratory of Atmospheric Environment, Research Center for Eco-environmental Sciences, Academica Sinica, PO Box 934, Beijing 100083, China.
Su, J.-C., Department of Agricultural Chemistry, National Taiwan University, Taipei, Taiwan 10764, China.
Suckling, H., Department of Maths and Statistics, Ploytechnic South West, Plymouthm UK.
Summerhayes, C. P., IOSDL, Wormley, Godalming, UK.
Svensson, B., Department of Microbiology, University of Agricultural Sciences, Box 7025, S-750 07 Uppsala, Sweden.
Swift, M. J., International Institute of Tropical Agriculture, Ibadan, Nigeria.
Tambiev, S. B., USSR State Committee for Science and Technology, Moscow, USSR,
Tamm, C.O., Department of Ecology and Environmental Sciences Environmental Research, Swedish University of Agricultural Sciences, PO Box 7072 S-75007 Uppsala, Sweden.
Targulian, V., IIASA, Schlossplatz 1, A-2361 Laxenburg, Austria.
Taylor, A. H., Plymouth Marine Laboratory, Plymouth, UK.
Taylor, G. V., Scientific Research Council, PO Box 350, Kingston, Jamaica.
Temnyi, V. V., IZMIRAN, Troitsk, Moscow Region 142092, USSR.
Tewungwa, S., PO Box 47074, Nairobi, Kenya.
Thierstein, H. R., Geologisches Institut, ETH-Zentrum, CH-8092 Zürich, Switzerland.
Thind, H. S., Department of Soil Science, University of Reading, Reading, UK.
Thom, B. G., Department of Geography, Institute Building HO 3, University of Sidney, Sidney, New South Wales, Australia.
Thompson, S., IOSDL, Wormley, Godalming, UK.
Thurau, K., ICSU, Physiological Institute, University of Munich, Pettenkoferstrasse 12, D-8000 Munich 2, FRG.
Tiessen, H., Institute of Pedology, University of Saskatchewan, Saskatoon, Canada S7N 0W0.

Tigyi, J., Biophysical Institute of the Medical University, PO Box 99, H-7643 Pécs, Hungary.
Tilford, S. G., NASA Headquarters, Code EE, Washington, DC 20546, USA.
Tischenko, A. P., Earth Science Museum, Moscow State University, Moscow 117234, USSR.
Tiszkov, A. A., Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109107, USSR.
Tomlinson, R. F., 17 Kippewa Drive, Ottawa, Ontario KIS 3C3, Canada.
Tongway, D., CSIRO, Division of Wildlife & Ecology, Rangelands Research Centre, Private Bag PO, Deniliquin, NSW 2710, Australia.
Townshend, J., Department of Geography, University of Reading, Reading RG62 AU, UK.
Triana, H. C., Universidad Nacional de Colombia, Faculdad de Agronomia, Departamento de Agua y Suelos, Apartado 14490, Bogota, Colombia.
Troitskaya, V. A., 8692 Brae Brook Road, Lanham, MD, USA.
Tsendenbal, Z., Institute of Evolutionary Morphology and Ecology of Animals USSR Academy of Sciences, ul. Fersmana 13, Moscow 117312, USSR.
Tuck, A., Aeronomy Laboratory of NOAA, Broadway, Boulder, CO 80303, USA.
Tucker, B., CSIRO, Division of Atmospheric Research, Private Bag No. 1, Mordialloc, Victoria 3195, Australia.
Turner, S., CSIRO, Division of Wildlife and Ecology, PO Box 84, Lyneham, ACT 2606, Australia.
Tyson, P., University of the Witwatersrand, PO Box 2050, Witwatersrand, South Africa.
Tyupkin, Y. S., Soviet Geophysical Committee, Molodezhnaya 3 Moscow 117296, USSR
Uchijima, Z., c/o T. Nemoto, Faculty of Science, Ochanomizu University, Otsuka 2-1-1, Bunkyo-ku, Tokyo 112, Japan.
Vadkovsky, V.N. Ecological Department, Moscow State University, Moscow 117234, USSR.
van Ameringen, M., Research and Liaison Office, IDRC van Bladel, J., Laboratorium voor Electromagnetisme en Acoustica, Rijksuniversiteit Gent, St-Pieters-nieuwstraat 41, B-9000 Gent, Belgium.
van Emden, H., Royal Netherlands Academy of Sciences, Kloveniersburgwal 29, PO Box 19121, NL-1000 GC Amsterdam, The Netherlands.
van der Hammen, T., Hugo de Vries Laboratorium, Vakgroep Bijzondere Plantkunde, Kruislaan 318, NL-1089 SM Amsterdam, The Netherlands.
van Lookeren Campagne, I. N., Shell Gebouw, Hofplein 20, Rotterdam, The Netherlands.
Vandysheva, V. M., All-Union Research Centre, Bolshevistsky per 11, Moscow 101000, USSR.
Vasiliev, L.N., Institute of Geography, USSR Academy of Sciences, Staromonetny per 29, Moscow 109117, USSR.
Velitchko, A. A., Department of Palaeogeography, Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109017, USSR.
Verhoog, F., F., Division of Water Sciences, Unesco, 7, Place Fontenoy, 75700 Paris, France.
Vette, J. I., WDC-A for R & S, Code 692, NASA GSC, Greenbelt, MD 20771, USA
Vianne, M. L., Department of Oceanography, INPE, Caixa Postal 515, 12201 SMo José dos Campos - SP, Brazil.
Victoria, R. L., Centro de Energia Nuclear na Agricultura, Campus de Piracicaba, Universidade de SMo Paolo, SMo Paolo, Braxil.
Vinogradov, M. E., Shirshov Institute of Oceanology, Academy of Sciences of the USSR, 1, letnaya (Ljublino), Moscow 109 387, USSR.
Virji, H., IGBP Secretariat, The Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden.
Viskov, V. V., Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296, USSR.
Vitousek, P., Department of Biological Sciences, Stanford University, Stanford, CA 94305, USA.
Von Droste, B., Division of Ecological Sciences, Unesco, 7 Place de Fontenoy, F-75700 Paris, France.
Vossen, P., Institute for Remote Sensing Applications, Agricultural Project, Ispra Establishment, 21020 Ispra (Varese), Italy.

Vostokova, E. A., Research Centre "Priroda", ul. Verkhnepervomajskaya 4b, Moscow 105264, USSR.
Wahlen, M., Wadsworth Center for Laboratories and Research, New York State Department of Health, Alabany, New York 12201, USA.
Wajsowicz, R., Hooke Institute, Oxford, UK. Waldteufel, Ministère de la Recherche et de la Technologie, 1 rue Descartes, F-75231 Paris Cedex 05, France.
Walker, B. H., Division of Wildlife and Ecology, CSIRO, PO Box 84, Lyneham, ACT 2602, Australia.
Walker, J., Division of Water Research, CSIRO, GPO Box 1666, Canberra, ACT 2601, Australia.
Walling, D. E., Department of Geography, University of Exeter, Amory Building, 5 Rennes Drive, Exeter, Devon EX4 4RJ, UK.
Wang, M. X., Institute of Atmospheric Physics, Academia Sinica, De Sheng Men Wai Street, Beijing, China.
Waring, R., College of Forestry, Oregon State University, Corvallis, Oregon 97331, USA.
Wasson, B., CSIRO, Division of Water Resources, GPO Box 1666, Canberra, ACT 2601, Australia.
Webber, J.D., Universities Space Research Assoc., American City Building, Suite 212, Columbia, MD 21044, USA.
Webster, F., College of Marine Studies, University of Delaware, Lewes, DE 19958, USA.
Weeks, A., Southampton University, UK. Weinert, E., Martin-Luther University, Sektion Biowissenschaften, 402 Halle, Neuwerk 21, GDR.
Wells, N., Department of Oceanogrphy, Southampton University, UK.
Werner, P., CSIRO, Division of Wildlife & Ecology, PM Box 44, Winnellie, NT 0821, Australia.
Westbroek, P., University of Leiden, The Netherlands. Westoby, M., School of Biological Sciences, Macquarie University, North Ryde, NSW 2113, Australia.
Westoby, M., School of Biological Sciences, Macquarie University, Sydney, NSW 2109, Australia.
Whelpdale, D. M., Atmospheric Environment Service, Environment Canada, 4905 Dufferin St., Downsview, Ontario M3H 5T4, Canada.
Whitfield, M., Plymouth Marine laboratory, Citadel Hill, Plymouth, Devon, UK.
Whyte, A. V., Social Sciences Division, IDRC, Toronto, Canada.
Wickland, D., Land Processes Branch, Earth Science & Applications Division, NASA Headquarters, Washington, D.C. 20546, USA.
Wieprecht, W., Heinrich-Hertz-Institut for Atmospheric Research, Academy of Science, Rudower Chausse 5, DDR-1199 Berlin, GDR.
Wille, S. O., Norwegian Research Council, Oslo, Norway. Williams, J., Division of Soils, CSIRO, Private Mail Bag, Aitkenvale, Qld 4814, Australia.
Williams, P. J., University College of Wales, Bangor, UK.
Williamson, P., Plymouth Marine Laboratory, Plymouth, UK. Wilson, G., Animal Resources Branch, Bureau of Rural Resources, GPO Box 858, Canberra, ACT 2601, Australia.
Withee, G., NOAA/NESDIS/NODC, 1825 Connecticut Avenue NW, Washington, DC 20235, USA.
Wolf, U., Institute für Meereskunde, Kiel, FRG.
Wölfli, W., Institut für Mittelenergiephysik, ETH Hönggerberg, CH-8093 Zürich, Switzerland.
Wood, R. A., Metorological Office, Bracknell, UK. Wood, E., University College of Wales, Bangor, UK.
Woodmansee, R., Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523, USA.
Woods, J. D., Natural Environment Research Council, Marine Sciences Directorate, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU, UK.
Woodward, F. I., Department of Botany, University of Cambridge, Downing Street, Cambridge CB2 3EA, UK.
Woolf, K. K., Department of Oceanography, University of Southampton, UK.
Wright, R., Norwegian Institute for Water Research, Brekkeveien 19, Box 69 Korsvoll, N-0808 Oslo 8, Norway.

Wroblewski, J., Memorial University of Newfoundland, St Johns, Newfoundland A1B 3X9, Canada.
Wulff, F., Asko Laboratory, Stockholm, Sweden.
Yajnik, K. S., CSIR Centre for Mathematical Modelling and Computer Simulation, National Aeronautical Laboratory (Belur Capus), Bangalore 560 037, India.
Yang, Z-L., Macquarie University, School of Earth Sciences, Sydney, NSW 2109, Australia.
Yang, W-X., Research Centre Eco-Environmental Sciences, Academia Sinica, PO Box 934, Beijing 100083, China.
Ye, D., Academia Sinica, 52 Sanlihe Road, Beijing, China. Yuan Yaochu, Second Institute of Oceanography, State Oceanic Administration, Hngzhou, China.
Zaletaey, V.S., Institute of Water Problems, Sadovo-Chernogriazskaya 13/3, Moscow 103064, USSR.
Zavarzin, G. A., Institute of Microbiology, USSR Academy of Sciences, Prosp. 60 -letija Octjabrja 7, Moscow 117812, USSR.
Zeitzschel, B., Institut für Meereskunde, Universität Kiel, Düsterburger Weg 20, D- 2300 Kiel, FRG.
Zepp, R. G., Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia 30605, USA.
Zhao, D., Research Center for Eco-Environmental Sciences, Aacdemia Sinca, PO Box 934, Beijing 100083, China.
Zhdanov, M. S., IZMIRAN, Troitsk, Moscow Region 142092, USSR.
Zhdanova, O. N., Soviet Geophysical Committee, Molodezhnaya 3, Moscow 117296,
USSR.
Zhizhin, M. N., Institute of Earth Physics, USSR Academy of Sciences, B. Gruzinskaya 10, Moscow 123810, USSR.
Zimmermann, P., National Center for Atmospheric Research, PO Box 3000, Boulder, Colorado 80307, USA.
Zimmermann, R., Department of Plant Physiology, Universität Bayreuth, D-8580, FRG.
Zlotin, R. I, Institute of Geography, USSR Academy of Sciences, Staromonetny per. 29, Moscow 109017, USSR.
Zonov, Y. V., Glavcentre "Ocean", VNIRO, Moscow 117140, USSR.

Acronyms and Abbreviations

Appendix 7

ABLE	Atmospheric Boundary Layer Experiment
ABRACOS	Anglo-Brazilian Climate Observational Study
ACE	Advisory Committee on the Environment (ICSU)
AEROCE	Atmosphere/Ocean Experiment
AGASP	Arctic Gas and Aerosol Sampling Programme
ALT	Radar Altimeter (Seasat, GEOS-3)
AMAHSE	Amazonas Heat Source Experiment
AMS	Accelerator Mass Spectrometry
AMUSE	Amazonian Land Use Project
AVHRR	Advanced Very High Resolution Radiometer
BAHC	Biological Aspects of the Hydrological Cycle (IGBP)
BAPMoN	Background Air Pollution Monitoring (WMO/UNEP)
BATS	Biospheric Atmospheric Transfer
CCCO	Joint Committee on Climatic Changes and the Ocean (ICSU - IOC)
CCN	Cloud Cendensation Nuclei
CD-ROM	Compact Disk-Read Only Memory
CEC	Cation Exchange Capacity
CFC	Chlorofluorocarbon
CGIAR	Consultative Group on International Agricultural Research
CIDA	Canadian International Development Agency
CIRAC	Canadian Institute for Research in Atmospheric Chemistry
CODATA	Committee on Data for Science and Technology (ICSU)
COHMAP	Cooperative Holocene Mapping Project
COMAR	Coastal Marine Project (Unesco)
COSPAR	Committee on Space Research (ICSU)
CPO	Core Project Office (IGBP)
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
CZCS	Coastal Zone Colour Scanner
DIAL	Diffenential Absorption Lidar
DIF	Directory Interchange Format
DIS	Data and Information System
DMS	Dimethyl sulphide
DMSP	Defense Meteorological Satellite Program (USA)
DNA	Dioxyribonuclic Acid
DOC	Dissolved Organic Carbon
EC-IGBP	Executive Committee IGBP
ECHIVAL	European International Project on Climate and Hydrological Interactions Between Vegetation, Atmosphere and Land Surfaces
ECMWF	European Centre for Medium Range Weather Forecasting
EFEDA	ECHIVAL Field Experiment in a Desertification Threatened Area
ENSO	El Niño - Southern Oscillation
EOS	Earth Observing System (USA)
ERBE	Earth Radiation Budget Experiment (NOAA, NASA)
EROS	Earth Resources Observing Satellite
ERS	ESA Remote Sensing Satellite
ESA	European Space Agency
ESF	European Science Foundation
ET	Evapotranspiration
EEZ	Exclusive Economic Zone
FAGS	Federation of Astronomical and Geophysical Services (ICSU)
FAO	Food and Agriculture Organization
FATE	Functional Attributes in Terrestrial Ecosystems
FIFE	First ISLSCP Field Experiment
FIRE-2	First ISCCP Regional Experiment (Phase 2)

GAC	Global Area Coverage
GAGE	Global Atmospheric Gases Experiment
GAIM	Global Analysis, Interpretation and Modelling (IGBP)
GARP	Global Amtospheric Research Programme
GBM	Geosphere-Biosphere Model
GBO	Geo-Biosphere Observatories (IGBP)
GC	Gas Chromatograph
GCEC	Global Change and Ecological Complexity (IGBP)
GCM	General Circulation Model
GCTE	Global Change and Terrestrial Ecosystems (IGBP)
GEDD	Global Environmental Data Directory
GEMS	Global Environmental Monitoring System (UNEP)
GEWEX	Global Energy and Water Cycle Experiment (WCRP)
GHM	General Hydrological Model
GIS	Geographic Information System
GLOMAC	Global Modelling of Atmospheric Chemistry
GMCC	Global Monitoring for Climate Change (USA)
GMS	Geostationary Meteorological Satellite (Japan)
GOES	Geostationary Operational Environmental Satellite (U.S.)
GOEZS	Global Ocean Euphotic Zone Study (IGBP)
GRID	Global Resource Information Database (UNEP)
GSFC	Goddard Space Flight Center
HAPEX	Hydrological Atmosphere Pilot Experiment
HEIFE	Heihe river Field Experiment
HIRIS	High Resolution Imagine Spectrometer (NASA/GSFC)
HRGC	Human Response to Global Change (IFIAS/ISSC/UNU/Unesco)
IABO	International Association for Biological Oceanography (IUBS/ICSU)
IACP	International Aerosol Climatology Project (IAMAP)
IAGA	International Association of Geomagnetism and Aeronomy (IUGG/ICSU)
IAHS	International Association of Hydrological Sciences (IUGG/ICSU)
IAMAP	International Association of Meteorology and Atmospheric Physics (IUGG/ICSU)
IBP	International Biological Programme (ICSU)
IBSNAT	International Benchmark Sites Network for Technology Tansfer
ICA	International Cartographic Association
ICACGP	Commission on Atmospheric Chemistry and Global Pollution (IUGG-IAMAP)
ICC	Interagency Coordinating Committee (IGBP)
ICL	Inter-Union Commission on the Lithosphere (ICSU)
ICSU	International Council of Scientifc Unions
IFIAS	International Federation of Institutes of Advanced Studies
IGAC	International Global Atmospheric Chemistry Project (ICACGP/IGBP)
IGAP	International Global Aerosol Programme (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 Quaternary Research
INTECOL	International Association for Ecology (IUBS/ICSU)
IOC	Intergovernmental Oceanographic Commission (Unesco)
IPCC	Intergovernmental Panel on Climate Change (WMO/UNEP)
IR	Infrared

IRC	International Resource Committee (IGBP/WCRP)
ISCCP	International Satellite Cloud Climatology Project (WCRP)
ISLSCP	International Satellite Land Surface Climatology Project
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 (ICSU)
IUCN	International Union for the Conservation of Nature
IUGG	International Union of Geodesy and Geophysics (ICSU)
IUGS	International Union of Geological Sciences (ICSU)
IUPAB	International Union of Pure and Applied Biophysics
JERS	Japanese Earth Resources Satellite
JGOFS	Joint Global Ocean Flux Study (SCOR/IGBP)
JSC	Joint Scientific Committee for WCRP
LAI	Leaf-Area Index
LANDSAT	Land Remote-Sensing Satellite (USA)
LAVIP	Land-Surface-Atmosphere-Vegetation Interaction Programme
LIDAR	Light Detection and Ranging
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP)
LST	Land Surface Temperature
MAB	Man and the Biosphere Programme (Unesco)
MACS	Middle Atmosphere in the Climate System (IAGA)
MAPS	Measurement of Air Pollution from Space
MARC	Middle Atposphere Responses to Change (IAMAP)
MODIS	Moderate Resolution Imaging Spectrometer (NASA/GSFC)
MOS	Marine Observational Satellite (Japan)
MS	Mass Spectrometer
N-ROSS	Navy Remote Ocean Sensing System (USA)
NAS	National Academy of Science (USA)
NASA	National Aeronautics and Space Administration (USA)
NCAR	National Center for Atmospheric Research (USA)
NDSC	Network for the Detection of Stratospheric Change
NDVI	Normalized Difference Vegetation Index
NERC	National Environmental Research Council (UK)
NOAA	National Oceanic and Atmospheric Administration (USA)
NSF	National Science Foundation (USA)
OCI	Ocean Colour Imager (NASA)
OCM	Ocean Circulation Model
OCTS	Ocean Colour Temperature Scanner (Japan)
PAGES	Past Global Changes (IGBP)
PAM	Plant Available Moisture
PAR	Photosynthetically Active Radiation
PBL	Planetary Boundary Layer
PFT	Plant Functional Type
PLSPC	Research Programme on Land-Surface Processes and Climate
POC	Particulate Organic Carbon
POLDER	Polarization and Directionality of Earth Reflectances (France)
PSC	Polar Stratospheric Clouds
QBO	Quasi-Biennial Oscilliation
RADAR	Radio Detection and Ranging
RRC	Regional Research Centres (IGBP)
SAR	Synthetic Aperture Radar
SAC	Scientific Advisory Council (IGBP)
SAFISY	Space Agency Forum for the International Space Year
SC-IGBP	Special (or Scientific) Committee for the IGBP
SCAR	Scientific Committee on Antarctic Research (ICSU)
SCOPE	Scientific Committee on Problems of the Environment (ICSU)

SCOR	Scientific Committee on Ocean Research (ICSU)
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics (ICSU)
SeaWiFS	Sea-viewing Wide Field of View Sensor
SiB	Simple Biosphere
SIFE	Second ISLSCP Field Experiment
SOTER	World Soils and Terrain Data Base
SPOT	Système pour l'Observation de la Terre (France)
SSC	Scientific Steering Committee (IGBP)
SST	Sea Surface Temperature
STEP	Solar Terrestrial Energy Programme (SCOSTEP)
STIB	Stratosphere-Troposphere Interactions and the Biosphere (IGBP)
SVAT	Soil-Vegetation Atmosphere Transfer
TM	Thematic Mapper
TOGA	Tropical Oceans and Global Atmosphere Programme (WCRP)
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean Topography Experiment POSEIDON (USA/France)
TOR	Tropospheric Ozone Research
TRACE	Transport of Chemistry near the Ocean
TRMM	Tropical Rainfall Measuring Mission (NASA/Japan)
TSBF	Tropical Soil Biology and Fertility (IUBS/ICSU)
TTO	Transient Tracers in the Oceans
UARS	Upper Atmosphere Research Satellite (USA)
UN	United Nations
UNCSTD	UN Center for Science and Technology for Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
Unesco	United Nations Educational, Scientific and Cultural Organization
UNITAR	United Nations Institute for Training and Research
UNU	United Nations University
URSI	Union Radio Scientifique Internationale (ICSU)
UV	Ultraviolet
VOC	Volatile Organic Compounds
WATOX	Western Atlantic Ocean Experiment
WCDP	World Climate Data Programme
WCIP	World Climate Impact Programme
WCP	World Climate Programme
WCRP	World Climate Research Programme (WMO/ICSU)
WDC	Panel on World Data Centres (Geophysical and Solar) (ICSU)
WDDES	World Digital Database for Environmental Science
WGNE	Working Group on Numerical Experimentation (WCRP)
WHP	WOCE Hydrographic Survey
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment (WCRP)

IGBP Reports

No. 1. The International Geosphere Programme: A Study of Global Change. Final Report of the Ad Hoc Planning Group, ICSU 21st General Assembly, Bern, Switzerland 14-19 Septemeber, 1986 (1986)

No. 2. A Document Prepared by the First Meeting of the Special Committee, ICSU Secretariat, Paris 16-19 July, 1987 (1987)

No. 3. A Report from the Second Meeting of the Special Committee, Harvard University, Cambridge, MA, USA 8-11 February, 1988 (1988)

No. 4. 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 (1988)

No. 5. Effects of Atmospheric and Climate Change on Terrestrial Ecosystems. Report of a Workshop Organized by the IGBP Coordinating Panel on Effects of Climate Change on Terrestrial Ecosystems at CSIRO, Division of Wildlife and Ecology, Canberra, Australia 29 February - 2 March, 1988. Compiled by B. H. Walker and R. D. Gratez (1989)

No. 6. Global Changes of the Past. Report of a Meeting of the IGBP Working Group on Techniques for Extracting Environmental Data of the Past held at the University of Bern, Switzerland 6-8 July, 1988. Compiled by H. Oeschger and J. A. Eddy (1989)

No. 7. A Report from the First Meeting of the Scientific Advisory Council for the IGBP. Volumes I and II. (1989)

No. 8. Pilot Studies for Remote Sensing and Data Management. Report from Working Group Workshop held in Geneva, Switzerland 11-13 January 1989. Edited by S. I. Rasool and D. S. Ojima (1989)

No. 9. Southern Hemisphere Perspectives of Global Change. Scientific Issues, Research Needs and Proposed Activities. Report from a Workshop held in Mbabane, Swaziland 11-16 December, 1988. Edited by B. H. Walker and R. G. Dickson (1989)

No. 10. The Land-Atmosphere Interface. Report on a Combined Modelling Workshop of IGBP Coordinating Panels 3, 4, and 5. Brussels, Belgium, 8-11 June, 1989. Edited by S. J. Turner and B. H. Walker (1990)

No. 11. Proceedings of the Workshops of the Coordinating Panel on Effects of Global Change on Terrestrial Ecosystems. I. A Framework for Modelling the Effects of Climate and Atmospheric Change on Terrestrial Ecosystems, Woods Hole, USA, 15-17 April, 1989. II. Non-Modelling Research Requirements for Understanding, Predicting, and Monitoring Global Change, Canberra, 29-31 August 1989. III. The Impact of Global Change on Agriculture and Forestry, Yaoundé, 27 November-1 December, 1989. Edited by B. H. Walker, S. J. Turner, R. T. Prinsley, D. M. Stafford Smith, H. A. Nix and B. H. Walker. (1990)

No. 12. The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP). The Initial Core Projects. (1990)