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The International Geosphere-Biosphere Programme: A Study of Global Change Final Report of the Ad Hoc Planning Group ICSU 21st General Assembly, Berne, Switzerland 14–19 September, 1986

International Council of Scientific Unions

AD HOC PLANNING GROUP ON GLOBAL CHANGE

THE INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME: A Study of Global Change

Final report of the Ad Hoc Planning Group authorized by a resolution of the 20th General Assembly in Ottawa, September 1984, "to review the relevant ongoing activities of bodies in the ICSU family and other organizations, to identify priority subjects for early action and to develop a coherent programme after analysis of the possible contribution of ICSU Scientific Unions, National Members and specialist bodies."

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Contents

Related Reports
(available separately)

Report of the Ad Hoc Working Group on Terrestrial Ecosystems and Atmospheric Interactions (F. diCastri, Chairman)
Report of the Ad Hoc Working Group on Marine Ecosystems and Atmospheric Interactions (J. McCarthy, Chairman)
Report of the Ad Hoc Working Group on Geological Processes, Past and Present (R. Price, Chairman)
Report of the Ad Hoc Working Group on Upper Atmosphere and Near-Space Environment (J. Roederer, Chairman)
Report of the COSPAR Working Group on Remote Sensing (S.I. Rasool, Chairman)

SUMMARY

A better understanding of the Earth and its immediate environment is essential if we are to improve our ability to detect and to respond to warnings of significant global change. Although the world community of scientists has in the last 30 years successfully completed a wide range of international programmes such as the International Geophysical Year, the International Biological Programme, the International Hydrological Programme, the International Lithosphere Programme and the Global Atmospheric Research Programme, these have tended to concentrate on isolated components of the whole Earth system: the atmosphere, the biosphere, the hydrosphere, the lithosphere. The progress made in these areas plus technological advances in high-speed computers and spaceborne sensors allow, for the first time, a synthesis of information on a global scale, and the development of interactive models.

The IGBP will be a carefully-designed programme of research directed at providing the information we need to assess the future of the Earth in the next 100 years, with an emphasis on processes that change on time scales of decades to centuries. It will be a programme of basic research with almost immediate practical applications in the management of resources at national and international levels and as a means of improving the reliability of warnings of global change of significance to our environment and to humankind.

The programme will be tightly focused, with emphasis on interactive processes that are not addressed by other existing programmes. Topics suggested for early emphasis in the IGBP include: (1) studies of biogeochemical cycles; (2) studies of the ocean euphotic zone; (3) studies of soil dynamics and soil chemistry; and (4) studies of variable solar inputs to the Earth. Emphasis is also put on the need for development of an adequate global data and information system, that must be an integral part of the programme.

It is recommended that ICSU create a Scientific Committee for the IGBP (SCGB) with responsibility for initiating a preparatory phase lasting about four years and for the implementation of an operational phase beginning in the early 1990s. The operational phase will last at least 10 years.

A primary responsibility of the Scientific Committee will be to ensure that the objectives of the programme are well designed and that it complements current and planned international scientific programmes. The Committee will also be responsible, first for the establishment and then for the maintenance of liaison with international and national organizations responsible for related programmes and for ensuring the coordination of inputs from other members of the ICSU family, including the National Members.

1. RATIONALE FOR THE IGBP

In the past 30 years the world community of scientists has undertaken a number of broadly-based international programmes of research aimed at increasing our knowledge in areas of the Earth and biological sciences, organized through the International Council of Scientific Unions and other international scientific organizations such as UNESCO, UNEP, and the WMO. Among these programmes were the International Geophysical Year and the International Biological Programme, the continuing World Climate Research Programme, Man and the Biosphere Programme, International Hydrological Programme and International Lithosphere Programme, and the planned International Solar-Terrestrial Programme. These and other major international efforts have tended to concentrate on individual components of the total Earth system: the atmosphere, the biosphere, the hydrosphere, the lithosphere, or the solar-terrestrial medium.

Progress in each of these areas now makes it possible to initiate a new and broader initiative aimed at a fuller understanding of the Earth as an interconnected whole. The International Geosphere-Biosphere Programme will build on the foundations that other programmes have laid and utilize their continued findings, to the benefit of both. Importantly, it will also initiate a set of new activities--uniquely appropriate for ICSU--that are directed at understanding the key interactions that link the various components of the Earth system, in an effort to fill the critical gaps between them. Its ultimate goals are a fuller understanding of the Earth as a system and a fuller awareness of the course and causes of significant global change.

The dominant changes that affect the environment and the course of life on Earth are natural ones, induced by such inexorable forces as natural selection, the shifting of winds and rivers, changing inputs from the Sun, the turbulent dynamics of the atmosphere and oceans, the drifting of continental plates, the building of mountains, and the expansion and contraction of ice masses. But imposed on these is now another set of changes, more recent and immediate in consequence, that are the clear result of human activities. Our uses of energy and practices of intensive farming and technology have altered the albedo of the Earth, the composition of soil and waters, the chemistry of the air, the areas of forests, the diversity of plant and animal species, and the balance of the global ecosystem. To read the impacts of human actions--or to forecast their effects--requires a fuller knowledge of the natural background of change on which they are imposed, and the processes and feedbacks through which they work.

Immediate practical problems of the global environment such as acid rain, desertification, soil degradation and the build-up of greenhouse gases are much alike in that they involve interactive processes that transcend the bounds of single disciplines. In many cases uncertainties in our understanding of the complex interdependencies of the geosphere and biosphere restrict our ability to identify causes or effects, or to anticipate the costs and benefits, economic or environmental, of possible responses.

These interactions now loom as a major unknown in our understanding of the Earth as a system; and they are not fully addressed in existing programmes of research. What is needed is a transdisciplinary effort among segments of the earth and biological sciences, a way of consolidating the advances made in more disciplinary, ongoing programmes, and the international organization and national commitments necessary to mount a truly global study.

The purposes of the IGBP are both fundamental and practical. Advances in knowledge of components of the Earth has reached the point where steps toward integration are needed; moreover, in identifying the interactive processes--that link the

geosphere to the biosphere, that trace the cycling of key elements between land and water and air and biota, and that couple the oceans to the air or the Sun to the Earth--we increase the base of knowledge in all of these fields. At the same time an improved description and a deeper understanding of the planet on which we live will improve the reliability of warnings of significant global change and will provide the bases for more rational management of resources.

Four reasons now suggest that it is time to begin this new endeavor:

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

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

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

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

The scientific questions that must be addressed in an IGBP are urgent, fundamental, and difficult. They are urgent because of the necessity to meet the needs and respond to the aspirations of the large human population that will live on the Earth within the next century. They are fundamental because they involve understanding the Earth as a whole and the functioning of interacting forces and complex processes under changing conditions. They are difficult because they require a new mode of scientific enterprise: a collaboration among disciplines and programmes that have in the past operated largely alone--and they must look at the Earth as a whole, requiring international scientific cooperation. Their solution demands the scope and approach of an international programme. Such an effort, though long needed, could not have been mounted 20 years ago or even 10 years ago. Nor can it be completed in the next 10 years or the next 20. But we have the means, today, to make a start.

2. OBJECTIVE

The IGBP will focus on a restricted set of specific problems within a broad intellectual framework with essential inputs from a number of strong international programmes that are already underway. The following objective has now been widely endorsed by member unions, special committees and national adherents of ICSU as an appropriate focus for the IGBP:

> **To describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions.**

The IGBP will be a tightly defined programme of research directed at providing fundamental knowledge that will serve as a basis for assessing likely future changes on the Earth in the next 100 years. The emphasis on processes of change on time scales of decades to centuries defines an important focus, directing the effort at an array of emerging issues that are most likely to affect the course of life in the ensuing century, and that seem most amenable to prediction.

Such an effort is both needed and timely. If planning starts now, the IGBP can be in operation in the 1990s--a significant period of projected change during which we may expect the first observable climatic impact of concentrations of greenhouse gases (such as CO_2, CH_4, and N_2O), the continued destruction of much of the tropical forest reserve, and increasing use of resources by an expanded world population. The long time scales of many of the processes involved--as well as the magnitude of the task--dictate that the IGBP will continue well into the next century. The programme will be based on a series of process studies, observations and modelling. It will also include increased efforts to recover a much longer history of the Earth and its environment, from geological records and the records preserved in tree rings and ice and ocean sediments, for we recognize that changes on a wide range of time scales, from years to hundreds of millions of years, are of significance for the stated objective of the programme. Knowledge of the past is essential for understanding the present or predicting the future. The IGBP will be a programme of cooperative efforts of varied disciplines--with key system interactions as the focus and discriminator in setting priorities and principal emphases. These critical linkages between living and nonliving components, involving physical, chemical, and biological processes are the outstanding unknown in our present understanding of the Earth as a system.

In concentrating on interactive biological, chemical, and physical processes the IGBP will of necessity put less emphasis on studies that, though they have great strengths and momentum of their own, are already being addressed in existing initiatives, or that will less clearly contribute to our understanding of the changing nature of the environment of life on timescales of decades to centuries. Priority in the IGBP will therefore fall on those areas of each of the fields involved that deal with key interactions and significant change on time scales of decades to centuries, that most affect the biosphere, that are most susceptible to human perturbation, and that will most likely lead to practical, predictive capability.

To satisfy such a need the IGBP must take full advantage of the modern ability to study the Earth's surface, oceans, biota, and inputs from the Sun from the vantage of space. Indeed the new technologies of spaceborne instrumentation and of high-speed computers allow the global synthesis of information needed for scientific understanding. These new technologies are proving central to advances in such fields as oceanography,

geophysics, atmospheric dynamics, regional and global ecology, and solar-terrestrial physics, and they are a sine qua non of the IGBP. Yet the programme cannot be based on space techniques alone. It will demand an even larger observational effort from the ground, on land and sea and ice, as well as from supporting aircraft. A part of this ground-based effort will be needed to validate and calibrate spaceborne measurements, but a larger part will be devoted to local studies of biomes and climatic zones in selected land or water regions, to understand the interdependence of changes on regional and global scales.

The IGBP must be truly international, in planning, in execution, and in final analyses, for the concerns of the programme are those of the entire globe. Considerations of facility needs, access to key regions and human effort will require the participation of scientific institutions, national funding agencies, and scientists and technicians from both the advanced and the developing countries in all areas of the world. A need equally great is that of the active involvement of the governments that will fund the programme and that will ultimately use the knowledge gained to make policy and economic decisions.

3. PROGRAMME PLAN

3.1 Background

The programme plan that is here described is based on a two-year study carried out under the auspices of ICSU by the Ad Hoc Planning Group on Global Change, following a resolution of the 20th General Assembly in Ottawa in 1984. An initial charge was to review relevant activities of bodies in the ICSU family and other organizations to define the IGBP in the proper context of other ongoing programmes. A second element called for the definition of a coherent programme and the specification of priority subjects for early action. These steps were undertaken in initial discussions that led to the circulation of a draft plan and, following this, the adoption of the programme goal and principles of focus that were enumerated in Section 2.

Four Ad Hoc Working Groups were appointed in October 1985, to consider related programmes, to provide inputs that would further define programme emphasis, and to suggest priority subjects for initial emphasis. Reports from these Ad Hoc Working Groups,

- Terrestrial Ecosystems and Atmospheric Interactions (F. diCastri, Chairman)
- Marine Ecosystems and Atmospheric Interactions (J. McCarthy, Chairman)
- Geological Processes, Past and Present (R. Price, Chairman), and
- Upper Atmosphere and Near Space Environment (J. Roederer, Chairman)

were reviewed with the report of the

- COSPAR Working Group on Remote Sensing (I. Rasool, Chairman)

as resource material for the structuring of a general plan. These five Ad Hoc Working Group papers are an available resource that can provide further background for future planning of the IGBP.

The plan outlined here is intended to define the scope, guidelines, criteria for initial emphasis, the principles of organization for the IGBP and its relationship to other programmes. Specific scientific research plans for the IGBP will be developed by the Scientific Committee defined in Section 5, and the problem-oriented Scientific Working Groups that the Scientific Committee will appoint.

3.2 General Considerations

The Planning Group recognizes the importance of other ongoing research activities, as explicitly charged in the ICSU resolution of 1984 and in subsequent policy decisions of the ICSU Executive Board. What is called for that is new is a transdisciplinary programme to address those areas of research that:

- Require multidisciplinary efforts for their accomplishment, i.e., that involve the simultaneous consideration of physical, chemical and biological processes and the collaboration or coordination of adjacent fields of study.

- Concern key interactive processes of the Earth system that are fundamental for our understanding of the regional and global interactions that now seem to effect the future habitability of the planet.

- Can aid in identifying the effects of human perturbations against the background of natural change, based in part on an expanded understanding of the past history of the global environment.

- Can serve as a basis for making better projections of the consequences of significant global change on time scales of decades to centuries.

The IGBP will concentrate on those aspects of global change, perceived or anticipated, that require the most attention and on the joint efforts among nations that are needed to address them scientifically. The programme must also be able to make the case for the substantially increased resources, coordinated internationally, that will be needed to ensure success.

3.3 Programme Elements

The IGBP will require the collaboration of different disciplines in five major areas: (i) the conduct of specific process studies; (ii) the taking of relevant observations; (iii) the development of global models; (iv) the recovery of the environmental history of the past; and, (v) the development of a global data and communication system. These five fundamental components are briefly described in following sections of this Report.

3.3.1 Process Studies

Any programme based on understanding global interactions must be built on a full understanding of the fundamental processes involved, and particularly those critical processes where additional knowledge is needed for the ultimate aim of developing interactive global models. For this reason the selection and design of process studies must proceed in parallel with the development of system models. An important facet of process studies is the synthesis of findings into quantitative models of the processes under consideration, which can be tested and also can serve as building blocks in the development of global models.

Testable hypotheses now exist for several of the interactive processes that govern critical global, regional, and local changes; new observations, or the recovery and interpretation of past records of global change will be required to investigate other hypotheses; while some studies will be guided by new models that address relevant interactions. It should be emphasized that the analysis of data already available is an important step in the definition and development of process studies. Such work is an essential part of the preparatory phase of the IGBP which will lead to comprehensive, global observation programmes using spacecraft.

Several types of process studies will be required, such as:

- Studies of interactive terrestrial processes. Initial questions are: how can we generalize from local or single site observations; what can we learn from transect and ecotone studies? The International Satellite Land Surface Climatology Project (ISLSCP) of COSPAR, IAMAP and UNEP, and the Cooperative Holocene Mapping Project (COHMAP) of INQUA are multidisciplinary programmes of this type that are already underway.

- Studies of essential interactions in the marine euphotic zone. Here, the work of a number of SCOR Working Groups is particularly relevant to the

goals of an IGBP. New activities of the IGBP will be directed towards the interactive processes that lie in the gaps between these and other efforts.

- Studies of biogeochemical cycles, involving interaction between many disciplines. An important segment is the study of tropospheric, stratospheric and mesospheric physical/chemical processes, to the extent that they are related to changes important to life. The Global Tropospheric Chemistry Programme, aimed at understanding basic chemical cycles in the troposphere, predicting atmospheric responses to perturbations, and providing information for the maintenance of the atmospheric component of the global life support system, is particularly relevant.

Other topics for emphasis include studies of species diversity, variations and effects of significant inputs to the Earth system from space (the "upper boundary condition"), the interactive effects of the land surface, soils, and the hydrology of the planet (the "lower boundary condition") and effects of large random perturbations to the system, as through vulcanism and extraterrestrial impacts (the "stochastic boundary condition"). Archives held in tree-rings, soils, sediments, glaciers and, on longer time scales, in the solid Earth will provide invaluable tests of past changes in the Earth system, including processes of fundamental interaction.

3.3.2 Observations and Data

The data needed for the IGBP will come from many sources, including both dedicated experiments and related programmes. An essential need are long time series records of physical, chemical and biological components of the global environment.

The information needed for specific process and modelling studies will be gathered by a number of means. First, coordinated work will be needed to collect data on ongoing changes in land use from more disciplinary sources. Within the context of the IGBP, one of the more promising possibilities is the development of dedicated, cooperative field stations that might be called "Biosphere Observatories". Coordinated physical, chemical and biological measurements taken within selected, representative biomes can fulfill many needs: providing inputs to modelling, monitoring change, and providing empirical inputs to research on problems of scaling and aggregation. These field sites will also provide measurements of the effects of biota on the environment, as well as the effects of biota on local conditions. The same sites will provide data for global model development concerning net productivity and the gross flows of energy and materials. They can also serve as specific test areas for the validation of remote sensing data. In view of the hetereogeneity of the Earth's surface and biota, a number of representative sites will need to be selected, involving vegetation and terrains of many types.

If we are to model and understand processes of interaction between biota and the physical and chemical environment on a global scale, we need first to describe conditions and fluxes in smaller, heterogeneous units of the Earth's surface. Remote sensing can provide some but not all of the needed process-specific information on appropriate time and space scales. It will be necessary to simplify and aggregate by classifying portions of the Earth's surface, oceans and atmosphere into comparable units that can be combined to adequately represent the response of a global system. Classification schemes will vary, depending on processes being studied, with guidance from the developing study of hierarchy theory. A preliminary study of the scaling problem has already been undertaken by SCOPE and INTECOL, through an initial international, interdisciplinary workshop held in St. Petersburg, Florida in 1985.

Remote sensing observations of land and ocean areas from space hold the greatest hope for observing significant global changes and for understanding large-scale, coupled processes in the environment. Such data reveal important patterns of atmospheric, ocean, ice, surface and biological activity. The full potential of remote sensing data cannot be realized, however, without careful planning of instrumentation, attention to conditions of measurement, and consistency of method and calibration. Equally important are meaningful interpretation, and comparisons against "ground truth". In these endeavors, scientists from many fields must collaborate to achieve progress at the level of global understanding. Constructive efforts are underway in this area, for example, in ISLSCP and in HAPEX. A comprehensive study of needs and opportunities of satellite observations in the IGBP has now been completed by the COSPAR Working Group on Remote Sensing.

Observations of the Earth from space are an essential element of the IGBP, and the reason, as much as any other, why the programme is now possible. Design and planning of spaceborne elements of the IGBP must be carried out as an integral part of the overall research design of the programme and in close connection with other early planning activities. The expense and long lead times of these endeavors require foresight, early planning and close coordination between national and international space agencies. The development of a comprehensive observing system to monitor global change, including both surface based and satellite observatories, will take at least a decade. The mounting of these new endeavors will represent an important milestone for the IGBP.

3.3.3 The Development of Global Models

The development and continued evolution of models of the various components of the Earth system, and of the system as a whole, is envisaged as the central unifying activity of the IGBP. By "models" we mean simplified descriptions of the Earth and its interactive subsystems in terms of minimal formulations of key processes (physical, chemical and biological) to allow analysis of interaction and prediction of response. Models will play several key roles in the IGBP. First, the goal of model development will provide an intellectual focus for research and a means for systematically exploring the relative significance of key processes. Second, models--however rudimentary--will guide the design of observing systems and experiments. At a later stage, models of the global system will contribute to the ultimate aim of the programme, i.e., the ability to explore quantitatively the future development of the planet under changing scenarios of human and natural perturbations.

The process of model development can best proceed as a diversified activity at many sites and centers, with intercommunication encouraged and provided by activities of the IGBP.

Several fundamental problems must be addressed before one can attempt a realistic model of a system as complex as the planet Earth. These include:

- Aggregation. How shall we segment the system into meaningful subsystems that are themselves amenable to tractable modelling?

- Interaction. What are the principal processes that link these subsystems, the critical interfaces and significant fluxes between them, and the key modes by which they influence each other?

- Scale. The domain of interest of the IGBP extends from chemical, physical and biological processes at the molecular level, through planetary-scale circulation in the global atmosphere and ocean, to solar and extraterrestrial changes affecting the Earth as a whole. The task of identifying mutually acceptable scales in space and time for meaningful study of the Earth as a system is at present a significant obstacle in integrating studies of the atmosphere, land, oceans, and biota.

The ultimate goal of predictive global models is an ideal that must be approached from many directions and more generally in stages. Preliminary models will be developed rapidly at the outset, to serve as conceptual tools to guide planning and to identify essential and less important elements. Based on these, more detailed models will be built which are flexible and expandable, and which will ultimately organize and summarize information as it is received. Finally, predictive models will evolve which will produce hypotheses that can be tested by further observation and experiment. Both process and prognostic models will be required, realizing that fully reliable predictions of the future evolution of the system are more an aim than an immediate goal. We need models initially in order to organize our understanding.

Computer modelling and the specialized techniques that are involved in the development of models are important areas of commonality in all the fields that study the Earth and life upon it. They provide today a common lexicon if not a single language for all the sciences. Global scale climate models, for example, deal primarily with the physical aspects of the climate system: energy, momentum, water, and effects of chemistry and trace gases. These are the same basic variables that are used in studies of geology, and, with the addition of nutrients, that are employed by ecologists in physiological studies, community analyses, and ecosystem modelling. Similarly, advection, turbulence, and chemistry are critical needs of the marine ecologist in understanding population/community dynamics.

Progress has already been made in modelling the responses of terrestrial ecosystems to external conditions, and biogeochemical cycling within idealized ecosystems. Some modelling of whole ecosystems has been attempted, although extrapolation to continental or global scale will require considerable thought and the development and adoption of new conceptual approaches. Nevertheless, development of explicit models on a global scale is an essential intellectual focus that must guide the overall programme.

3.3.4 Recovery of Environmental History

We have now in hand an initial picture of the main climatic events and trends of the past half million years, together with reasonably good histories of other global indicators such as glacier extent, global ice volume, surface ocean temperature, atmospheric CO_2 content, vegetation zones, lake levels and soil types. It is now appropriate, within the IGBP, to take a more penetrating look at the dynamic content of these records, in terms of what they tell of significant interactions in the coupled Earth system.

This will require the acquisition and rigorous study of continuous records that contain quantifiable environmental indicators such as isotope ratios, chemical ratios, vegetation, and accumulation/deposition ratios. Such records are to be found, for example, in lake and ocean sediments, ice caps, tree-rings and coral deposits as well as in rocks. These records provide unique and valuable insights into the past history of the Earth, each covering a characteristic span of time, and with different temporal

resolution. Paleoclimatic reconstructions carried out within INQUA, and particularly in the Cooperative Holocene Mapping Project (COHMAP) have demonstrated the power and promise of these techniques.

One need for these natural records is in the development of global models, by permitting tests of model validity under conditions that are different from those of today. A recent example are the findings in polar ice of significant changes in global CO_2 abundance at the end of the last Ice Age: an important factor in trying to foresee the future impacts of anthropogenic changes in the abundance of this important trace gas.

Several specific tasks may be identified as particularly fruitful:

- Construction of global "biomaps" depicting, in as much spatial detail as possible, the land surface, climate, vegetation and animal life during critical periods of the past. Two such projects might be: (i) a first order reconstruction of the global environment, chemistry, and distribution of life during an extreme of the last glacial period (about 20,000 years ago), building upon COHMAP studies already underway; and (ii) a more detailed, chronological series of biomaps spanning the last 200 years: the modern era of major human impact.

- The recovery of the past history of significant changes in the chemical composition of the atmosphere, oceans and soils.

- Significant refinement in the histories of climate, solar inputs to the Earth, vulcanism and records of neotectonic activity, as a method of improving our knowledge of the natural background on which human changes are now imposed.

3.3.5 Global Data and Communication System

The IGBP will recquire a new global data and communication system to handle and disseminate the vast amount of information that will be generated and obtained; it is also essential to provide rapid communication between programmes and between individual scientists. It will provide the comprehensive data bases needed for compiling relevant observations, for conducting interactive process studies, and for the design and testing of global models. The extensive data base needed for the IGBP must be quickly and readily accessible to all participating scientists, as should the results of associated analyses, models and tests.

A comprehensive data system employing modern techniques of data storage and worldwide access is a task of great magnitude--and perhaps the largest single challenge of the IGBP. Its design must be an integral part of the overall programme, carried out in close and continued contact with the design and development of the research elements of the programme. Planning for this essential activity must begin early, following the better definition of specific scientific components. UNEP's Global Resource Information Database (GRID) is an example of the type of data base that is needed.

3.4 Temporal Development of the IGBP

The goals of understanding the Earth as a coupled system and ultimately, of predicting significant global change are major intellectual endeavors that may require initial subdivision, as a temporal strategy while planning develops toward a whole-Earth programme. A separation by disciplines must be avoided for it will thwart the purpose of the IGBP. A better approach is to organize programme efforts, initially, into multidisciplinary Terrestrial and Marine Sectors, that will merge into a third, ongoing and all-encompassing study directed at the overall Global System. The initial subdivision by sectors within an overlaying whole, defines a temporal strategy for the IGBP that maintains the essential interdisciplinary character of the programme while allowing it to progress toward the ultimate goal of global synthesis.

Activities in each of the three parts will begin at once, though more intensively, initially, in Terrestrial and Marine Sectors, and more deliberately and with a slower buildup in the encompassing, Global System effort. Activities of process studies, observations and modelling will be pursued within each part. Findings and experience in Terrestrial and Marine Sectors will be continually applied to the study of the Global System, and these two temporal sectors will eventually merge with it. Certain activities, such as the recovery of environmental records, the study of global biogeochemical cycles, and related studies of the global atmosphere or of solar and cosmic inputs belong clearly in the overlaying Global System study and should be commenced immediately, during a time of early planning for global model development.

Listed below are examples of related programmes and of process studies that are relevant to each of the three efforts.

A. Terrestrial Sector

Included are interdisciplinary studies of terrestrial ecosystems, fresh water systems, vulcanology, groundwater and soil studies, and studies of the interfaces between atmosphere, biota and land surface. Examples of related programmes include MAB, IGCP, ISLSCP, IHP, COHMAP, Decade of the Tropics, and activities of SCOPE and UNEP. Examples of process studies include

- chemistry, dynamics and biogenic coupling in specific biomes,
- interdisciplinary studies in Biosphere Observatories,
- studies of soil dynamics and soil chemistry,
- studies of regional desertification,
- studies of effects of deforestation,
- studies of terrestrial productivity and decay,
- interdisciplinary studies of polar regions and other ecosystems that are particularly sensitive to global change,
- studies of global tropospheric and stratospheric chemistry, and
- studies of land-air exchange processes.

B. Marine Sector

Included are transdisciplinary studies of marine ecosystems, particularly of the ocean euphotic zone, and related studies of ocean surface and subsurface circulation and atmosphere-ocean interactions.

Examples of related programmes include WOCE, GOFS, the Greenland Sea Project, TOGA, MIZEX, and other activities of SCOR and of CCCO. Examples of process studies include

- air-sea exchange processes,
- ocean flux studies,
- processes in the euphotic zone,
- effects of surface processes on deep-sea chemistry,
- studies of polar and sea ice, and
- estuarine and coastal zone studies.

C. Global System

Studies within this encompassing activity will aim at the development of comprehensive, global environmental models, and include studies of global processes, the taking of long time series measurements of the global environment and the recovery of environmental records of the past. Examples of related programmes include WCRP, IHP, ISTP, and the Global Tropospheric Chemistry Programme. Examples of process studies include

- studies of global biogeochemical cycles,
- studies of land-sea interactions,
- related studies of atmospheric circulation and global transfer processes,
- studies of atmospheric aerosols and effects of volcanic activity,
- studies of solar and other external influences on the Earth,
- recovery of the history of climate and other aspects of the terrestrial environment,
- studies of the interplay of climate and biotic distribution, and
- studies of global perturbations induced by man.

4. RELATIONSHIP TO OTHER PROGRAMMES

The intellectual scope of the IGBP reaches from the interior of the Earth to the center of the Sun. As such it shares many of the interests of other, more disciplinary programmes within ICSU and in other international scientific organizations such as UNEP and UNESCO. Related, ongoing programmes such as the World Climate Research Programme, International Lithosphere Programme, and the Man and Biosphere Programme of UNESCO, complement the IGBP and lay the essential groundwork for it. From these related programmes will come essential inputs to the IGBP, and vice versa; through effective communication and exchange the existence of one will enhance the scientific returns of the other. The IGBP will recognize the important roles of other, existing efforts that study components of the total Earth system while promoting and organizing a limited number of high-priority activities of its own, in areas of interaction that are not addressed by these other programmes.

The IGBP will exist as an organizationally-separate entity that interacts with other related programmes of research through an initial principle of complementarity: that is, it will interact as needed with related, ongoing programmes without duplicating or subsuming them. In this way the IGBP can serve as a connective matrix that links the activities of related programmes and through its own specific activities, fills essential gaps between them. Some of the inputs and expertise needed to accomplish the IGBP will be drawn from member unions, special ICSU committees, and their ongoing programmes.

Liaison and cooperation should be established early on with a number of ongoing programmes of research fostered by ICSU and other international organizations. There are, for example, several planned and ongoing programmes of particular interest in this context. These include the World Climate Research Programme (coordinated jointly by ICSU and WMO), the International Lithosphere Programme, the International Solar Terrestrial Programme, and the Man and the Biosphere Programme and International Hydrological Programme of UNESCO.

International coordination of ongoing research is a responsibility of a number of special committees of ICSU. Several are of particular concern to the IGBP. These include:

- Scientific Committee on Problems of the Environment (SCOPE),
- Scientific Committee on Oceanic Research (SCOR),
- Committee on Climatic Change and the Ocean (CCCO) (a joint committee of SCOR and the Intergovernmental Oceanographic Commission (IOC) of UNESCO),
- Scientific Committee on the Antarctic Research (SCAR),
- Committee on Space Research (COSPAR), and
- Scientific Committee on Solar-Terrestrial Physics (SCOSTEP).

Member unions of ICSU of particular relevance to the IGBP include for example IUBS, IUGG, IGU, IUGS, IUPAC and URSI.

5. ORGANIZATION AND SCHEDULE

5.1 Organizational Principles

The unique breadth and scale of the IGBP impose important requirements on plans for organization and implementation:

- That the programme have a clear and unique definition, a coherent focus, and distinct scientific goals.
- That careful stages of planning and pilot study precede the operational phase.
- That programme plans be developed with broad participation from the disciplines and from the nations that need to be involved, and with the full participation of national and international agencies that schedule and operate spacecraft.
- That effective ties be established with both national committees and with related national and international programmes of research.

5.2 Scientific Committee for the Geosphere-Biosphere Programmme (SCGB)

Principal direction of the IGBP will be through an international, Scientific Committee for the Geosphere-Biosphere Programme (SCGB), that will guide the programme through the preparatory and buildup phase, initiate the implementation phase, and steer it through subsequent operations. The SCGB will consist of about 15 members who are appointed for staggered terms by the Executive Board of ICSU. The ICSU Executive Board will also appoint its chairman, who must be an active scientist with a broad grasp of earth and biological sciences. Members of the SCGB will be selected on the basis of their active participation in research in key, relevant fields and with due regard for appropriate disciplinary and international representation.

The IGBP will be an action-oriented programme, guided by a strong Scientific Committee (SCGB), planned and carried out by a limited number of Science Working Groups and administered by a minimal secretariat. The initial planning and pilot activities will be formulated primarily through international planning activities organized in the 1987-1990 time period by the Science Working Groups. During this period agreement should be reached on a detailed programme and implementation should be begun for the operational phase, to commence in the early 1990s. Appropriate liaison with other ICSU programmes and other international programmes will be arranged by the SCGB. The implementation of the IGBP will demand significant national contributions and long-term planning, realized through national committees and national liaison representatives with whom the SCGB must work.

The SCGB will be responsible for:

- establishing the scope and objectives of the programme,
- developing and approving scientific and implementation plans,
- taking needed steps for the organization of the implementation phase,
- establishing and appointing Science Working Groups as needed to carry out the programme plan,
- establishing and maintaining liaison with related programmes, unions, and committees, which have an interest in contributing to the IGBP,

- establishing and maintaining contacts with other international organizations, particularly those of the UN family,
- establishing and maintaining contacts with national committees, and
- evaluating programme progress.

A smaller Executive Board (4-5 members) of the SCGB will be appointed to carry on the work of the committee between its regular meetings.

The SCGB will be supported by a salaried Executive Secretary and a salaried clerical assistant. Other staff support will be decentralized for specific assignment to the working groups.

5.3 Science Working Groups

Detailed programme design will be the charge of Science Working Groups that are each multidisciplinary in makeup, to preserve the essential character of the programme. The SCGB will define the Science Working Groups that are needed, and will appoint their chairmen, who will normally attend meetings of the SCGB. Resources may be provided to the chairman of each Science Working Group for part-time professional and clerical support at his/her home institution. The Science Working Groups may establish ad hoc Subcommittees as required for individual activities, such as panels to address specific experiments and the design of Pilot Projects.

The activities of these appointed Science Working Groups and panels will constitute the principal planning effort of the IGBP in the early phase of the programme. These initial activities will in many cases lead to the definition of Pilot Projects. The ultimate product of the Science Working Groups, and the rationale for Pilot Projects, is the development of strategies and coordinated research plans for the operational phase of the IGBP, which will commence in the early 1990s.

A number of candidate topics for early emphasis in the IGBP have been identified in the reports, referred to in Section 3, of the four preliminary Ad Hoc Working Groups that assisted the Ad Hoc Planning Group on Global Change. Selected topics from these reports are prime candidates for further definition in planning sessions of the SCGB and the Science Working Groups that it appoints. These include, for example:

- studies of biogeochemical cycles, recommended by the (Ad Hoc) Working Group on Terrestrial Ecosystems and Atmospheric Interactions,
- studies of the global ocean euphotic zone, recommended by the (Ad Hoc) Working Group on Marine Ecosystems and Atmospheric Interactions,
- studies of soil dynamics and soil chemistry, recommended by the (Ad Hoc) Working Group on Geological Processes, and
- studies of variable solar inputs to the Earth, recommended by the (Ad Hoc) Working Group on Upper Atmosphere and Near-Earth Environment.

Other candidate projects for consideration, derived from these initial reports and the report of the COSPAR Working Group on Remote Sensing, are listed in Table 1. Some of them have already been planned or organized by ICSU special committees in anticipation of the IGBP.

Final choices for initial emphasis will be made from these and other inputs by the SCGB. These critical choices should be made in part from suggestions offered by other ICSU bodies, as candidates for final decision by the SCGB.

5.4 National and International Participation

It is essential for the success of the IGBP that many nations are actively involved in both the programme definition and implementation, from both developed and developing countries. Ground-based observations from all parts of the globe will be an important component of the IGBP that requires national participation. Spaceborne observations require national commitments, national and multinational involvement and international coordination. The programme will be funded nationally and must enjoy the broad endorsement of national programmes if it is to succeed. The participation of scientists from many different countries is required to ensure that the findings of IGBP research will be broadly recognized and used throughout the word as a basis for policy decisions. Such a programme cannot be imposed from the top down. The success of the IGBP will rest entirely on the commitment of key scientists in relevant fields of research and on the contributions of national programmes; its vitality will spring entirely from the vitality of national scientific committees.

The SCGB should therefore encourage the formation of national committees or focal points to maintain the necessary contacts with relevant research agencies in participating countries of the world. National liaison representatives will be appointed to the SCGB to serve in parallel with liaison representatives from related programmes. At a later stage it may be desirable to establish a Scientific Forum for the presentation and discussion of research results, progress, and plans, with broad international participation. Working relations must be established early-on with other related international scientific bodies and organizations including UNESCO, UNEP and the WMO.

5.5 Schedule

The IGBP will begin immediately, achieve full status and operation in the early 1990s, and last at least a decade. The Programme will develop in two phases, following approval at the 1986 General Assembly.

A Preparatory, Buildup Phase will begin as soon as possible after the General Assembly with the appointment of the Scientific Committee for the Geosphere-Biosphere Programme (SCGB). In this phase a series of international planning meetings will be convened under the guidance at the SCGB to develop plans for initial activities involving process studies, data collection, modelling, and the recovery and interpretation of past records of the environment. Decisions and major plans for the programme will be made in the 1988-1990 period, followed by gradual implementation. The preparatory phase will be characterized by the conduct of Pilot Experiments and the development of Implementation Plans for the main operational phase of the programme.

The Operational Phase of the IGBP will begin in the early 1990s, marking the era of coordinated study. Continuous global monitoring from both in situ and spaceborne stations can be expected during the latter part of the decade and continue into the next century.

5.6 Financing

Funds for the IGBP will be sought from governmental and private sources at both the national and international levels. Core support for the activities of the SCGB, its working groups, and staffing and office expenses should be provided via the participating national members of ICSU. The programme may also require, as a unique feature, the capability at the international level of funding interdisciplinary research at designated institutes around the world. A Special Geosphere-Biosphere Programme Fund might be created to support international planning activities. Administered by the SCGB, the fund would accept contributions from governments, foundations, corporations, and funding agencies, for the specific purpose of planning international, interdisciplinary collaborative research efforts. This feature could be a significant complement to the nationally-organized and funded activities which would support the research efforts of the programme. The Fund would also be responsible for assuring that interested communities in the developing world are brought fully into research efforts and made full participants in global information and data systems.

TABLE I

Research Areas	Suggested Priority Topics for Initial Definition and Study
A. MODELLING AND SCALING	Interactive modelling and problems of scaling (including terrestrial and marine ecosystems, and groups of ecosystems (e.g., watersheds, coastal zones and regions))
	Global modelling of biogeochemical cycles and their interaction
B. PROCESS STUDIES	Critical processes in the ocean euphotic zone
	Design and selection of ecosystem experiments in relation to global change
	Design and interpretation of ecotone studies as indicators of change
	Soil dynamics, chemistry and microbiology of soils
	The role of biological diversity in global change
	Past and present variations of significant trace gases as elements of global change, including studies of biogenic inputs
	Variations in solar inputs to the Earth
	Studies of the global electrical circuit
C. IN SITU OBSERVATIONS	Observational studies of hydrological basins
	Criteria for selection of Biosphere Observatories for monitoring global change, definition of data to be collected, and the role of Biosphere Observatories as ground-truth stations for remote sensing
D. MONITORING FROM SPACE	Use of spacecraft, now and in the future, in detecting significant parameters of global change (with particular emphasis on human-induced changes (such as salinization, urbanization, desertification, deforestation and including significant natural variations))
E. INTERPRETATION OF RECORDS FROM THE PAST	Design of biomap projects to reconstruct the global environment and patterns of vegetation at representative areas, particularly: a) the last 20,000 years; b) the last 200 years
	Recovery of past history of vulcanism, climate, solar inputs, and chemical constitution of the air, Earth and oceans

List of Acronyms

CCCO	Committee on Climatic Changes and the Ocean
COHMAP	Cooperative Holocene Mapping Project
COSPAR	Committee on Space Research
GOFS	Global Ocean Flux Study
GRID	Global Resource Information Database
HAPEX	Hydrological-Atmospheric Pilot Experiment
IAMAP	International Association of Meterology and Atmospheric Physics
ICSU	International Council of Scientific Unions
IGBP	**International Geosphere-Biosphere Programme**
IGCP	International Geological Correlation Programme
IGU	International Geographical Union
IHP	International Hydrological Programme
IOC	Intergovernmental Oceanographic Commission
INQUA	International Union for Quaternary Research
INTECOL	International Association for Ecology
ISLSCP	International Satellite Land Surface Climatology Project
ISTP	International Solar-Terrestrial Programme
IUBS	International Union of Biological Sciences
IUGG	International Union of Geodesy and Geophysics
IUGS	International Union of Geological Sciences
IUPAC	International Union of Pure and Applied Chemistry
MAB	Man and the Biosphere Programme
MIZEX	Marginal Ice Zone Experiment
SCAR	Scientific Committee on Antarctic Research
SCGB	**Scientific Committee for the Geosphere-Biosphere Programme**
SCOPE	Scientific Committee on Problems of the Environment
SCOR	Scientific Committee on Oceanic Research
SCOSTEP	Scientific Committee on Solar Terrestrial Physics
TOGA	Tropical Ocean and the Global Atmosphere Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
URSI	Union Radio Scientifique Internationale
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment

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