GLOBAL
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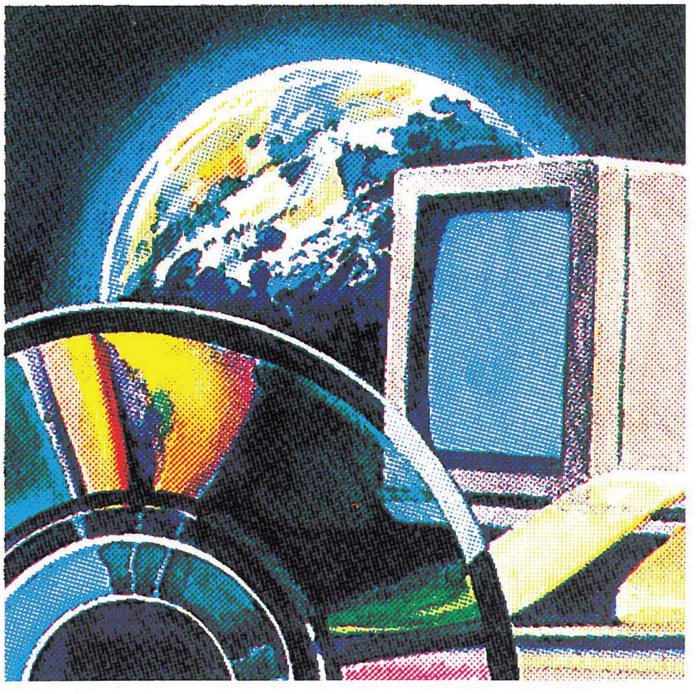
REPORT No. 30



IGBP Global Modelling and Data Activities 1994 - 1998

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)
Stockholm, 1994

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Strategy and Implementation Plans for Global Analysis, Interpretation and Modelling (GAIM) and the IGBP Data and Information System (IGBP-DIS)

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)
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Support for the GAIM Task Force Office is currently provided by the US Environmental Protection Agency, and, for the IGBP-DIS office by the Centre National de la Recherche Scientifique, the Centre National d'Etudes Spatiales (both of France), the European Commission and the US National Aeronautics and Space Administration.

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Preface

There are currently six established Core Projects in the International Geosphere-Biosphere Programme: a Study of Global Change (IGBP): Biospheric Aspects of the Hydrological Cycle (BAHC), Global Change and Terrestrial Ecosystems (GCTE), International Global Atmospheric Chemistry Project (IGAC), Joint Global Ocean Flux Study (JGOFS), Land-Ocean Interactions in the Coastal Zone (LOICZ) and Past Global Changes (PAGES). In addition, a project on Land Use/Cover Change (LUCC) is being developed. All are involved in the collection, management and interpretation of data, and the development of quantitative models, with many collaborative links between projects to promote programme-wide information exchange, synthesis and analysis. Nevertheless, no single Core Project has specific responsibility for such matters as coordinating the acquisition of global data sets from external sources, and ensuring inter-project compatibility for data management systems – nor for exploiting the greatest strength of IGBP results: the opportunity to investigate the behaviour of the Earth system as a whole. This integrative function is essential for the programme to achieve its overall goal; it requires global models that cross all ecosystems and disciplines. Such models provide the key tool for interpreting the past, analysing the present, and developing realistic scenarios for future conditions.

Two IGBP Framework Activities have been developed to carry out these vital scientific functions, working closely together: the IGBP Data and Information System (IGBP-DIS), and the Task Force on Global Analysis, Interpretation and Modelling (GAIM). IGBP-DIS has responsibility for assisting Core Projects in meeting their data acquisition and data management needs, and for liaison with the space agencies, other data-producing bodies, and international data centres; the role of GAIM is to promote the development, evaluation and application of comprehensive, prognostic models of the global biogeochemical system, and subsequently linking such models to those of the physical climate system.

This Report sets out the goals and directions for GAIM and IGBP-DIS over the next five years, expanding on the recent overview of their activities within IGBP Report 28 (1994). Whilst the two main parts of the current document can each be regarded as equivalent to a combined science and implementation plan for a Core Project, many of the objectives for IGBP global modelling and data-related activities are more "short term" (3 - 5 yr), co-evolving with other components of the programme and focusing on problems that are of particular importance at the present phase of IGBP's development. Thus much of the effort within IGBP-DIS is currently directed at the assembly of global databases of land surface characteristics, and, within GAIM, to modelling the global carbon cycle and climate-vegetation interactions. It is expected that by 1998 these tasks should be largely completed, and attention will then be directed at other cross-cutting topics, providing further insights into the functioning of biosphere-geosphere interactions at the global scale.

GLOBAL ANALYSIS, INTERPRETATION AND MODELLING

Background: Biogeochemical Cycles

Planetary atmospheres with an incident solar energy flux are subject to an energy pumping which takes the form of a matter flux from lower chemical potential forms to those at a higher potential. This is reflected, for instance, by the existence on Mars of compounds with high and low chemical potential. The existence of planetary geochemical cycles is the inevitable result of the energy flow through such a system.

When life is present, this geochemical cycle can take another pathway: the basic chemical constituents of organic matter, carbon, nitrogen, oxygen, phosphorus and sulphur, follow a closed loop or cycle through increasing molecular energy states, as the elements are incorporated into living tissue, and then decreasing energy levels as the tissues decompose, giving rise to biogeochemical cycles. The chemical disequilibrium observed on Earth is a signature of a living planet.

The significance of the role of living systems in all of the Earth's biogeochemical cycles is a relatively recent discovery. The recognition of biotic factors as potential homeostatic controls of biogeochemical cycles and of the physical climate system has allowed for significant advances in our understanding of the natural metabolism responsible for the compositions of the atmosphere, oceans and sediments on the surface of our planet. Such a planetary metabolism is interactive, with physical, chemical and biological processes inextricably linked; as a result, it is essential to quantify the characteristic dynamics of these cycles, and their controlling factors, if we are to gain a better overall understanding of global processes.

The varied dynamic patterns reflected in various states of the biogeochemical cycles are the consequences of a myriad of processes that operate across a wide spectrum of time and space scales. In the absence of significant disturbances, these processes define a natural cycle for each element with approximate balances in sources and sinks that result in a quasi-steady state for the cycle on time-scales less than a millennium.

Since ancient times humans have modified natural systems, but only since the beginning of the Industrial Revolution has human activity significantly altered biogeochemical cycling at the planetary scale. The magnitude of human disturbance to biogeochemical cycles may now be approaching a critical level: the values of important state variables, such as the concentration of atmospheric CO_2 and CH_4, are moving into a range unprecedented during the past one million years. For example, during the 30 years between 1957 and 1987, the pool of carbon in the atmosphere (in the form of CO_2) has increased from 670 to almost 755 Pg (10^{15} g) C as a result of fossil fuel burning and forest clearing. The annual rate of increase is currently about 3 Pg (equivalent to roughly 0.4%); methane has, until recently, been increasing by nearly 1% per year. From ice core records we know that the concentration of both carbon dioxide and methane was relatively constant for several thousand years prior to 1700 and that since 1700 the concentrations of CO_2 and CH_4 have increased by more than 25% and 100% respectively. The increase in the atmospheric CO_2 and CH_4 concentrations, as well as other greenhouse gases, due to human activity, has produced serious concern regarding the heat balance of the global atmosphere.

Despite the fact that knowledge of the global carbon cycle is a key to comprehending the biosphere, that cycle is not adequately understood or quantified. The ocean is without question a sink for anthropogenic CO_2, but the strength of this sink is uncertain. There is also uncertainty regarding the role of terrestrial ecosystems, where at least two factors affect the level of carbon storage. First and most obvious is the anthropogenic alteration of the Earth's surface, such as the conversion of forest to agriculture, which results in a net release of CO_2 to the atmosphere. Second and more subtle is the possible change in net ecosystem production (and hence carbon storage) resulting from changes in atmospheric CO_2 and changes in other global biogeochemical cycles, as well as changes in the physical-climate system. Determining such changes will require better knowledge of the nitrogen and phosphorus cycles, since they are the limiting nutrients in most terrestrial ecosystems. Unfortunately, we do not yet have an adequate general understanding of the individual cycles of these elements, and our knowledge of the way these biogeochemical cycles relate to each other is even poorer.

Methane is also a significant gas in the earth system, acting both as a greenhouse gas and as the major sink for the OH radical, the key species in tropospheric photochemistry. As mentioned, methane has been increasing in the atmosphere; however, its rate of increase has recently slowed. Neither the causes of the increase nor the change in rate are well-understood. The picture for methane is complicated by its diverse and dispersed sources, by the complexity of its photochemical sink, and by its poorly understood biological sink in upland soils. Changes in the atmospheric concentration can result from changes in either sources or sinks or a combination of sources and sinks whose contributions vary over time. Improving our predictive understanding of methane will require synthesizing inventory data for industrial and agronomic sources, developing global models for biological sources and sinks, and improving significantly models of global atmospheric chemistry.

Human activities have had similar impacts on the nitrogen cycle. For example, the pool size of atmospheric N_2O, which is about 1500 Tg (10^{12} g) N, is increasing by 0.2 to 0.3% per year. A large portion of this increase may be due to biomass burning over the past forty years. There have also been large increases in the application of nitrogen fertiliser and in the discharge of sewage. Much of the N in fertiliser and sewage is reaching recipient aquatic systems such as groundwater, wetlands, rivers, estuaries, and the coastal ocean. Estimates of the N_2O generated as a result of this eutrophication show that total releases have increased by around 50% over the past 50 years.

There have been substantial changes in the global biogeochemical sulphur cycle as well. Human activity has increased the present total flux of sulphur to the atmosphere from a pre-industrial level of about 228 Tg S yr^{-1} to a current flux of approximately 340 Tg S, a 50% increase. Indirect calculations suggest that emissions of gaseous sulphur to the atmosphere from fossil fuel combustion are already on the same order of magnitude as discharges from natural systems. Some of the largest changes have occurred over continental regions where present anthropogenic emissions account for 70% of the total sulphur released to the atmosphere. In industrial areas, sulphur dioxide (SO_2) is the

major sulphur compound emitted; this gas is rapidly hydrolysed to sulphuric acid (H_2SO_4) which is then deposited back to terrestrial and aquatic ecosystems in the form of acid rain. Another possible consequence of changing sulphur emissions is the hypothesised change in the concentration of cloud condensation nuclei; that could have a significant impact on cloud optical properties, and hence a feedback on the physical-climate system.

These perturbations produce complex, information-rich transient states among the interlocked elemental cycles. Even if human activity stabilises, decades will be required before even the most rapid processes of re-adjustment establish new equilibria. In a sense, therefore, these natural and human-induced perturbations, and the system's subsequent responses, constitute an ongoing biogeochemical experiment at the global level.

At the present time, major questions need to be answered regarding not only the details of global budgeting of individual cycles, but more importantly the interactions of such cycles with each other for which very little, if any, experimental data exists. For example, whereas it is clear that carbon (in the form of CO_2) has been accumulating in the atmosphere since early in the 18th century, attempts to balance the sources and sinks of atmospheric CO_2 remain unsuccessful.

One difficulty lies in the higher C/N ratio in fossil fuels as compared to organic carbon, thereby potentially limiting any increase in carbon assimilation by biota due to limited nitrogen loading from fossil fuels. In other words, fossil fuels have more carbon per nitrogen than soils or organic plant matter; therefore, refixing the released carbon from fossil fuels may require use of nitrogen pools beyond that released by the combustion of the fuel. However, the increasing concentration of CO_2 in the atmosphere may raise C/N ratios by either making plants more water efficient (more carbon fixed per H_2O transpired) or through other indirect mechanisms. For instance, increasing atmospheric CO_2 concentrations can enhance carbohydrate formation that is generally not balanced by increased nitrogen uptake. Consequently, there remains the possibility that higher CO_2 levels may lead to an increase in net primary production and perhaps net ecosystem production (carbon storage). In any event, the cycles of carbon and nitrogen are tightly coupled in the terrestrial biosphere, and understanding this coupling is essential to determine the source/sink pattern for carbon.

The biogeochemical system is strongly coupled with the planet's physical-climate system. The climate is clearly a strong determinant of the distribution and growth of terrestrial vegetation; of litter decomposition and trace gas production; of ocean circulation and marine production; and of atmospheric transport and chemical change. The coupling is, however, not just one-way. For example, vegetation strongly controls the exchange of water and energy between the Earth's land surface and the atmosphere; furthermore, there is evidence that marine primary production may influence the depth of the mixed layer in the ocean, and, as previously mentioned, many biologically-produced gases influence the planet's heat balance through the greenhouse effect. We know from ice core records that these gases have varied greatly in concentration on glacial and interglacial time scales, and the detailed analysis of such palaeo-environmental records provides good reason to believe that changes in atmospheric composition are directly involved in the natural regulation of climate.

Understanding the nature of the link between the biogeochemical cycles and the physical-climate system represents a fundamental goal of the IGBP. This understanding bears directly on key scientific questions concerning the co-evolution of different components of the Earth system including life, as well as on the most pressing environmental questions of our time. Present understanding of these issues is very incomplete; the attack on the problem will require extensive interdisciplinary collaboration and will rely upon the achievements of all of the IGBP Core Projects. This attack will employ a hierarchy of models; it will include interdisciplinary problem analysis and the synthesis, interpretation, and application of global-scale data sets, especially those obtained by continuous monitoring from space, and it will also require the active participation of the World Climate Research Programme (WCRP).

Role and Characteristics of GAIM

The role of the IGBP Task Force on Global Analysis, Interpretation, and Modelling (GAIM) is multi-fold. The Task Force must analyse current models and data, assess the capability of current models and experimental programmes to resolve key questions, and advance and synthesise our understanding of the global biogeochemical cycles and their links to the hydrological cycle and to the physical-climate system as a whole.

Modelling is fundamental to the IGBP effort. That is because the ability to model some aspect of the Earth system correctly and repeatedly on the basis of component processes is a litmus test of whether or not predictive understanding of that component has been achieved. Models also provide an indispensable way of organizing current knowledge and pinpointing critical gaps. The aim is not simply to produce ever larger and more complex models of the Earth, but rather to produce a family of models of varying complexity and realism to attack specific questions. The models and model experiments have to be designed in such a way that their predictive characteristics can be tested with existing or planned data sets.

Though coupled, one can conceptually partially "decouple" the Earth system as a means of studying aspects of the important subsystems. This decoupling is not without strong scientific precedent nor completely devoid of risk. It is, without question, valuable. Specifically, the Earth system can be viewed as being composed of two interacting subsystems – the physical climate subsystem and the biogeochemical subsystem – linked together by the global hydrological cycle and by subsystem state variables such as greenhouse gas concentrations, surface roughness, and albedo (Fig. 1). This observation is at the heart of the initial five year work plan (1994 - 1998) of the GAIM Task Force. By exploiting the conceptual decomposition of the Earth system into two coupled subsystems, one can formulate an attack upon these central problems of global change. Central to this approach is the development, testing, evaluation, and application of a suite of models of and associated data sets for the global biogeochemical subsystem, that are comparable in prognostic dynamics to the current models of the global physical climate subsystem, the general circulation models (GCMs).

GCMs exist at a variety of institutions around the world; prognostic global biogeochemical models are at a relatively primitive stage. *The challenge to GAIM is to initiate activities that will lead to the rapid development and application of a suite of global biogeochemical models.* These global biogeochemical models would, in time, be linked, partly through the hydrological coupling, to general circulation models, thereby, providing models of the Earth system.

This challenge to GAIM was recognised early in the development of IGBP: "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" (IGBP Report No. 12; 1990).

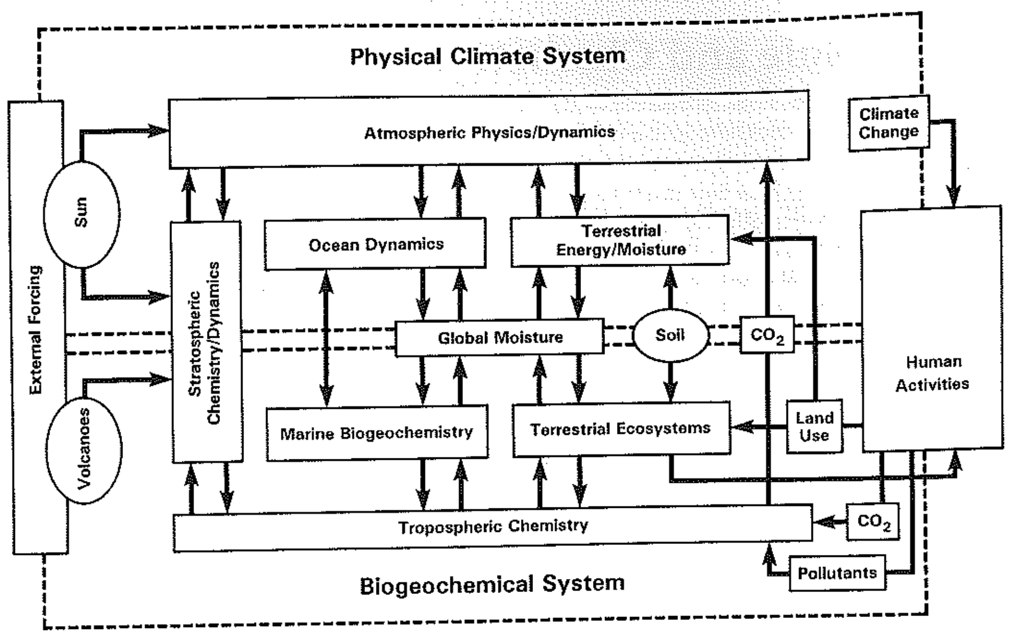

Figure 1. A conceptual diagram of the Earth system showing aspects of the interaction between the biogeochemical subsystem and the physical-climate subsystem.

It is also consistent with the current activities and structure of the World Climate Research Programme (WCRP): "The Joint Scientific Committee (JSC) for the WCRP [WMO/ICSU/IOC] considered that the time was ripe to foster a coordinated approach to the development and application of comprehensive models of the global climate system comprising atmosphere, oceans, and cryosphere, and to assess the sensitivity and predictability of climate by use of such coupled models. The JSC therefore decided to constitute the Steering Group on Global Climate Modelling to undertake this coordination, to promote development of comprehensive models of the climate system including large-scale oceanic and hydrological processes and, eventually, to cooperate with the International Geosphere-Biosphere Programme to develop models of the total Earth system." (Report of the First Session of the WCRP Steering Group on Global Climate Modelling, Geneva, November 1990; WCRP Report 55).

The IGBP Task Force on Global Analysis, Interpretation and Modelling is envisaged as playing a role similar to that of the WCRP Steering Group on Global Climate Modelling, and it will liaise with that Steering Group on important areas of common interests between the WCRP and IGBP. As mentioned, an important difference is that global modelling of biogeochemical cycling is, at present, less advanced than global climate modelling; a considerable amount of new science must be done in order to develop and test global biogeochemical models and coupling schemes. There are, however, good reasons to expect that this new science can and will be done given sufficient encouragement and funding. The last 5-10 years has seen enormous progress in the development of process-based models for ecosystem metabolism in a variety of terrestrial and marine ecosystems and in the acquisition of crucial data sets for testing these models,

including space-based measurements of vegetation and surface-ocean greenness and palaeoenvironmental records of key global climatic and geochemical variables. There are also several major efforts underway to generalise ecosystem models to the global scale and to couple these models with atmospheric and ocean GCMs. Thus, this is a crucial time: the foundations for substantive progress have already been laid by pioneering groups of scientists in several countries, and as a consequence, the Task Force has the opportunity to assist significantly in coordinating a major worldwide effort.

Much of the progress to date in modelling specific components within the global biogeochemical subsystem sets the context for modelling activities within the various IGBP Core Projects. GAIM recognises, supports, and will benefit from these efforts. The GAIM activity is by definition cross-cutting; therefore, the activities of GAIM intersect fundamentally with all the Core Projects. In fact, the GAIM activity depends, in part, upon all the Core Projects, which themselves are in varying states of development. This close complementarity must be acknowledged in any implementation plan.

Considering the role and characteristics of GAIM, certain organizing principles have been established:

(i) GAIM is not structured as an IGBP Core Project; instead it is organized through a Task Force of the IGBP Scientific Committee, with a specific and agreed upon Action Plan that is flexible and timely. The Action Plan will be implemented in part by the Task Force itself, and in part via activities that GAIM catalyses. The Action Plan will have a horizon of five years; however, the plans will be rolling and renewed at least every other year.

(ii) GAIM activities will engage scientists who are currently involved in the Core Projects, who are focused upon modelling issues, and who would be willing to undertake projects that occur at important interfaces in the global biogeochemical subsystem.

(iii) Analysis and modelling strategies must be devised that recognise the different levels of development of quantitative expression or models for the various subcomponents. Such strategies need to include specific proposals for addressing key processes within the global biogeochemical subsystem.

(iv) GAIM activities must include specific attempts to link various components of the biogeochemical system which require the contribution of more than one Core Project. Examples involving both the International Global Atmospheric Chemistry (IGAC) and Global Change and Terrestrial Ecosystems (GCTE) projects include: the development of global terrestrial models with atmospheric transport models, for carbon dioxide gradient studies; and linking terrestrial emissions of methane and carbon monoxide to global atmospheric chemistry models that include active chemistry. How these linkages are treated is a non-trivial problem, with the need to take account of, and build on, initiatives already underway; e.g., the GCTE Long-term Ecological Modelling Activity (LEMA).

(v) The strategy for implementing GAIM must include progressively closer coordination and collaboration with the WCRP Global Climate System Modelling Programme and its Steering Group. This cooperation is vital: duplication of effort must be avoided, and both IGBP and WCRP need to be able to respond to the needs of the other in this field. Joint linked experiments are foreseen. Areas of common interest with WCRP include: ocean-atmosphere models in which the ocean component accurately describes the distribution of selected dissolved chemicals, including those involved in the carbon cycle; land-atmosphere models treating the exchange of energy, water and carbon; and atmospheric chemistry models incorporating realistic source-sink terms.

(vi) GAIM must work closely with the IGBP Data and Information System (IGBP-DIS), with initial emphasis on a series of concrete projects aimed at making particularly useful data sets, such as global data on soil characteristics, available to the modelling community.

Goal and Objectives

The goal of GAIM is: To advance the study of the coupled dynamics of the Earth system using as tools both data and models.

GAIM emphasises activities designed to expand upon the development, testing, and analyses of integrative data sets and models of those aspects of the Earth system where IGBP has the scientific lead, and it commits to collaborate on aspects of the Earth system where WCRP has the lead. GAIM will work with IGBP Core Projects to identify appropriate component models, to assist in integrating these into coupled models, and to test and apply these coupled models. The integration, testing, and analysis of coupled models will generate specific requirements for data: for initialisation, forcing, and validation. Development of these data sets will be coordinated through IGBP-DIS.

In order to achieve this goal, the GAIM Task Force has established the following specific objectives:

- Implement a strategy for the rapid development, evaluation, and application of comprehensive prognostic models of the global biogeochemical subsystem which could eventually be linked with models of the physical climate subsystem.

- Propose, promote, and facilitate experiments with existing models or by linking subcomponent models, especially those associated with IGBP Core Projects and with WCRP efforts. Such experiments would be focused upon resolving interface issues and questions associated with developing an understanding of the prognostic behaviour of key processes.

- Clarify key scientific issues facing the development of global biogeochemical models and the coupling of these models to general circulation models.

- Contribute to international assessment exercises, particularly the Intergovernmental Panel on Climate Change (IPCC) process, by conducting timely studies that focus upon elucidating important unresolved scientific issues associated with the changing biogeochemical cycles of the planet and upon the role of the biosphere in the physical climate subsystem, including its role in the global hydrological cycle.

- Advise the IGBP Scientific Committee on progress in developing comprehensive global biogeochemical models, and to maintain scientific liaison with the WCRP Steering Group on Global Climate Modelling.

During the first phase, the focal biogeochemical cycle for GAIM will be the carbon cycle, including its interaction with aspects of the nitrogen cycle. Coupled analyses of feedbacks between dynamic biogeochemistry and climate, mediated by greenhouse gas concentrations, and of climate-ecosystem interactions mediated by the hydrological cycle will be initiated by GAIM and, where appropriate, conducted in collaboration with components of WCRP.

Action Plan 1994 - 1998

The IGBP Task Force for Global Analysis, Interpretation, and Modelling intends to honour the three overlapping themes in its title.

Analysis

GAIM analysis activities are already underway, based on a series of short (2-3 day) workshops focused upon clarifying scientific issues that limit progress on developing models and deepening our understanding of global biogeochemical cycles and how these cycles and the associated key subsystems may change in response to climate change. Many of these workshops have been conducted in joint sponsorship with other IGBP Core Project Offices and IGBP-DIS.

The first GAIM workshop, co-sponsored by IGBP-DIS, was held in January 1992 at the University of Maryland, USA and addressed the issue "Monitoring and Modelling of Terrestrial Net and Gross Primary Production" (IGBP-DIS/GAIM Working Paper 1, 1994). The importance of this subject was clearly recognised at the 1991 IGBP-DIS meeting in Toulouse, and rests upon the fact that most models of terrestrial carbon, energy and water fluxes must include in a fundamental manner either gross primary productivity (GPP) or net primary productivity (NPP). Remotely-sensed (generally satellite) measurements of reflectance produce constructs (e.g., the normalised difference vegetation index, NDVI) which may be highly correlated to GPP and even NPP; however, there are significant differences in the calculation of GPP and NPP within current global terrestrial models, as well as a lack of intercomparison of these calculated values with remotely sensed data and derived indices such as NDVI. The subject is difficult, complex, and central to models of the global carbon cycle. A small follow-up meeting was held with IGBP-DIS (November 1993, Paris) to plan a model intercomparison effort (see below).

Another important question is the adequacy of soils data for modelling biogeochemistry and the hydrological cycle. There are problems in obtaining adequate, global soil data sets that are appropriate to the issues associated with global carbon cycle modelling and climate-vegetation modelling. IGBP-DIS, assisted by GAIM, held an important workshop to address these issues in October 1992 (Silsoe, UK; IGBP-DIS Working Paper 7); follow-up activities are described below in the section *Data and Information System* under *Action Plan 1994 - 1998.*

A workshop on trace gas fluxes in African savannas (including the extent and type of biomass burning) was held at Victoria Falls, Zimbabwe in June 1993, co-sponsored by IGAC, GCTE, IGBP-DIS and GAIM (IGBP Report 31, 1994). This workshop helped increase the coordination between the various projects considering biomass burning. It also provided a needed compilation of emission factor estimates and controls on these factors – an area previously identified by IGBP-DIS as a high priority focus.

Subsequent workshops in 1994 and 1995 focus on the following themes:

Palaeovegetation mapping. One of the four initial modelling experiments to be carried out by GAIM will investigate vegetation-climate interactions in the 6000 BP era. Developing an adequate vegetation data set raises several problems; these include appropriate functional type classification schemes, data availability, dating control standards, and mapping methods. Significant community advice, effort, and support are needed. A PAGES/GCTE workshop on these issues, with GAIM and IGBP-DIS involvement, was held in Lund, Sweden in May 1994.

Net primary production: modelling and remote sensing. This meeting will be held in Potsdam, Germany, on July 6-9, 1994, and will focus on establishing the guidelines for a terrestrial model intercomparison effort that is central to all of the modelling experiments discussed below. The workshop will be co-hosted with IGBP-DIS and GCTE and will provide follow-up to the 1992 meeting in Maryland.

The global extent and type of wetlands. There is need for better estimates of the areal extent of global wetlands, and an improved classification from the perspective of methane flux. Two workshops are initially planned for 1995, focusing on boreal wetlands and tropical wetlands; they will be sponsored jointly by GAIM and IGBP-DIS, and planning will be coordinated with IGAC, BAHC, and GCTE.

Spatial and temporal scaling. The issue of coupling global terrestrial models across spatial and temporal scales is recognised to be an important issue on which progress is needed. Three main temporal scales are involved: fast time steps (minutes to hours), used in terrestrial energy-water flux calculations; intermediate time steps (days to weeks), used in biogeochemical terrestrial models; and annual time steps, generally used in ecosystem successional dynamics. These temporal scales have associated various spatial scales adding further complexity. A workshop on this important topic is tentatively scheduled for 1995, with the involvement of GCTE and BAHC.

Interpretation

GAIM interpretation activities will be implemented through workshops and study teams (the latter probably arising from workshops). Together, these will provide a mechanism for rapid and informal scientific mini-assessments, clarifying key scientific issues relevant to IGBP – and also contributing to the IPCC process.

One area that merits consideration is the potential for increasing carbon storage in terrestrial ecosystems: how much, how fast, and where can carbon be stored through reforestation and afforestation? A model for such an investigation is the way in which the corresponding issue of the possibility for increased biotic storage in marine systems by iron fertilisation has recently been explored and clarified. The approach used a workshop format (American Society of Limnology and Oceanography Symposium, San Marcos, California; February 1991), followed by a set of model, field and laboratory experiments, with JGOFS involvement.

The Task Force will give further consideration to how best it can provide timely interpretive insights on issues relevant to IPCC, in addition to its analysis and modelling activities.

Modelling

The initial modelling component of GAIM is framed by two broad, linked scientific issues:

- What are the characteristic dynamics and controls on the global carbon cycle? How has this cycle been perturbed? What is its linkage to other biogeochemical cycles, and how might it evolve in the future?

- What are the linkages between climate and vegetation, and what are the effects of these interactions in a changing climate?

These two broad questions are themselves linked and are also closely coupled with the ongoing activities of several IGBP Core Projects. However, they are only guides for an initial framework; although the questions are expansive, they do not address all aspects of the Earth's biogeochemical system, how it is linked to the physical-climate system, and how it is being changed by human activities. Thus the work will broaden, and will be re-defined, in subsequent versions of the GAIM Action Plan.

These questions will be addressed initially by modelling studies in three temporal frames: a Contemporary time frame, a Fossil Fuel Era time frame, and a Palaeo time frame. During this start-up phase of GAIM activities, planning will also be initiated for experiments in a Futures temporal frame.

An overarching objective of the initial focus upon the global carbon cycle is to develop a consistent and comprehensive framework within which to diagnose, intercompare, validate, and document existing and future comprehensive models of the global carbon cycle. The framework can be considered as a pilot project which may serve in the future as a framework to evaluate models of other biogeochemical cycles besides carbon. The carbon cycle is addressed in each of the temporal frames, focusing on methane in the palaeorecord and fossil fuel era; on the terrestrial component of carbon dioxide sinks and sources in the fossil fuel era; and on carbon dioxide gradients (and their implication) in the contemporary period (see Table 1).

Similarly, the overarching objective of the initial focus on the linkage between climate and vegetation is to speed progress towards an understanding of the two-way coupling between terrestrial ecosystem and the physical-climate system. The coupling arises because terrestrial ecosystems respond dynamically to climate, while influencing climate through modification of surface energy, momentum, water vapour and trace gas exchanges. As with the carbon cycle, modelling experiments are envisaged at different temporal scales. A 6000 BP experiment enables the equilibrium behaviour of a coupled model to be tested under a different global climate state; in the Contemporary time frame, coupled regional models will be tested against newly emerging data sets from field studies within both IGBP and WCRP. These experiments will therefore greatly enhance the basis for linking global biogeochemical models to general circulation models.

Table 1. Temporal framework of carbon-cycle studies within the initial modelling component of GAIM.

ERA \ TOPIC	CO_2	Trace Gas	Clim-Veg
Future	To Be Determined	To Be Determined	To Be Determined
Contemporary	- Coupled Carbon Models - Atm Gradients	Currently Not Planned	- Atm-Terr Models - Perturbations - Regional Climate & Ecosystem Data
Fossil Fuel	- Terrestrial Models & Landcover Conversion - Historic Atmospheric Records	- Terr-Atm-Chem Models - Focus: CH_4 - Historic CH_4 Records	Currently Not Planned
Palaeo	Currently Not Planned	- Terr-Atm-Chem Models - Focus: CH_4 - Historic Values for Fixed Temporal Periods	- Atm-Terr Models - Orbital Perturbations - 6000 BP - Vegetation Data

Four modelling experiments provide the initial focus for the 1994-98 GAIM Action Plan; two further experiments will be more precisely defined during 1994. Additional details on all of these follow.

The Contemporary Era

The Contemporary Era provides the greatest availability of data (from the immediate past) and the easiest task of validation (over the immediate future); it is also a time of rapid change (the most rapid change available to study over the last 1000 yr). The period of 20 years, 1980-2000, was chosen as the shortest time scale suitable for investigating "decades to centuries" change; over shorter periods, the trends are not detectable because of natural year-to-year fluctuations of the system, such as El Niño - Southern Oscillation (ENSO) events.

The Coupled Atmosphere-Land-Ocean Carbon System, 1980-2000

Purpose and approach. The validation and critical assessment of comprehensive global biogeochemical models represents a crucial step in their development. While validation may proceed for certain individual components on the local scale, there is a clear need to assess overall model performance on the regional and global scale. For example, it has

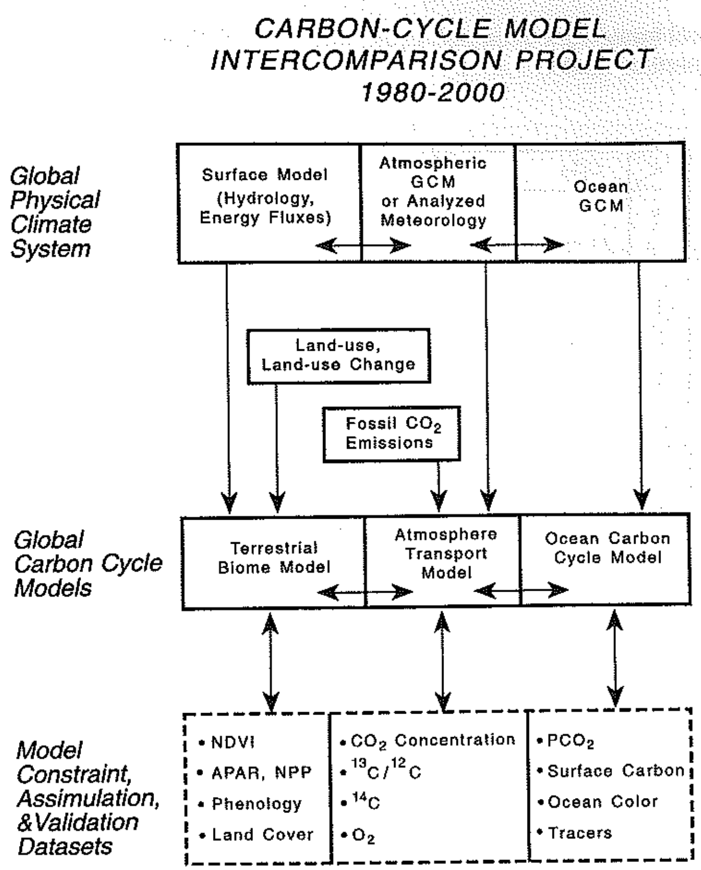

Figure 2. The model set-up for the Coupled Atmosphere-Land-Ocean Carbon System for the Period 1980 - 2000 Experiment is composed of physical system components, carbon cycle model components, and validation data sets. This modelling framework should insure that comparable simulations are performed under similar conditions such as initial conditions, meteorological and/or climatic driving variables, and other common data sets to support these models.

been shown recently that the spatio-temporal distribution of atmospheric carbon dioxide and its isotopic forms provide powerful constraints on the location and magnitude of surface sources and sinks. During the next decade a wealth of new atmospheric and oceanic data will become available, both from the observational components of IGAC and JGOFS (as well as from the WCRP), and from remote sensing platforms, which will enhance the power of this approach. In order to assess systematically this potential, a strategy is needed to link component models into a comprehensive, global carbon model, exploiting detailed, contemporary, spatio-temporal patterns. This modelling framework should ensure that comparable simulations are performed with similar initial conditions, meteorological and/or climatic driving variables, and using other common data sets.

The experiment proposed here is designed initially for the period 1980-1990, paralleling the time period under consideration by the Atmospheric Model Intercomparison Project (AMIP). As new data sets become available, it is envisaged that this target period will be extended, eventually spanning the 20 year time frame 1980-2000. It is expected that this experiment will serve as a pilot project which may serve in the future also as framework to evaluate models of other biogeochemical cycles besides carbon.

The model set-up for the simulations is depicted schematically in Figure 2. It is composed of physical climate system components, carbon cycle model components, and validation data sets.

Physical climate system components. These components (atmosphere, ocean and land surface) provide the information of the background within which the carbon compounds are imbedded. As an initial simplification, it is assumed that on short time scales no substantial feedback processes operate between the carbon components and the physical-climate system. As a consequence the carbon system simulations may be run off-line from the physical-climate system model simulation resulting in considerable savings in computer resources. It is envisaged, however, to perform a fully coupled simulation at a later stage.

Since the experiment is designed to be validated against synoptic observations, the most realistic meteorology and oceanic circulation during the simulation period is needed. For the atmosphere, the stored output fields of the AMIP simulation runs will be used in a first phase. In a second phase, the data from the re-analysis project currently planned at the European Centre for Medium Range Weather Forecast (ECMWF) and the US National Meteorological Center (NMC) will be used. In order to obtain the time-dependent oceanic circulation, the Ocean Carbon Cycle Model (OCCM) will have to be driven by observed sea surface temperatures and surface buoyancy fluxes.

Carbon cycle model components. These components consist of an Atmospheric Transport Model (ATM), an Ocean Carbon Cycle Model (OCCM) and a Terrestrial Biogeochemical Model (TBM). All models are driven by their respective component of the physical climate system. In addition, the anthropogenic input of CO_2 from fossil fuel use and changing land-use statistics have to be specified.

The OCCM and the TBM are each coupled to the ATM. For sensitivity studies the OCCM and TBM may be replaced by prescribed diagnostic surface fluxes derived, for instance, from remote sensing data or from direct observations (e.g., maps of inferred air-sea CO_2 fluxes; see Fig. 2). For example, using a diagnostic constant oceanic component, this framework will permit comparison of several TBMs driven by the same spatio-temporal variations in climate. Finally, in addition to simulating the dispersal of CO_2 and its isotopes in the atmosphere, the ATM must also address inert atmospheric tracers, such as CFC-11 or ^{85}Kr, for concurrent validation of the large-scale transport.

Implementation. The initialisation of the models, which will be defined in detail at an early workshop, will require special care. A possible strategy would be to distinguishes three stages which are needed to drive the carbon models to and through the validation target period 1980-90. Such a set-up would minimise the amount of computer resources that would be required.

In the first stage the TBM and the OCCM are run to equilibrium with prescribed atmospheric CO_2 concentration and a constant climatology, assumed to represent preindustrial conditions. This may require considerable simulation time periods which are dictated by the longest time constants involved – in the order of 3000 years for the OCCM and 500 years for the TBM. There is also a new perturbation approach which provides a solution for just the time span of the industrial revolution; however, it does have drawbacks in that it does not allow the direct comparison of model results with data, nor does it predict the effect of changes in the natural cycle of carbon. This issue needs explicit consideration in the formulation of the experiments.

In the second stage the OCCM and TBM are run each through the industrial period up to the end of the year 1975, forced with prescribed:

- Globally averaged atmospheric CO_2 concentration
- Globally averaged atmospheric $^{13}C/^{12}C$ isotope ratio
- Globally averaged atmospheric $^{14}C/^{12}C$ isotope ratio, and
- Anthropogenic land-use change scenario.

In this stage, either a constant climate or a climate scenario as developed within the Fossil Fuel Era project "Changes in Terrestrial Carbon Storage", will be prescribed (see below).

In the third stage the three-dimensional ATM is coupled to the TBM and the OCCM. The ATM is initialised with uniform concentration and isotope fields representing globally averaged conditions for January 1976. The three coupled carbon models are run through the four years 1976-1979 and then through the target period 1980-1990. This stage also requires the specification of the spatio-temporal distribution of CO_2 emissions, both from fossil fuels and from land-use and land-use change.

The effects of the different possible initialisation strategies on the simulation results for the target period 1980-90 will be critically assessed.

Input and validation data sets. Essential input data include those needed to determine or force the state variables of the physical climate system and data on the anthropogenic perturbations.

Data relating to the physical climate system:

- Global meteorological fields (temperature, moisture, vector winds, geopotential, surface fluxes, sub-gridscale transport terms) to drive the ATM
- Oceanic surface fluxes (windstress, buoyancy fluxes) to drive the OCCM
- Land surface fluxes/fields (irradiance, precipitation, surface moisture, temperature) as input data for the TBM.

Data relating to anthropogenic perturbations:

- Fossil fuel CO_2 release data
- Land-use statistics
- CFC-11 and ^{85}Kr source distribution.

The basic target variables for diagnostic studies or validation need to reflect or provide information, either directly or indirectly, about large scale source-sink regions. Atmospheric gradients are an essential and powerful feature in these temporally restrictive studies, but additional oceanic and terrestrial remotely sensed and *in situ* data will add important constraints and hence valuable information.

Atmospheric monitoring data:

- The average seasonal cycle at a selected set of monitoring stations
- Mean annual gradients in the concentration of CO_2 and its principle isotopic forms (^{13}C, ^{14}C)
- The interannual CO_2 variability, both in mean field and in seasonal amplitude
- CFC-11 (^{85}Kr)
- Oxygen concentration data.

Oceanic monitoring data:

- JGOFS timeseries data of surface carbon compounds and nutrients
- Ocean colour as determined from remote sensing platforms.

Biospheric monitoring data:

- Vegetation indices as determined from remote sensing platforms
- *In situ* calibration data.

The validation protocol, to be established at the initial workshop, will define the precise ranking of the observational data in terms of its quality and representativeness.

Schedule

Early 1994:	Perform pilot study at Hamburg. Workshop to discuss results with interested participants and to establish target variables, refine modelling strategy/protocol, define documentation protocol, and agree upon first suite of model experiments
Mid/late 1994:	Start one suite of experiments at least at one modelling centre
Early 1995:	Present preliminary results

Regional Interaction of Climate and Ecosystems

Purpose and approach. One of the expected consequences of climate change from increasing greenhouse gases over the next century will be changes in distribution of biomes (and rates of carbon pool cycling). These changes will in turn modify the climate changes. Present model simulations of climate change from greenhouse warming assume prescribed distributions of biomes and non-interactive scenarios for changing atmospheric CO_2. Two-way coupling between climate change on the one hand and the effects of biome distribution and carbon fluxes, on the other hand, must eventually be addressed. A prerequisite to carrying out such two-way coupling is first the validation of the individual subcomponents. There is presently developing a considerable body of information regarding the effects of vegetation changes on regional climates. Thus, the initial activity of this project will be to synthesise this present body of knowledge, identify gaps, and put it into a global framework. Likewise, as a second activity, we will learn how to use GCM supplied regional climate excursions to drive model simulations of fast carbon fluxes from terrestrial ecosystems, and also changes in biome distributions (and/or terrestrial ecosystem dynamics). As such, this effort falls between the "Contemporary" and the "Futures" time frame. The Contemporary time frame stems from the opportunity to validate aspects of the experiment against the new regional-scale terrestrial flux studies planned by WCRP and IGBP (e.g., the GEWEX Continental-Scale International Project in the Mississippi Basin (GCIP), and the Large Scale Atmospheric Moisture Balance of Amazona using Data Assimilation (LAMBADA); see IGBP Report 27, 1993).

The role of terrestrial ecosystems in modifying regional climate, soils, and nutrient exchanges is acknowledged but not quantified. At regional scales, vegetation exerts feedback on the climate of the planetary boundary layer, changing humidity, temperature, momentum transfer, and CO_2 concentrations. In addition, the spatial heterogeneity of the landscape form and vegetation patches also influence exchange processes with the boundary layer. To date it has been difficult even to quantify regional climatic sensitivity to dramatic land-use changes such as the complete removal of the Amazon forest because of the poor spatial resolution of the models employed and the lack of adequate data for initialisation and evaluation. Nonetheless, as water and carbon exchange by plants occur concurrently, the impacts of disturbances must extend beyond the physical-climate system to include the modification of biogeochemical cycles. The feedbacks between these interlocking systems are likely to be complex and warrant detailed investigation. This GAIM activity complements the WCRP Project for Intercomparison of Landsurface Parameterization Schemes (PILPS) and builds upon other intercomparisons such as the Scientific Committee on Problems of the Environment (SCOPE) project on forest succession models.

In sum, the purpose of this experiment is to understand better the relationships between climate and terrestrial ecosystems by focusing upon changes (natural and human-imposed) to terrestrial ecosystems and regional climate.

Implementation. The project will be conducted in three phases:

I. Sensitivity of regional climates to prescribed ecosystem changes
II. Sensitivity of ecosystem models to imposed regional climate excursions
III. Sensitivity of coupled ecosystem and climate models to imposed disturbances (e.g., trace gas increases, land-use change).

Phase I will comprise detailed analysis and interpretation studies. Research groups who have (or will soon have) conducted similar land-use change experiments will intercompare experiments and results, to identify common sensitivities and increase understanding of the sensitivity of regional climates to terrestrial ecosystem changes. The first focus will be Amazonian deforestation for which experiments have been conducted by several groups (e.g., Goddard Institute for Space Sciences (GISS), UK Meteorological Office, US National Center for Atmospheric Research (NCAR), the US National Aeronautics and Space Administration (NASA)/ University of Maryland, and Macquarie University). One aim will be to identify the various components and treatments within existing models that collectively most fully represent the regional climate changes.

One means of further investigating the role of terrestrial ecosystem changes in modifying regional climates follows a two-step procedure. The perturbed climate simulated as a

result of the imposed disturbance is used to determine a new ecosystem distribution for the region. From this it is possible to assign new values of land-surface parameters and then re-run the GCM/regional climate model to determine the new climate and "final" biome distribution. Similar sensitivity studies should be conducted for other large-scale land-use changes including desert transition and boreal forest removal. For future studies prescribed protocols would be highly advantageous. Throughout Phase I there needs to be an intense effort just to characterise the nature and extent of the feedbacks from terrestrial ecosystems to climate.

In Phase II (sensitivity of ecosystems to imposed regional climate excursions), advantage will be taken of the fact that the complex land-surface schemes which are being incorporated into GCMs are now beginning to include biogeochemical dynamics, as well as predictive components relating to shifts in the distribution of terrestrial ecosystems. In addition, global ecosystem models incorporating both terrestrial ecosystem dynamics and carbon exchange suitable for coupling to GCMs through land-surface schemes are a major objective of GCTE, and prototypes are likely to be available in the next 2-3 years. In this phase, it is proposed that a hierarchical series of intercomparisons be undertaken. These will begin with a community-wide inter-comparison of ecosystem changes in response to different initialisation assumptions and different imposed meteorology. The experiments will include:

- Ecosystem equilibration: integrate from initial conditions set equal to community-wide means until the selected model equilibrates using a one-year, prescribed climate with diurnal resolution employed for as many annual cycles as necessary.
- Disturbed climate: equilibrate ecosystem models and then switch to an alternative, imposed climate and re-equilibrate.
- Enhanced/reduced CO_2: double (or halve) ambient atmospheric CO_2 and equilibrate with both of the climate forcings used previously.

The ecosystem changes will be monitored and analysed by intercomparison across all models. Results of the physical exchanges including moisture, energy, and momentum will become part of the PILPS. These stand-alone (or off-line) intercomparisons should then be repeated but this time testing model performance against observations, especially of carbon exchanges for an "adequately large" region (a region is defined here as the size of a major river basin such as the Amazon, Mississippi). The goal is not to identify the "best" model, but rather to seek differences (and similarities) and understand and evaluate these.

Phase III (sensitivity of combined ecosystem and climate models to imposed disturbances), cannot be successfully completed until there is agreement from Phases I and II. The plan is to obtain one or more pairs of climate and ecosystem models which together provide a representative range of sensitivities. The experiment(s) must depend upon the availability of adequately resolved parameterizations and input and evaluation data. One possibility is to use the observational data to be provided by the basin-scale land surface experiments of WCRP and IGBP (see IGBP Report 27, 1993).

Phases I and II could be conducted concurrently. Indeed, some simulations of these types have already been carried out. GAIM will propose base experiments and offer the

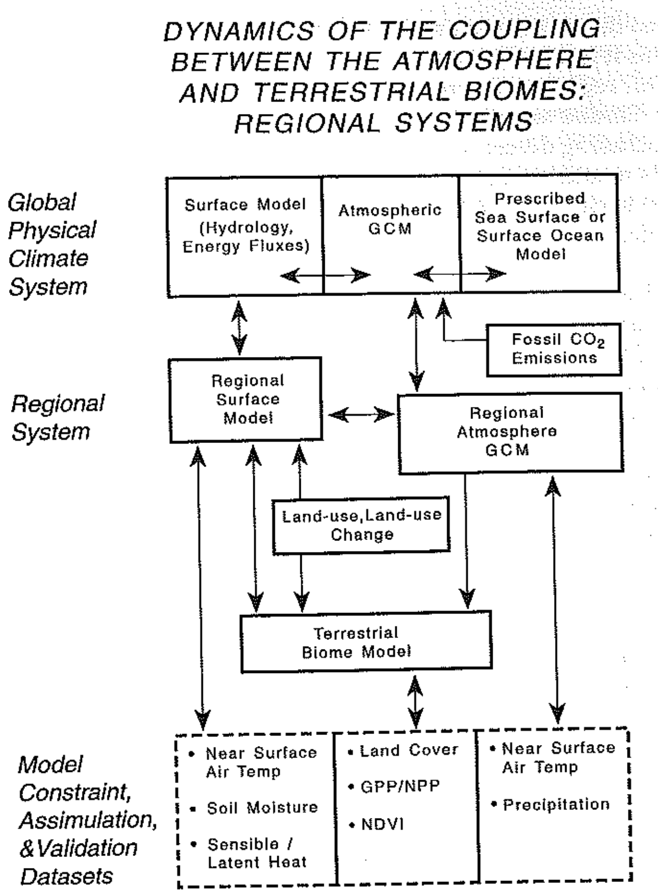

Figure 3. This framework focuses upon the coupling between climate and terrestrial ecosystems at regional scales. The GAIM Experiment considers the feedback, through a Terrestrial Biome Model, of the effects of regional climate change on Regional Surface Model and hence back to climate. This GAIM project complements the WCRP Project for Intercomparison of Landsurface Parameterization Schemes (PILPS) which is represented schematically by the two-way connection between Regional Surface Model and Regional Atmosphere GCM.

framework for intercomparison. It is expected that these studies will identify models exhibiting considerable sensitivity and models showing little response. The strategy is to exploit existing models and simulations to assess the sensitivities of regional climate to landscape change and of terrestrial ecosystems to climate change. These two aspects of the combined response to disturbances will be investigated separately first, partly to simplify interpretation and partly because validated coupled models do not yet exist. Phase III combines "example" climate and land-surface schemes offering a synergistic evaluation of the sensitivity of coupled ecotype-climate response to imposed disturbance.

Figure 3 provides a conceptual sketch of the model linkages and interplay.

Input and validation data sets. The (relatively) short time-scale of this study (± 20 yr from present) means that full ocean submodels are not required: however, it may be desirable to use a mixed-layer ocean model in order to offer information about teleconnections to regions beyond those studied. Such models, if used, can be tuned to observed temperatures from the last 20 years.
The major requirement is for data needed by global ecosystem models (e.g., vegetational functional type, soils hydrological properties, land-use data) in addition to detailed meteorological/climate information (such as that being derived from the re-analysis projects at ECMWF and NMC).

Detailed climate data (3 hr resolution, for between 1-20 yr) are needed for diagnostics and validation for Phase I, especially near-surface air temperature, precipitation, moisture convergence, sensible and latent heats; data on imposed land-use changes are also required. For Phase II, additional requirements include ecosystem changes; particularly changes in vegetation composition and structure, for one or more regions.
For Phase III validation, the data needs are as for Phases I and II, plus other nutrient exchanges, especially nitrogen.

It is very difficult to propose effective means of validating the new generation of coupled climate/global change models. However, this project does offer such a possibility. It is planned to conduct the Phase III sensitivity studies by combining "typical" model pairs. The minimum experimental framework would be a low response land-surface scheme coupled to a low-response climate model and a similar pairing of high response models.

The simulations would be undertaken for a 10-20 year period which will coincide with, or at the least overlap, the observational stages of one or more of the large-scale field experiments now being planned. Intercomparisons and validation efforts will offer the basis for subsequent project development.

Schedule
1994: Data acquisition, analysis and interpretation under Phase I; simple intercomparisons and workshop for Phase II; data acquisition for Phase III
1995: Initial testing of one or two coupled models within Phase III.

The Fossil Fuel Era

Steadily increasing fossil fuel emissions beginning in about 1860 are thought to have caused most of the observed increase in atmospheric CO_2 concentration. However, we are presently unable to quantify the relationship between observed increases and estimates of past fossil fuel emissions, other sources, and the redistribution of carbon within its global cycle. This questions the reliability of estimates of future CO_2 increase and drives a substantial effort to understand carbon cycle responses to human activities over the past several centuries. The causes since the industrial revolution of increases in other greenhouse gases such as CH_4 and N_2O are less certain, primarily because changes in the distributions and magnitudes of their sources are poorly known.

Given reliable estimates of past fossil fuel emissions, knowledge of carbon uptake from the atmosphere by the oceans is the most important requirement either for analysing past changes in CO_2 concentration or for estimating future CO_2 increases due to different levels of further fossil fuel use. But historic (and future) changes in terrestrial carbon storage, whether due to natural phenomena or because of human activities, cannot be ignored. If estimates of past fossil fuel emissions are reasonably accurate, then either the oceans remove carbon from the atmosphere more readily than data and models suggest, or another sink influences atmospheric CO_2 increases. This is a large sink if human activities have released as much carbon into the atmosphere from plants and soil as estimates derived from land-use and demographic data suggest, and the magnitudes of future CO_2 increases depend significantly on the characteristics of the sink.

In order to resolve inconsistencies in our understanding of fossil fuel era CO_2 increases, we need to re-evaluate and refine our understanding of the carbon cycle and the perturbations of interest from several standpoints:

- The oceans may remove carbon from the atmosphere more readily than current models indicate.
- Other ecosystem responses, including the potential responses to changes in climate over the last 300 years, may compensate for decreases in terrestrial carbon storage due to land-use and other activities.
- Estimates of historical fossil fuel emissions or of releases of carbon from vegetation and soil may be wrong.

All of these points probably contribute to our inability to explain fossil fuel era changes in the carbon cycle.

The atmosphere is responsible for most of the coupling between carbon pools in terrestrial ecosystems and those in the oceans. Rivers and runoff also transfer carbon from land into the oceans, but these links are weak by comparison. Terrestrial and oceanic carbon models can therefore be decoupled for many purposes. This is a practical advantage because the data and formalism used in each are quite different. Operationally, the solutions to terrestrial models are summarised as a net flux into the atmosphere and treated as an additional atmospheric input or sink in the solution of models of the atmosphere and oceans.

Rather than the uptake by other reservoirs, chemical reactions in the atmosphere control changes in the concentrations of greenhouse gases other than CO_2. But industrial emissions and agriculture have altered the sources of gases such as CH_4 and N_2O, and thus a thorough explanation of past increases in the concentrations of these gases requires analysis of historical data similar to that involved in CO_2 analyses, but with models of terrestrial sources and sinks coupled to atmospheric chemistry models.

Changes in Terrestrial Carbon Storage

Purpose and approach. The broad objective of this experiment is to develop more realistic, generalised ecosystem element cycling models for analysing global responses over decades and centuries and to gain more consistent understanding of past changes in atmospheric CO_2 concentration and the carbon cycle. Through a series of model sensitivity tests and comparisons, this activity seeks to improve our understanding of

terrestrial ecosystem contributions to fossil fuel era increases in atmospheric CO_2 concentration. The potential for further carbon releases from terrestrial ecosystems during the next 100 years and the degree to which climatic change and rising CO_2 levels may alter terrestrial ecosystem structure and function, and thus biogeochemistry, will also be considered.

Human activities, such as forest harvest and clearing, have reduced the amounts of carbon in plants and soil, contributing to the observed increase in atmospheric CO_2 concentration. The magnitude and timing of terrestrial carbon releases are uncertain, however, and model studies suggest that during the last several decades, oceanic uptake was not large enough to accommodate significant releases from land pools in addition to fossil fuel emissions. This inconsistent understanding of past changes in atmospheric CO_2 and the carbon cycle forces scepticism about estimates of future CO_2 increases and global environmental change.

Thus far, analyses of past changes in terrestrial carbon storage have relied on models with simplistic representations of ecosystem carbon dynamics. Some studies have used purely empirical representations of terrestrial exchanges with the atmosphere. This was largely because more detailed and realistic ecosystem models were specific to certain sites where they were developed or, at best, to limited areas. There are now, however, a number of more mechanistic terrestrial element cycling models that seek wide applicability and need to be used in global carbon cycle studies. This experiment will analyse the carbon cycling response characteristics of selected ecosystem models within a common framework of calibration data, land-use forcing functions, climate histories, and atmospheric CO_2 increase.

Implementation. In examining the role of terrestrial systems in the global carbon cycle over the last 300 years, three items guide the strategy. First, it is important to involve as many global terrestrial models as possible in order that significant developments can be accrued from model intercomparisons, even if the model does not formally treat land-use dynamics. This can be accommodated by having a standard model for handling the effects of land-use and simply accounting for these "areas" separately at each grid cell.

Second, ^{13}C and ^{14}C information is essential; therefore, a standard "fractionation model" may need to be developed to provide this capability for all models. Third, models for specific, yet large, biomes should be accommodated by using a standard global model for treating the other terrestrial areas.

An initial workshop will review available ecosystem models and select those for initial consideration. This will be coordinated with GCTE. The feasibility of applying a model globally will be important but is not crucial if reasonable and useful approximations can be made that allow global simulations. For example, some models include parameters, such as stomatal conductance or biochemical coefficients, that are difficult to estimate. These models can be included by estimating parameter values from laboratory data or by judgement. Sensitivity tests will indicate the importance of poorly known parameter values in analysing the global influence of terrestrial ecosystems on atmospheric CO_2. We note that it may prove difficult to isolate some of these parameters and adequately test the model's sensitivity.

Different ecosystem models emphasise particular processes, such as primary productivity or decomposition, and some models that are not designed for carbon cycle analysis contain important components that this activity needs to consider. A general ecosystem model framework will be formulated to allow substitution of different process representations for comparison and sensitivity tests without incorporating a complete model into the analysis. This model framework will include vegetation and dead organic matter pools with carbon uptake from the atmosphere by net primary productivity and loss by decomposition. Aspects of this basic structure will be extended where feasible. Through this approach, components of different models will be combined to form alternative ecosystem models in addition to those already available.

Most model comparisons will be based on standard 300-year solutions from equilibrium initial conditions in 1700 to 1990. Terrestrial models will be coupled to a well-mixed atmosphere, with atmospheric CO_2 concentration either specified from ice-core measurements and direct observations or simulated by including a one-dimensional model of carbon turnover in the oceans, such as the box-diffusion model. Fossil fuel CO_2 emissions will also add carbon to the atmosphere. Historical estimates derived from energy data will be common to all solutions prior to 1990. Forest clearing and harvest will perturb the terrestrial models. Again, a standard set of historical estimates of these forcing functions. Analysis in this total carbon cycle framework will consider ^{13}C and ^{14}C as well as total carbon. Climatic variables will be set both to observed long-term averages for the historic period of simulations as well as climate histories that include observed variabilities. During the historical period of model solutions, a residual flux into the atmosphere that is required to match the model solution to the standard history of atmospheric CO_2 concentration will be calculated. This latter option allows projections beyond the historical records (Fig. 4).

This experiment could also set the stage for considering a Futures time frame by simply adding the following to this effort: (i) alternative scenarios of future fossil fuel emissions; (ii) a selection of scenarios of future land-use activity; and (iii) a selection of climatic change scenarios derived from global circulation model experiments to specify alternative future climate parameters. This possibility will be discussed concurrently with the implementation of this experiment.

There are several implementation issues that have yet to be resolved:

- The spatial and temporal resolution of the pre-1940 climate, as data records worsen in quality prior to that date.
- The resolution and number of classes of land-use.
- The method for modelling the anthropogenic carbon inputs and losses associated with land-use, as some ecosystem models can carry out such calculations while others do not directly support these calculations.
- Some models require climatic variables with time resolution substantially greater than that of observations (e.g., hourly as opposed to long-term monthly means). Rough estimates can be made but may be misleading.
- The spatial resolution of estimates of past forest clearing and harvest must be extended to the scale of model calculations without satisfactory data.

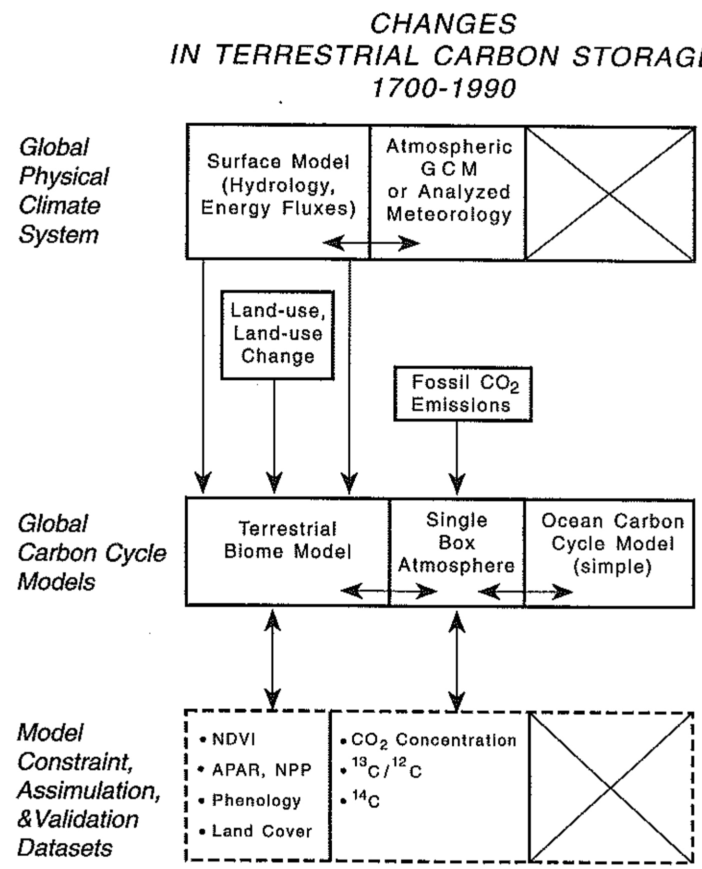

Figure 4. This Experiment analyses the carbon cycling response characteristics of selected ecosystem models within a common framework of calibration data, land-use forcing functions, and atmospheric CO_2 increase. Terrestrial models will be coupled to a well-mixed atmosphere, with atmospheric CO_2 concentration either specified from ice-core measurements and direct observations or simulated by using simple one-dimensional models of carbon turnover in the oceans, such as the box-diffusion model.

- Developing adequate global, geographically referenced data of soils and their dynamic characteristics is an important early activity.
- Determination of degree and characteristics of CO_2 fertilisation at the ecosystem level will be a troubling issue. For example, to what extent does fertilisation mean a net long-term increase of the carbon storage in forests or rather only a more rapid turnover? In other words, how is the climax state of an ecosystem influenced by climate change and increasing CO_2 concentrations in the atmosphere? This is particularly important for modelling the future behaviour of the system and meeting this challenge is one reason for understanding better the past and current behaviour of the carbon cycle.

Input and validation data sets. As far as possible, models will be calibrated to common data. Initial ecosystem distribution, carbon standing stocks, and net primary productivity will be common to all models so that comparisons focus on model response characteristics. Thus, the project will assemble global data sets on these variables. Estimates of moisture availability and evapotranspiration are involved in most models, and data on soil characteristics needed in these calculations will be assembled. Data for describing past forest clearing and harvest on a country basis will be used in addition to global estimates of past fossil fuel emissions.

Some of the input data needs are:

- Standardised land-use forcing 1750-1990, geographically resolved
- Standardised, geographically resolved climatology for that period
- Standardised land surface configuration and soil characteristics
- Mean equilibrium carbon and nitrogen standing stocks by ecosystem type to set common initial conditions or for comparison
- A framework that will allow the comparison of the widest possible variety of models. The eventual inclusion of succession models is essential given the time span proposed for the analysis.

The terrestrial model comparisons developed by this experiment will focus on the influence of terrestrial ecosystems on atmospheric CO_2 concentration as they respond to land-use perturbations, rising CO_2 levels, and climatic change. Thus, exchanges between the atmosphere and terrestrial ecosystems, and net ecosystem production through time, will be the primary variables for comparison. Response times associated with terrestrial pool sizes will also be analysed. Where feasible, changes in relative ^{13}C abundance will be compared.

Among the diagnostic variables are:

- Geographically specific annual net ecosystem production with annual increments for live, dead, and soil carbon pools
- Causal relations for changes in carbon storage must be assigned to ecosystem changes (NPP, respiration) and to human intervention (land-clearing, biomass burning, etc.)
- Isotope budgets and nutrient stocks.

Schedule. A three-year effort is anticipated. The project will begin with a workshop in 1994 to select models and to agree on standard data sets and analyses. Data sets will be assembled while models are constructed and modified. Initial model experiments will begin near the end of 1994. Alternative models will be explored in detail during 1995, and initial results will be documented during the remainder of that year. In depth studies will be conducted in 1996 and beyond.

Changes in Trace Gas Concentrations in the Atmosphere since the Industrial Revolution

Purpose and approach. The concentration of radiatively and chemically active species such as CH_4 and N_2O has substantially increased over the last 200 years and has led to an enhancement in the greenhouse forcing to the atmosphere. The abundance of CH_4, for

example, has increased from 600 ppbv in the 18th century to approximately 1700 ppbv at the present time. Over the last decade, the average CH_4 trend has been approximately 0.8% per year. In the case of N_2O, the concentration has increased from approximately 280 ppbv to 310 ppbv over the past 200 years. The current trend is estimated to be of the order to 0.25% per year.

The causes for these observed trends are not yet fully understood. Anthropogenic sources of these gases are related to agricultural and industrial activities. In particular, there is poor quantification of the potential changes in soil emissions and consumption associated with changes in land-use and other modifications in terrestrial ecosystems. Finally, and especially in the case of methane, the oxidising capacity of the atmosphere is directly affected by the abundance of chemical constituents such as carbon monoxide and nitrogen oxides, and the atmospheric concentration of these compounds is strongly affected by anthropogenic activities.

The development of a coupled atmosphere-ecosystem model that satisfactorily describes the evolution of CH_4 and N_2O since the beginning of the industrial revolution is an important long-term objective, leading eventually to a comprehensive model for the nitrogen and carbon systems as well as for other important biogeochemical cycles. As an important interim step, this experiment focuses upon the chemically active (in the atmosphere) portion of the carbon system including many compounds such as CH_4, non-methane hydrocarbons, and CO, species whose budgets are poorly known. As mentioned, methane has been increasing in the atmosphere at about 0.8% yr^{-1}, though this rate has apparently declined in the past few years. It is not clear if this is due to changes in the magnitude of surface sources or changes in the atmospheric sink terms, perhaps related to alterations in the oxidising capacity of the atmosphere due to anthropogenic forcing. Including these reactive carbon species adds considerable complexity, since their atmospheric lifetimes depend on the concentrations of other compounds, on UV flux, and on other factors. Because of the reactivity of methane and other carbon compounds (but not CO_2), their atmospheric lifetimes, and hence contributions to the greenhouse effect, change along with other changes in the Earth system.

A series of tools which can be employed to analyse key aspects of the problem are being produced by the scientific community. Global, three-dimensional chemistry-transport models are being developed at several research institutes: GISS/Harvard, NCAR, Geophysical Fluid Dynamics Laboratory, Lawrence Livermore National Laboratory, UK Global Atmospheric Chemistry Modelling Project, Global Modelling of Atmospheric Chemistry (Max Planck Institutes for Meteorology at Hamburg and for Chemistry at Mainz), Universities of Stockholm, Utrecht, and Paris, and the European Institute for the Environment. At present, these models suffer from low spatial resolution and most only treat the "background" photochemistry of the $O_3/H_2O/NO_x/CH_4/CO/HO_x$ system. On a more positive note, some have been used to make estimates of the pre-industrial and industrial oxidation efficiency or state of the atmosphere, and hence could be used to probe the consequences of changing methane sources on the lifetime of methane and other greenhouse gases produced by its atmospheric oxidation (e.g., O_3).

Process-level CH_4 production models are also being developed, which can begin to predict CH_4 production in natural ecosystems (and rice agriculture) in response to changing climate. Simple models for the estimation of global methane oxidation in soils are being developed and will soon be published. Such models can be used to assess the magnitude of methane production and consumption responses to changing climate and land-use. Analyses using source models alone would not include an estimate of the changing lifetime of methane, or its secondary effects on O_3 and so would be an incomplete analyses of the role of CH_4 in the carbon-climate system.

Methane source and soil oxidation models, combined with inventory data for natural gas leaks, cattle and other anthropogenic sources, and forced by GCM climatology can also provide inputs to tropospheric chemistry. This modelling strategy includes feedbacks to methane's lifetime mediated by tropospheric chemistry, and will also allow the estimation of the effect of changing CH_4 fluxes on both the lifetime of CH_4 and on the subsequent production of other trace gases such as O_3. These indirect but potentially large effects of changing CH_4 can be factored into subsequent climate analyses parametrically in order to estimate the magnitude of feedbacks between chemistry and climate. If the effects appear to be large in these "partially coupled" analyses, then fully coupled analyses with chemistry code running concurrently with the rest of the carbon-climate model are warranted and should be pursued.

Treatment of both the CO_2 (model experiments on "The coupled atmosphere-land-ocean carbon system, 1980-2000" and "Changes in terrestrial carbon storage") and chemically active portions of the carbon system (this experiment and the experiment "Changes in atmospheric methane during glacial-interglacial transitions") will position the community well for treating more completely the changing nitrogen cycle. For instance, models of the biotic emissions of N_2O, which is a non-linear function of soil temperature, soil moisture and nitrate availability, will be developed from the turnover of inorganic nitrogen, as provided by the global soil models that will be employed in carbon cycle modelling.

Implementation. The full implementation plan is not yet developed. This is an issue that will be addressed by the GAIM Task Force in 1994-95, in collaboration with the community.

One obvious difficulty associated with such complex model simulations, especially when performed in a time-dependent mode, is the amount of computer time required. Therefore, rather than using immediately a full three-dimensional model, preliminary tests should first be done by using less detailed formulations such as two-dimensional models. Another limitation in the model calculation arises from the fact that changes in land surfaces over the last 200 years are not well documented for all regions of the world and consequently different hypotheses will have to be made and tested.

Input and validation data sets. Models of land-use and surface hydrology will be critical for modelling CH_4. Methane is produced in inundated areas and consumed in upland soils as a function of soil moisture dynamics. Improved global wetland data and soil moisture estimates will be required for simulation of the terrestrial CH_4 cycle.

It will be important to constrain the model with available observations. For example, the latitudinal gradients and seasonal variations in the atmospheric concentrations of these gases will have to accurately reproduce the data gathered at different stations over the last decade. This type of validation will require that the transport formulation used in the model will be provided by data regarding isotopic composition of CH_4 and possible N_2O.

The output of the model will be the three-dimensional distribution of CH_4 and N_2O concentrations as well as isotopic ratios. Thus data on these distributions will serve as the key diagnostic data

Schedule. As mentioned, two- and three-dimensional models of global tropospheric chemistry and process models for biological production, emission, and consumption are being developed and should exist by mid to late 1995. Consequently, efforts to couple sources and surface sinks to an atmospheric model could commence then, although there may be some delays before land-use and industrial emissions can be fully included. Initial simulations and analyses can be expected by late 1996. The approach will be refined during the first half of 1995.

The Palaeo Era

The concern with future Earth system responses to large perturbations in atmospheric composition and climate makes it important to exploit the recent geological record as studied by the IGBP Core Project on Past Global Changes (PAGES). With ingenuity, this palaeo record can be made to provide tests of Earth system models under conditions substantially different from present. The palaeo record provides the only means to test such models under conditions (in the past) that are as different from present as the conditions expected to apply in 50-200 years' time. This principle is well established in the physical-climate modelling community and underlies the recent establishment of a Palaeoclimate Model Inter-comparison Project (PMIP), in which different GCMs will be run with agreed boundary conditions to represent the state of the climate system at key times during the past 150,000 years.

Here we identify related experiments for key times used in PMIP. The first experiment tests the performance of coupled, equilibrium vegetation-atmosphere models for the period around 6000 BP, and the second experiment explores CH_4 emissions for selected periods between 18,000 BP and 6000 BP, covering the well-documented history of deglaciation between these times. The power of these tests lies in the richness of available palaeo-data describing the state of all parts of the Earth system, including atmospheric composition, the extent of ice-sheets, regional climates, and terrestrial ecosystems, with excellent radiometric dating control for the past 18,000 years. As noted below, planning for a more extensive test of ocean-atmosphere-biosphere biogeochemistry models and simplified whole Earth system models including cryosphere dynamics (deglaciation) for the period 18,000 BP to 6000 BP will begin during this first phase of GAIM activities.

The aim of the first experiment is to compare the results with palaeo-ecological data worldwide, for a period when global climate was substantially different from present, but without the major differences in the distribution of land and sea ice that complicate the interpretation of previous 18,000 yr BP (glacial maximum) simulations.

Six thousand years BP is a well-accepted "cardinal point" for synthesis of palaeo-environmental data (e.g., by PAGES) since the 6000 BP period corresponds to a time in which all boundary conditions excepting orbital forcing, which is exactly known, were very similar to present. It is an epoch which is especially interesting from the perspective of testing hypothesis concerning climate-ecosystem feedbacks. There is a large amount of good-quality terrestrial pollen data, with patchy but extensive worldwide scope, which PAGES could synthesise in suitable form for comparisons with biome model results. Also, 6000 BP is a time for which standardised atmospheric general circulation model (AGCM) experiments are being carried out a for the PMIP, a global palaeoclimate data base already exists, and new efforts to organize existing palaeoclimate and palaeovegetation data are being started in connection with PAGES.

The analysis of the chemical composition of air bubbles trapped in ice has shown that over geological time-scales the level of atmospheric CH_4 has been remarkably correlated with CO_2 concentrations and surface temperatures. Specifically, the abundance of atmospheric CH_4 nearly doubled between the last glacial maximum 18,000 years ago and the interglacial period 6000 years ago. This suggests that, in addition to changes in the solar forcing associated with modifications in orbital parameters of the Earth, complex feedback mechanisms between the biosphere and the atmosphere have played a significant role in the evolution of the climate. The period 18,000 BP to 6000 BP should therefore provide insights into the connection between trace gases and climate change.

In this initial phase of GAIM, we focus on a 6000 BP experiment testing climate-vegetation equilibrium interactions, and a set of steady state CH_4 experiments for selected intervals in the period 18,000 BP to 6000 BP. A more extensive 18,000 BP to 6000 BP climate-vegetation-trace gas experiment will begin to be planned during this initial GAIM Action Plan.

Climate-Vegetation Interactions: A 6000 BP Experiment

Purpose and approach. A key issue is the extent to which vegetation distribution modifies itself through feedbacks to climate, through mechanisms such as increased evapotranspiration leading to increased precipitation inland. To investigate this issue requires the coupling of atmospheric and vegetation models.

A coupled model, run to equilibrium, should naturally be able to reproduce present vegetation patterns (assuming that the vegetation is at equilibrium). A more stringent test is whether such a model can also reproduce vegetation patterns at a time when the atmospheric circulation was substantially different. This test, obviously, must recognise that palaeovegetation patterns are not completely known nor is the palaeoclimate.

Data from the millennium around 6000 BP provide an opportunity to "observe" the equilibrium state of the coupled vegetation-atmosphere system at a time when orbital changes, affecting the seasonal and zonal distribution of insolation, caused a substantially different global pattern of temperature and precipitation than present. In many subtropical regions the climate at 6000 BP was even more different from than the climate at 18,000 BP because of the major expansion of northern-hemisphere summer monsoons, which brought moisture to areas such as the Sahara that are extremely dry today.

Data from the vegetation for 6000 BP (mainly inferred from pollen records) can be used to check the performance of climate models forced by a different orbital configuration. It has already been observed that the degree of monsoon expansion simulated by AGCMs is not enough to explain the near-disappearance of the Sahara desert at 6000 BP as shown in the palaeovegetation record unless the land-surface conditions are also changed to be consistent with the palaeovegetation record. In this light, a purpose of this experiment is

to use the palaeovegetation record as a means of testing the equilibrium performance of a coupled climate-biome model. Note that the aim of the experiment is not to seek a direct analogue for global warming, but rather to test the linked models under a climatic regime substantially different from present.

Because the biome response to climate is slow compared with the reverse response, it is justified to couple initially AGCM and biome models asynchronously using an AGCM and an equilibrium model for the distribution of vegetation as a function of climate ("biome model"). First, the AGCM is run to equilibrium with the land-surface prescribed as it is at present (but excluding land-use change). Second, the resulting simulated climate drives the biome model. The biome model output is then used to prescribe a new land-surface and the AGCM is run to equilibrium again; the simulated climate drives the biome model as before. The two simulated global vegetation patterns are compared with one another, and with global palaeovegetation data. The AGCM would be run throughout with prescribed sea surface temperatures (SSTs), ice-sheets and atmospheric composition as present, and 6000 BP orbital parameters. This overall approach is sketched in Fig. 5.

More complex experiments could be envisioned that would employ non-equilibrium ecosystem models with transitional dynamics. While not appropriate initially, this possibility will be considered in subsequent Action Plans. Substantial progress has been made during the last 5 years in developing dynamic global vegetation models, including: the development of semi-mechanistic biome models; major improvements in the computational efficiency of patch-scale vegetation dynamics models; development of patch-scale models to handle competition among multiple life-forms (allowing for transitions between structurally distinct vegetation types); definition of generalised protocols for scaling up from patch dynamics to landscape-average terrestrial ecosystems dynamics, including stochastic treatment of disturbance regimes; prototype models for dispersal and migration of plant types; and schemes to couple terrestrial ecosystem dynamics with geophysical processes.

It is recognised, however, that a non-equilibrium, global vegetation model with transitional dynamics including multiple life forms and functional groups has not yet been implemented. This will entail a major modelling effort, as proposed by GCTE, to develop dynamic global terrestrial ecosystem models based on mechanistic principles and including the relevant ecological as well as physiological processes.

The GCTE model development will take a number of years. The GAIM strategy and contribution is to begin this exploration by conducting a simple, specific and key experiment in which ecosystem transitions are handled in a step-wise, quasi-parametric manner using equilibrium, global vegetation models. We turn to some of the implementation issues for this experiment.

Implementation. Implementation is relatively straightforward given that suitable values of the land-surface parameters for the GCMs can be ascribed to the different biomes. Thus, similar experiments could easily be run by different climate modelling groups (e.g., in the context of PMIP). The main implementation issues are:

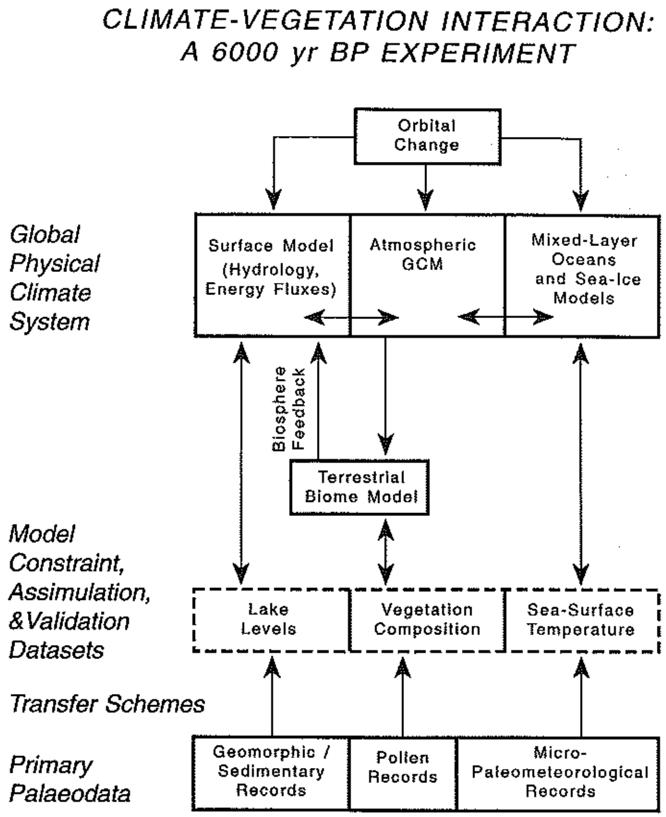

Figure 5. This framework focuses upon the initial tests within the 6000 BP GAIM Experiment on Climate-Vegetation Interaction.

- Should the SSTs be prescribed at modern values (PMIP's standard approach for the 6000 BP case), or should an attempt be made to prescribed realistic 6000 BP values using palaeo-oceanographic data? The latter approach would require the development of a new SST data set.

- What is the best way to summarise the palaeovegetation data (mainly pollen) for objective comparison with the coupled model results? This question is under active consideration by the community.

Input and validation data sets

- Orbital parameters are known and needed.

- SST: as mentioned, the PMIP planned benchmark experiments will use modern SSTs. It would be more realistic to use prescribed SSTs derived from data (e.g., foraminiferal assemblages in high resolution ocean cores) if this were possible, but the signal may not be sufficiently pronounced to warrant consideration.

- Vegetation/climate model interface: the AGCM would be used to produce climate variables required by the biome model. Present biome models typically require monthly values of temperature, precipitation and solar radiation averaged over several years. Direct output of biome models is a categorisation of grid cells into 10-20 vegetation cover states, which must be assigned typical values of land-surface parameters (rooting depths, leaf area index, roughness, etc.) according to the requirements of the land-surface scheme used in the AGCM.

- Palaeovegetation data: data sets exist (Cooperative Holocene Mapping Project, COHMAP) but not in a form suitable for straightforward data to model comparisons at a global scale. An effort is required to organize existing pollen data sets for 6000 BP in such a form with plant taxa characterised in terms of the plant functional types used by biome models; this would also be a natural PAGES activity.

Schedule. Liaison has been established with the GCM groups running the standard PMIP experiments for 6000 BP. Concurrently, a set of surface parameters for biomes can be generated on an informal basis with the community; however, a more organized effort in coordination with IGBP-DIS and the relevant scientific communities will be needed to develop the required global palaeovegetation data set. This more sustained 1-2 yr effort started in late 1993 and continued with an important planning workshop in May 1994. This foundation should allow the GAIM experiments to be conducted during 1995, including the detailed systematic data-model comparisons, with initial results by mid 1996.

Changes in Atmospheric Methane during Glacial-Interglacial Transitions

Purpose and approach. The experiment is to calculate the atmospheric concentration of CH_4 at different stages of past climatic evolution. Because CH_4 before industrialisation was produced mainly by microbial activity in terrestrial ecosystems (e.g., wetlands), oxidised by the OH radical in the atmosphere, and to a lesser extent consumed in soils, a model to study the evolution of CH_4 must include a coupled formulation for biological emissions, atmospheric transport, chemical transformations and surface deposition on various ecosystems. The emission model will calculate the potential decomposition rate of phytomass to CH_4 from a model of water table dynamics and other site characteristics including climate. The type and geographical distribution of ecosystems will be derived by an ecosystem dynamics model coupled to an atmospheric general circulation model for conditions representative of specific palaeoclimatic conditions.

As climate changes from a glacial to an interglacial period and the ecosystems adjust accordingly, the release of CH_4 to the atmosphere and the surface deposition of this molecule are modified accordingly. To calculate long-term changes in the abundance of atmospheric CH_4, changes in the oxidising capacity of the atmosphere must also be quantified. Since the concentration of OH in the atmosphere depends on the amount of water vapour, ozone, carbon monoxide, nitrogen oxides, and non-methane hydrocarbons, a full chemical scheme must be implemented in the atmospheric model. The distribution of these species is affected by their boundary conditions, which are determined by natural biomass burning and to a lesser extent, physical and biological processes in the ocean. These need to evolve together with the changing physical-climate and ecosystem distribution as calculated by the coupled model. Another factor which needs to be taken into account is the change in sea level. Finally, an important component of the coupled model is its transport formulation which must be accurate and, in addition to pure advection must include adequate representations of convective and sub-grid transport.

Implementation. The implementation scheme will begin in 1995 with a full assessment of the data constraints and their implications. Initially the scheme will consider a series of quasi-steady states through the period of interest before treating the far more complex transient case.

Input and validation data sets. Very few data are available for palaeoclimatic conditions. The model will provide distributions of trace constituents in the atmosphere as well as global quantities such as burden, lifetime, production and destruction rates, etc. for these constituents. The model will have to be validated using measured concentrations and isotopic ratios in ice cores.

Because data covering this period of time are limited, the validation of the model will be quite incomplete. Boundary conditions for trace gases are almost all based on record from the Antarctic and the Arctic: very little information covering low and mid-altitudes is available. As mentioned, no fully transient model simulations will be possible over a period of time covering thousands of years but quasi-steady state calculations representative of different climatic situations will be done. Note that the coupled model will be driven by climatic conditions produced by a general circulation model; however, a comprehensive study should also take into account the impact of methane changes on the physical parameters in the climate system. It is assumed in this proposed study that these effects are secondary (although not negligible) and they will therefore be neglected.

Schedule. This experiment will be defined during 1994-95 and presented more fully in the next GAIM Action Plan.

Organization

The Task Force structure of GAIM differs from the Core Project structure adopted elsewhere in IGBP. Given the special nature of GAIM activities, and their broad purpose, it is appropriate that a major portion of the modelling work will be conducted by the Task Force (see Appendices) in close collaboration with modelling groups around the world. A recognised responsibility and opportunity of the Task Force is to expand the community of scholars participating in GAIM activities and, in particular, in modelling the biogeochemical system and its coupling to climate.

The Task Force is currently chaired by Berrien Moore III, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire. The Task Force has a Task Force Office located at the University of New Hampshire, Durham, New Hampshire 03820, USA.

During 1994, the activities of the Task Force will focus on initiating four modelling experiments (Table 1):

1. Contemporary Era: The coupled atmosphere-land-ocean carbon system, 1980-2000
   Lead: Martin Heimann
   Co-Leads: Patrick Monfray & Jorge Sarmiento

2. Contemporary Era: Dynamics of the coupling between the hydrological cycle, carbon cycle and terrestrial biomes
   Lead: Ann Henderson-Sellers
   Co-Leads: Robert Dickinson & Carlos Nobre

3. Fossil Fuel Era: Changes in terrestrial carbon storage
   Lead: William Emanuel
   Co-Leads: Dave Schimel & Ian Woodward

4. Palaeo Era: Climate-vegetation interactions, a 6000 BP experiment
   Lead: Colin Prentice
   Co-Leads: William Peltier & Ichtiaque Rasool

Each of the Leads has a post-doctoral fellow supported 50% by funding obtained through the GAIM Task Force Office and 50% by the home institution. The IGBP and the US Environmental Protection Agency are the sole sources of funds at present. During the second half of 1994 an aggressive effort will be made to enhance the GAIM funding base. Additional funds are being sought for the fourth fellow (for experiment 3) and for a Task Force Officer.

The two trace gas experiments, "Changes in trace gas concentrations in the atmosphere since the Industrial Revolution" and "Changes in atmospheric methane during glacial-interglacial transitions", require additional definition. The modelling experiments will be reviewed yearly, and the Task Force Action Plan will be revised at least every other year – with an overall planning emphasis on timely results that exploit the evolutionary character of global modelling today.

Rationale and Objectives for IGBP-DIS

The acquisition, processing, manipulation and archiving of global-scale environmental data sets are all essential for the success of the International-Geosphere Biosphere Programme. These activities are necessary not only for the successful implementation of individual IGBP Core Projects, but also for their overall synthesis, to meet the objectives of the programme as a whole. The data dependency of IGBP at all levels and phases requires that the development of its Data and Information System (IGBP-DIS) should be interactive and iterative with the other components of IGBP, responding to the scientific evolution of the Core Projects. But IGBP-DIS must also be pro-active, influencing and assisting the development of the Core Projects by providing leadership in data policy issues and ensuring that gaps in data provision are identified and filled.

The need for a cross-cutting, data-focused activity within IGBP was recognised during the programme's early planning phase, with pilot studies in remote sensing and data management identified in IGBP Report 8 (1989) and 12 (1990). The subsequent development – and implementation – of IGBP-DIS has been achieved through workshops, scientific collaborations, and other activities of the IGBP-DIS Standing Committee and its Office in Paris. Most workshops have been held jointly with one or more IGBP Core Projects, or with the GAIM Task Force. Documentation on the main developments is provided in IGBP Report 20 (1992) and the IGBP-DIS Working Paper series (see Appendices), with a planning overview given in IGBP Report 28 (1994). A more detailed definition of the mission of IGBP-DIS is now timely, due to developments within IGBP-DIS itself, within other parts of IGBP and externally.

IGBP-DIS is not, and was never intended to be, a hardware-based, data centre responsible for receiving, processing and supplying all data for IGBP. That scale of effort would be an inefficient use of resources, duplicating the efforts of various international and national agencies. It would also mean taking on responsibility for many aspects of data handling that are best dealt with by the individual Core Projects and non-IGBP bodies. Instead, the rationale for IGBP-DIS stems from a number of generic issues for data acquisition and management which cut across the activities of Core Projects and relate to their integration. Among the most important of these issues are:

(i) The increasingly integrated nature of global change science, requiring greater exchange of data from diverse sources within and between projects and programmes. A key issue for IGBP-DIS is the provision of efficient data exchange mechanisms, meta-data and catalogues, to ensure data sets can be obtained and properly interpreted.

(ii) The current lack of many crucial data sets needed by several Core Projects for model development and operation. There is a requirement both for new global data sets and for existing global data sets in new forms. In developing their models, Core Projects need to specify the data sets required to run them. This involves assessments of the usefulness and availability of existing data sets, and of the feasibility of assembling new data sets.

(iii) The very large volumes and novel character of many new data sets expected to be available from space platforms in the late 1990s, with distinctive problems of information manipulation and extraction.

(iv) The need to ensure the provision of long-term data sets to detect significant global changes in environmentally important parameters. Such data sets may well have different space and time characteristics from those required for the running or testing of models. Long-term support for monitoring activities, and access to the data arising from such work, has often been hard to secure.

(v) The need for consistent and complementary data management policies for individual IGBP Core Projects, GAIM and the Global Change System for Analysis, Research and Training (START), and for the programme as a whole. This will necessitate IGBP-DIS advising on appropriate data management protocols, with emphasis on scaling problems, the development of methods for integrated data assimilation, the application of satellite data and other aspects of global synthesis.

The principal beneficiaries of the work of IGBP-DIS will be researchers within IGBP Core Projects and Framework Activities. However, IGBP-DIS also has a role in assisting the supply of data to external organizations, whose activities in turn are important for IGBP. For example, the World Climate Research Programme (WCRP), that has shown particular interest in the land cover data sets that are being produced as a result of current work by IGBP-DIS. Other groups include various space agencies and their data and information systems. It is also important that IGBP data products from the IGBP are useful to such bodies as the IPCC of the United Nations Environment Programme/the World Meteorological Organization (UNEP/WMO), and thereby contribute to policy-making processes at the national and international levels.

Taking account of all these issues, the main aim for IGBP-DIS has been defined as follows:

- To improve the supply, management and use of the data and information that are needed to attain IGBP's scientific goals.

Component objectives are to:

- Carry out activities directly leading to the generation of relevant data sets and other data system components for IGBP

- Ensure the development of effective data and information management systems for IGBP, including the preparation and implementation of a programme-wide Data System Plan, and assisting IGBP Core Projects in the development of their individual Data System Plans

- Assist in meeting the data and information needs of IGBP through partnerships and collaborations with other organizations and agencies.

A suite of activities and tasks has been defined, to achieve these objectives, grouped under three foci. Details of their current status are given in the section *Action Plan 1994 - 1998* below, with information on where most effort is being directed in 1994 - 1998. To provide necessary limits to the activities of IGBP-DIS, it will normally confine its responsibilities to

data sets and data-management issues that: are of a global or at least multi-national scope; are relevant to the needs of many users, usually from more than one Core Project; and require special care to ensure consistency and quality. Furthermore, effort will be focused on data problems of high scientific priority for IGBP; for example, where the absence of a particular data set directly limits research progress in a key area, or where its increased availability would substantially improve the accuracy of current models.

Strategy Development

The development of mechanisms for the efficient handling of data and information within IGBP has to take account of the fact that most data-related activities will take place within individual Core Projects. However, considerable interactions between these are required, and with the IGBP Framework Activities, GAIM and START. Furthermore, there is significant dependency on other international and national organizations for many aspects of data and information. It is therefore convenient to consider the development of IGBP-DIS strategy under four main headings: i) generic aspects, relating to the development of data and information systems for IGBP as a whole; ii) development of data and information systems for the Core Projects; iii) interactions of IGBP-DIS within IGBP, including GAIM and START; and iv) interactions external to IGBP. The evolution of the structure and organization of IGBP-DIS is, of course, also highly relevant to strategy development; these issues are considered under *Structure and Organization* below.

Generic Aspects

An IGBP-wide Data System Plan is currently being developed to assist in the overall scientific coherence of the programme. This will emphasise data-related inter-connections and inter-dependencies, thereby facilitating cooperative activities between Core Projects. Furthermore, by providing guidance on how IGBP data can be used for maximum scientific benefit, it should assist in obtaining resources from funding agencies for programme management and IGBP research. The main topics that must be addressed within the IGBP Data System Plan are as follows:

Data management and exchange policies. The International Council of Scientific Unions (ICSU) has established general guidelines on data exchange for ICSU bodies, with the aim of making research data as widely available as possible. Computing and communication developments are making it easier to realise the scientific ideal of free (or at least low cost) exchange of data on a fully international basis; however, intellectual property rights, national sensitivities and, in some cases, commercial considerations must also be taken into account. An overall data exchange policy for IGBP is therefore needed, and this is being developed by IGBP-DIS, in close contact with the Core Projects, the IGBP Scientific Committee, and the IGBP Secretariat. Within the IGBP Data System Plan, the division of data-related responsibilities between IGBP-DIS, Core Projects, GAIM and START must be clearly defined.

Partnerships. Many partnerships and collaborations on data-related issues have already been established between IGBP and other bodies. However, the development of new data sets will, in many cases, require new linkages, with clearly defined commitments and responsibilities by IGBP and the partners involved.

Interoperability and standards. There is need for an assessment of where the major data flows will be within and outside of IGBP, and hence the benefits which might be gained through application of common data-handling standards and computing procedures. It is

clearly beneficial to strive for a high degree of interoperability. A wide range of data management protocols have been developed, especially with the increasing importance of computer-based systems. Adoption of the standards most appropriate to IGBP needs would do much to reduce the effort and cost of handling data sets; thus recommendations should be made regarding the standards that best fit IGBP requirements.

Mechanisms and timetables for the implementation of the IGBP Data System Plan must also be included in that document. These components should include specific "milestone" achievements (although these would generally be less detailed than those given in the Data System Plans of the Core Projects).

Data System Plans for IGBP Core Projects

Each Core Project needs to formulate and implement its own Data System Plan. This will build on the effort that has already been directed within the projects to data and information problems; for example, JGOFS' guidance on data quality and availability (IGBP Report 23, 1992). Several Core Projects cover a very wide range of research disciplines and methodologies, and data may need to be treated differently within different foci or activities. Such complexities must be addressed within each Data System Plan, that must closely relate to the scientific organization of the project.

At a minimum, the following topics must be considered in the Data System Plans for individual Core Projects:

Identification of data and information needs. Research experiments and observations are driven by scientific hypotheses and the models that are being built. Specifying data needs in a precise, quantitative way can be time-consuming, yet this is an investment of fundamental importance for each Core Project, defining its basic identity and direction.

Data quality. Technological capabilities, resource availability and model requirements all contribute to the definition of data quality, in terms of such properties as accuracy, precision, spatial and temporal resolution and coordinate systems. Whilst the model requirements are arguably of greatest importance, it may be difficult to specify the optimal data characteristics for modelling purposes until after preliminary models have been put into operation. Thus an iterative procedure is the practical approach, leading to progressively better specification of data set properties.

Data set creation. Plans need to be formulated to ensure the timely production of data sets created by the Core Projects themselves – arising not only from field observations and laboratory studies, but also from model outputs.

Metadata and catalogues. Agreements need to be reached on how to describe the data sets at three levels: (i) by directories, identifying the existence of data sets; (ii) by guides, containing information on their quality characteristics; and (iii) by inventories, specifying the individual data items that are present. Core Projects need to generate these descriptions for the data sets that they create, as well as having the means to find and access other data sets that they may require.

Archiving. Plans need to be made for the long-term archiving of the data sets created by the Core Projects, with more short-term arrangements for other data sets which may need to be temporarily held by Core Project scientists.

Standards. As already noted, for many data system components, the adoption of common data-handling standards makes it easier to manage and use data (and hence reduces costs). There should therefore be common standards within each Core Project, based, in most cases, on IGBP-wide agreements.

External cooperation and linkages. The production, management and handling of large-scale data sets are expensive and time-consuming activities. It is therefore highly advantageous if many aspects of these roles can be carried out by other agencies and organizations, that have existing responsibilities and capabilities for data management. The various responsibilities of all those individuals, groups and organizations contributing to and using the data system need to be clearly specified. Such people and organizations cover a very wide range – from the individual researcher to external bodies such as space agencies.

Networking. Procedures for distributing data need to be established within and between Core Projects, and with other programmes.

Future instrumentation. Technological advances increase our ability to make more and better measurements; in addition, measurement requirements become more exacting as models evolve. Because it typically takes 5 - 10 years to get a new global observation network in place, or dedicated satellites in orbit, it is important that the Core Projects frequently reassess what their measurement and instrument development needs will be several years ahead.

Procedures for the development and implementation of Data System Plans for Core Projects are discussed in greater detail below. Examples of such plans exist to assist in their development specifically for IGBP needs, taking account of the current differences in the maturity and stage of implementation of data-related activities within IGBP Core Projects.

For the IGBP Framework Activities GAIM and START, somewhat different data management issues arise. The requirements of the GAIM Task Force for large-scale data sets to analyse, interpret and model key global change issues are detailed in Section 1 of this Report. As noted there, close links between GAIM and IGBP-DIS are essential, and these are already well-developed at many levels. Within START, high priority is given to improving data gathering and management capabilities, especially in developing countries. Increased computational capacity, and better electronic communications, are key features in such strengthening of regional infrastructure. However, the research activities promoted by START are based on the science plans of the IGBP Core Projects (and the scientific agendas of WCRP and HDP); thus many aspects of the Core Projects' Data System Plans will also apply to START.

Interactions within IGBP

As already indicated, there is an obvious requirement for an intimate, iterative relationship between IGBP-DIS and other components of IGBP. The starting point is that Core Projects must define the information needed to meet their own scientific objectives. Each project has then to decide on the new data-gathering activities that are required, prioritised according to resource availability, and their need for supplementary data from other IGBP projects and external sources. It is essential that IGBP-DIS plans its activities on the basis of detailed knowledge of the quality and quantity of data required to meet IGBP's scientific objectives; it is also necessary to know how the information will be gathered and processed, and how it will later be used.

The development of Data System Plans for the Core Projects will provide the main basis for these interactions. Good communications between IGBP-DIS and the Core Projects are essential to achieve that goal. The Core Project Offices have responsibility for general liaison within the programme, and IGBP-DIS will keep them informed of relevant data-related developments. In addition, it has been agreed that each Core Project, as well as GAIM and possibly START, should appoint a Data Coordinator, with responsibility for data-related issues within that part of IGBP. That person should either be a member of the Core Project Scientific Steering Committee (SSC) or should have other close involvement with the project.

The responsibilities of a Core Project Data Coordinator are broadly as follows:

(i) Coordinate the development of the Data System Plan for the Core Project (or other IGBP component), in cooperation with IGBP-DIS

(ii) Oversee the implementation of that Data System Plan, with the assistance, as appropriate, of IGBP-DIS, the Core Project SSC and the Core Project Office

(iii) Serve as the main point of contact with IGBP-DIS. In most cases, the Data Coordinator would attend meetings of the IGBP-DIS Standing Committee, either as a member or invited participant, thereby facilitating communication with other data users and suppliers within the programme, and helping to inform IGBP-DIS of data needs and the status of data sets generated by each project. Wider discussions will be held through data workshop meetings, either covering the data needs of multiple projects, or on more specific problems on which IGBP-DIS can provide assistance.

IGBP-DIS will respond to requests for data from Core Project Data Coordinators, Core Project Offices and IGBP researchers, either by providing information on data availability and access arrangements, or by directly supplying data if appropriate transfer arrangements exist. If a requested data set is not readily available, but could be prepared from other sources, the IGBP-DIS Standing Committee will consider (in consultation with GAIM and Core Projects, where appropriate) whether special effort should be made to produce such information. That could be achieved at three levels: either through external organizations; or by encouraging its production in laboratories associated with IGBP-DIS (but with minimal subsequent supervision and involvement by the IGBP-DIS Standing

Committee); or by the setting up of a Working Group to oversee a more complex activity, where the data products are expected to be of particularly high value to one or more IGBP Core Projects.

The interaction between IGBP-DIS and the Core Projects and other parts of IGBP will change over time. This can be illustrated by considering the topic of data set acquisition. Initially, general data requirements for Core Projects need to be determined. IGBP-DIS will then define the steps necessary to obtain the primary data sets in terms of data availability and data processing. Subsequently, when the Core Projects have detailed plans for their own field programmes and models, there would be an assessment of the data needs in terms of existing capabilities. A re-evaluation of the initial definition of data sets would take place, and IGBP-DIS in conjunction with the Core Projects would identify requirements for specific sets of derived products. This matching of requirements and capabilities is a crucial and interactive process, involving Core Project scientists as well as key experts in the various data areas. It would ensure that a realistic schedule of activities and products is developed, thereby assisting funding sources in prioritising the allocation of support for data set development, in concert with their support for other IGBP activities. Finally, as the data sets and derived products begin to come on-line, IGBP-DIS will work with the Core Projects to make these data available to the wider scientific community. This will require the development of an IGBP information management system which contains metadata for each data set, and points the scientist to the appropriate location and methods for obtaining the data. It would also keep each Core Project appraised as to the current status of a given data set as it is being developed.

Although this function of IGBP-DIS will, in part, involve the development and implementation of software, the approach would be simple and limited to the domain of data sets developed by IGBP. It would include information on data sets assembled by IGBP-DIS as well as the Core Projects themselves. The dissemination of the data sets is a closely related activity; this would be achieved by a coordinated effort between IGBP-DIS, the Core Projects and the laboratories where the data sets are being produced. However, the IGBP-DIS office itself would not normally be directly involved in data distribution.

The current status of the relationship between IGBP-DIS and each of the IGBP Core Projects and Framework Activities is summarised below, including any already-identified requirements of the Core Projects for IGBP-DIS support.

Biospheric Aspects of the Hydrological Cycle (BAHC)

The IGBP-DIS Toulouse Workshop (June 1991; IGBP-DIS Working Paper 2) gave preliminary consideration to the data needs of BAHC. This project shares GCTE's requirement for global data sets on topography (including snow cover and run off), soils, land cover, and climate fields, to provide the information needed for soil-vegetation-atmosphere transfer (SVAT) models. The Advanced Very High Resolution Radiometer (AVHRR) satellite observational system should be able to meet many of these data needs, providing that the appropriate algorithms can be developed. Close liaison is envisaged between IGBP-DIS, BAHC, the re-defined International Satellite Land-Surface Climatology Project (ISLSCP), and WCRP's Global Energy and Water Cycle Experiment (GEWEX). Additional details of BAHC's data needs are given in its Operational Plan (IGBP Report 27, 1993; e.g., see Table 4, p 30). BAHC Data Coordinator: Alfred Becker.

Global Change and Terrestrial Ecosystems (GCTE)

GCTE requires many large-scale data sets to develop a Global Vegetation Model, and for other modelling activities related to finer scale ecological changes, and impacts on agriculture and forestry. Specific data needs were identified at the IGBP-DIS Toulouse Workshop: at the global scale, highest priority was given to improving the acquisition and availability of data sets on land cover (vegetation type), human use and disturbance, soil parameters, topography and climate. Fine scale data requirements would primarily be met by GCTE's own field programme, as detailed in the GCTE Operational Plan (IGBP Report 21, 1991). GCTE Data Coordinator: Will Steffen.

International Global Atmospheric Chemistry Project (IGAC)

IGAC's needs for terrestrial biospheric data were also addressed at the IGBP-DIS Toulouse Workshop. They included improved global data sets on the distribution and extent of wetlands, biomass burning, vegetation and soil types, use of fertilisers, surface ozone concentrations and atmospheric deposition. IGAC's marine data requirements were considered at an IGAC/JGOFS Workshop (Bermuda, January 1992; JGOFS Report 14), and protocols for data gathering and data management in other areas are being decided by IGAC/IGBP-DIS workshops and expert groups. Close liaison with WCRP has been established to meet IGAC's needs for physical atmosphere data sets and links to GCMs. IGAC Data Coordinator: Alex Pszenny.

Joint Global Ocean Flux Study (JGOFS)

The JGOFS field programme began in 1989 with a series of internationally-coordinated research cruises in the North Atlantic. For that study, around 20 "Level 1" measurements were defined (with standard experimental and data-entry protocols), and a two-stage data management system was developed. The first stage involved national collection and quality assurance of project data, followed by merging into common-format files and distribution on diskette and/or CD-ROM. In the second stage, now nearing completion, a distributed data management system, based on UNIX workstations connected via Internet, will provide wider access to the data held in national and international data centres. Similar arrangements are being applied to the data sets now arising from process studies in the Equatorial Pacific, Arabian Sea and Southern Ocean, and from the JGOFS time series and large-scale survey studies. JGOFS data policies have been developed in liaison with the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) Committee on International Oceanographic Data and Information Exchange (IOC/IODE).

Although the oceanographic community has well established practices for data exchange (developed through IOC, and using GF3 format), there are still problems in quality assurance for data on biological rates and processes, and an under-resourcing of oceanographic data centres at the national and international level. Two data sets will be managed with outside assistance: WOCE (The World Ocean Circulation Experiment, of WCRP) has agreed to archive CO_2 data collected by JGOFS on WOCE survey cruises, and NASA will manage SeaWiFS data (ocean colour satellite, due for launch in late 1994). JGOFS Data Coordinator: Hugh Ducklow.

Land Ocean Interactions in the Coastal Zone (LOICZ)

The more recently established LOICZ project will benefit from an extensive background of scientific studies in shelf seas, estuaries, river systems and coastal land. However, the existing data sets arising from such work are widely distributed, variable in quality, and many are not readily accessible nor easily integrated on a global scale. LOICZ has interests in common with BAHC, GCTE and LUCC on land use change within catchment basins, and shares JGOFS' interests in SeaWiFS and other ocean colour data sets. Algorithms for sediment load and biological productivity in coastal waters have been developed, but their global applicability has yet to be tested. LOICZ Data Coordinator: John Pernetta.

Past Global Changes (PAGES)

Proposed procedures for data management within PAGES were outlined in the project's Implementation Plan (IGBP Report 19, 1992), and the detailed treatment of specific data sets was considered at a recent PAGES workshop (Berne, August 1993). Data will be collected on a regional and topical basis, with their international exchange coordinated by the PAGES Core Project Office (Berne) and the US National Geophysical Data Center. Seven types of data will be distinguished: primary (raw); secondary (derived); tertiary (inferred); calibration data; climate forcing functions (time series); climate boundary conditions; and model outputs. It is not expected that PAGES will have any requirement for remotely-sensed data. Future cooperation between IGBP-DIS and PAGES is expected relating to the requirements from GAIM for a data set of vegetation attributes for 6000 BP. PAGES Data Coordinator: Jonathan Overpeck.

Land Use and Cover Change (LUCC; proposed Core Project, with HDP)

The IGBP and the Human Dimensions of Global Environmental Change Programme (HDP) are currently developing the science plan for a joint Core Project on Land Use and Cover Change (IGBP Report 24, 1993). This project will address the significance of land-use/cover changes as driving forces for many aspects of global environmental change. These issues are an important component of most other Core Projects. It is expected that LUCC will link closely with many of the data efforts of IGBP-DIS, particularly the land cover mapping from 1 km AVHRR data and the high resolution data activities. LUCC Data Coordinator: David Skole.

System for Analysis, Research and Training (START)

Plans for START are directed at the establishment of a world-encompassing system of Regional Research Networks (RRNs), each including a number of affiliated Regional Research Sites (RRSs) and at least one Regional Research Centre (RRC). The main purpose of an RRN is to develop and coordinate indigenous capacity for research on the regional specificities, origins and impacts of global change in accordance with the scientific objectives of its three parent programmes (IGBP, HDP and WCRP).

Two of the most important functions of START are to ensure the dissemination of data sets in forms appropriate for regional use, and to ensure that data networks are

established both within and between the regions, and with the other parts of IGBP and related scientific programmes. The content and character of these data sets need to be specified, through a joint START/IGBP-DIS activity, to ensure the timely and effective dissemination of these data sets. Data Coordinator: to be appointed.

Global Analysis, Interpretation and Modelling (GAIM)

Details of GAIM activities are given in Section 1 of this Report. As noted there, GAIM and IGBP-DIS are working closely together on the development of spatially-referenced global data sets, initially at low resolution, on key biogeochemical and hydrological processes. Not only are contemporary data sets required (when remote sensing can be of considerable value), but also spatially referenced data sets representing past conditions, notably a global data base of vegetation properties for 6000 BP.

Later analyses will be at increasingly fine resolution, as models become more sophisticated, more computing power becomes available, and new satellite sensors are developed and deployed. GAIM is not a direct data gatherer; instead, in liaison with IGBP-DIS and the IGBP Core Projects, it will define the data needs and relevant diagnostic variables for global modelling studies. Such data will subsequently be obtained from both IGBP and non-IGBP sources, using IGBP-DIS as GAIM's main data broker. GAIM Data Coordinator: Berrien Moore III.

Interactions external to IGBP

A central function of IGBP-DIS is to work with other data-generating organizations, and the national and international agencies which are collecting, processing, or archiving data which could be important for IGBP – and thereby contribute to the international coordination, development and dissemination of global change data and derived products. IGBP-DIS needs to be linked with three kinds of organizations external to IGBP: organizations with research interests complementary to IGBP; bodies that coordinate space activities related to Earth observations; and data centres. The current status of such links (many of which are already well-established) and plans for their further development are considered below.

Organizations with research interests complementary to IGBP

There are many other bodies within and outside ICSU that are involved in research that produces and uses global change data. Of particular relevance to IGBP is the World Climate Research Programme (WCRP), jointly sponsored by ICSU, IOC and WMO. WCRP addresses the dynamic and physical aspects of the climate system: its components include the Global Energy and Water Cycle Experiment (GEWEX), the Tropical Ocean and Global Atmosphere project (TOGA), the World Ocean Circulation Experiment (WOCE), and WCRP data projects and global environmental monitoring studies.

Much expertise in obtaining land surface parameters from space observations resides within the International Satellite Land-Surface Climatology Project (ISLSCP; originally established by UNEP, now associated with WCRP-GEWEX). Development of several data sets would be facilitated by working closely with the ISLSCP research community, complementing the collaborations being developed by the re-formed IGBP/WCRP Working Group on Land Surface Experiments.

The Human Dimensions of Global Environmental Research Programme (HDP, sponsored by the International Social Science Council, ISSC) complements IGBP and WCRP by focusing on the socio-economic aspects of global change. Within HDP, a Data and Information System is currently being developed (HDP-DIS), to assess its data needs and carry out a similar role to IGBP-DIS. Since there are many areas of shared interest between IGBP and HDP (particularly with regard to LUCC and LOICZ), close links with HDP-DIS are highly desirable.

Three closely-linked global observational systems have been proposed to provide long-term, interdisciplinary monitoring of global change: the Global Climate Observing System (GCOS; being developed under the aegis of ICSU, IOC/the United Nations Educational, Scientific and Cultural Organization (UNESCO), UNEP and WMO), the Global Ocean Observing System (GOOS; being developed under the aegis of ICSU, IOC/UNESCO and WMO), and the Global Terrestrial Observing System (GTOS, being developed under the aegis of ICSU, FAO, UNEP, UNESCO and WMO). These operational programmes would build on existing monitoring and research activities, with IGBP (primarily through IGBP-DIS) playing a significant role in developing their scientific specifications and strategy for use.

The ICSU Committee on Data for Science and Technology (CODATA) aims to improve data quality and accessibility for all areas of science. However, it has a special interest in data relevant to sustainable development and global change, with close links to IGBP-DIS.

Bodies that coordinate Earth observations from space

Nations and regions with relevant satellite programmes and agencies include the USA (NASA and the National Oceanic and Atmospheric Administration (NOAA)), Japan (NASDA), Europe (ESA), Brazil (INPE), Russia, China, India and Canada. International coordination of their Earth observation activities has, until recently, been greatly stimulated by the Space Agency Forum of the International Space Year (SAFISY). About a dozen multi-agency projects were started in 1989, on the collection, validation and dissemination of space data relevant to global change. Several of these SAFISY projects are now continuing under the international Committee on Earth Observations Satellites (CEOS), with WCRP and IGBP involvement.

There are many other important links between IGBP and CEOS, including IGBP-DIS involvement in its working groups on calibration/validation (IGBP-DIS Working Paper 5) and data analysis, and the CEOS/IGBP-DIS pilot project on the exchange of high resolution satellite data (Fig. 6). Beyond the aspects of data management, CEOS has a key role in coordinating the forward planning and implementation of environmentally-oriented remote sensing programmes by space agencies, for the late 1990s and early next century. Much of the rationale for the development of the next generation of Earth observation satellites has been based on their contribution to understanding global change

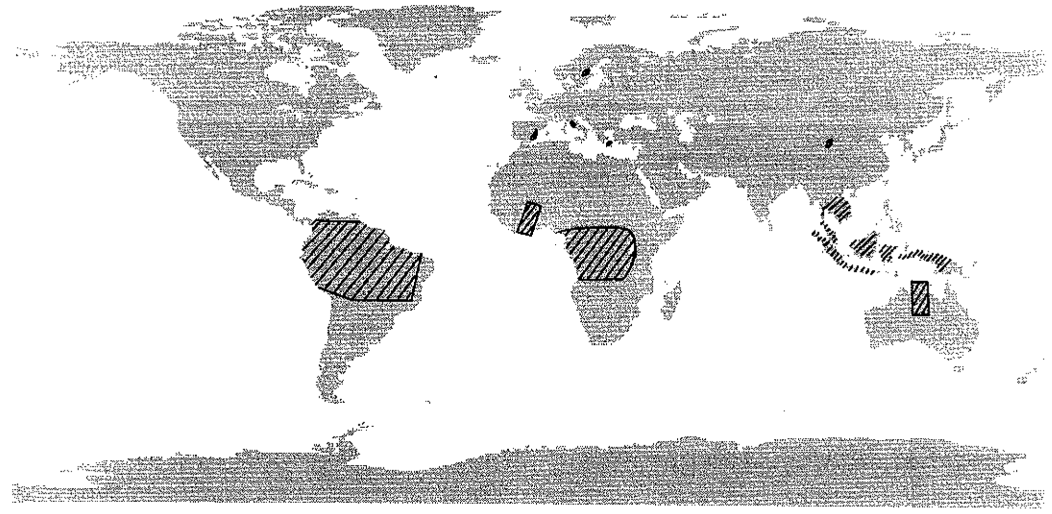

Figure 6. Investigations chosen for the Pilot Project are (i) Tropical Deforestation and Regrowth in Brazil, Central Africa, and Southeast Asia; (ii) Transect studies in Australia and West Africa; (iii) European and Chinese Field Studies.

and climate variability: IGBP-DIS should maintain a strong voice in the activities of CEOS, reaching the highest levels of authority within that body and its constituent activities.

IGBP-DIS should also closely monitor other initiatives for international discussion and collaboration between the space agencies, in liaison with the ICSU Committee on Space Research (COSPAR).

Data Centres

The third kind of external link is with institutions with internationally-recognised competence in the archiving and management of environmental data. These include the main components of the ICSU World Data Centre (WDC) system, in the USA, Russia, Japan and China, and within Europe. The World Data Centre System is becoming an increasingly important player in the field with the creation of a number of new centres with data holdings highly relevant to many of IGBP's activities. Within WDC-A (USA), these include data centres for atmospheric trace gases (at Oak Ridge, Tennessee); for remotely-sensed land data (at Sioux Falls, South Dakota); and palaeo-climatology (Boulder, Colorado). Components of the US Earth Observing System Data and Information System (EOS-DIS) have also applied to become WDCs; if successful this would provide an appropriate mechanism for the IGBP to interface with EOS-DIS.

Similar activities to EOS-DIS are being developed within Europe, with a Centre for Earth Observation (CEO) jointly proposed by the ESA, the European Union, and other regional groupings. The very large scale of such developments makes it essential for IGBP to have effective linkages (through IGBP-DIS) with the relevant national and multi-national organizations.

Action Plan 1994 - 1998

Focus 1: Data Set Development
(Leader: Christopher Justice)

The data needed for IGBP studies of the land and ocean biosphere, and its interactions with the atmosphere, will be derived from a combination of many different sources, including those acquired from remote sensing (at various time and space scales) and from surface networks and experimental studies. Surface observations are, of course, also necessary for the calibration and validation of satellite-based measurements.

IGBP-DIS is currently involved in the development of both remotely sensed and non-remote sensing types of data. IGBP-DIS activities include the compilation of the baseline remotely sensed data collected by various satellite systems as well as the derivation of the higher order products which are required by the Core Projects. The scientific community often has little interest in the "raw" satellite data, and is frequently hindered by the overhead effort required to develop the required derived data products. Two types of remotely sensed data are currently being addressed by IGBP-DIS. Coarse resolution data (>1 km) are being compiled into global data sets, and high resolution data (>50 m) are being acquired in support of local test site activities.

The typical sequence of events involved in specifying, producing and evaluating new data sets is set out in Tables 2 and 3. The current definition of Focus 1 Activities and Tasks, and the plans for their development in 1994 - 1998, are as follows.

Activity 1.1 Development of a global 1 km land-surface data base from AVHRR and similar satellite sensors

Rationale: Stimulation and coordination have been required to assemble a basic terrestrial data base, with global coverage at around 1 km resolution, from meteorological satellites. Agreement was needed with space agencies and AVHRR ground stations to ensure continuing receipt, standard pre-processing, individual archiving and the creation of, and access to, a unified global archive. These global data provide the baseline data needed to generate higher order data sets (see Activities 1.2 and 1.4).

Task 1 *Data base definition.* Task completed: "Improved Global Data for Land Application" IGBP Report 20, 1992.

Task 2 *Data prototypes.* This task is currently in progress at the USGS's EROS Data Center funded principally by NASA and the USGS.

Task 3 *Data base production and project management.* Started in 1993 at the Earth Resources Observing Satellite (EROS) Data Centre, Sioux Falls, operated by the US Geological Survey. There are plans for similar facilities to be established in Europe, involving ESA.

Task 4 *Data base evaluation.* Although this task is not yet underway, it is expected that the IGBP-DIS Working Group on Land Cover Change will play a major role in the evaluation and assessment of the 1 km data base.

Table 2. The IGBP-DIS data set development process.
The following sequence of events for data set development ensures that science objectives remain at the forefront of IGBP-DIS Activities within Focus 1.

Data Set Specification

1. Obtain a clear statement of the data requirements from the Core Projects and/or other IGBP components.

2. Compare these data requirements to the currently-available data sets, and assess the feasibility of matching the data needs by generating a new data set. In many cases existing data can be collated to improve the data base, or procedures can be applied to make existing data more suitable to IGBP needs. However, existing data may be wholly inadequate; IGBP-DIS might then need to promote a programme of research and development that would lead to such data set provision.

   This step of matching data requirements to current capability is an essential part of the IGBP-DIS data development process and is usually performed as a series of workshops attended by IGBP-DIS, Core Project representatives and scientists active in the particular area of data production and analysis.

3. Provide recommendations for the implementation phase of the data set development process, including specifications of the algorithms to be used.

Data Set Production

1. Identify agencies interested in supporting the specific data base development.

2. Identify a group which is capable of generating the data set.

3. Establish an advisory group to guide the data set development and ensure that IGBP data needs are met. This group also has responsibility for preparing a prototype data set and evaluating the prototype products.

4. Initiate full scale production.

Data Set Evaluation and Assessment

1. Establish procedures for independent evaluation and assessment.

2. Promote data set validation by IGBP scientists.

3. Concluding review by IGBP-DIS of the data set production and evaluation process, with generation of associated documentation on limitations as well as advantages of the new data set.

Table 3. Hierarchy of meetings and workshops required for the IGBP-DIS data set development process.

1. "All hands" requirements: presentation and discussion of general Core Project data needs

2. Specific data set requirements meeting:

- Precise definition of data set needs
- Evaluation of existing data
- Evaluation of current capabilities for data set generation
- Definition of preferred approach to developing a new data set, or the research and development required for long-term data set generation
- Identify sources of funding and potential implementation groups

3. Algorithms/processing Working Group meeting:

- Define community consensus algorithm and processing procedures
- Advise on data set production

4. Product evaluation group meeting

Activity 1.2 Sample high resolution satellite data

Rationale: The objective of this activity is to improve the availability of high resolution satellite data from such sensors as SPOT and Landsat to the IGBP science community. Favourable pricing for many of these data sets has already been negotiated (primarily with CEOS; see Activity 3.1 below).

Task 1 *Land cover conversion in the humid tropics.* This task is a joint one between IGBP-DIS and the proposed LUCC Core Project. High resolution data are being obtained for the humid tropics for three time periods; the early 1970's, the mid 1980's and the early 1990's. LUCC has identified the humid tropics as an area of particular interest, because of the importance of tropical deforestation and other land cover conversions to biogeochemical processes, such as the global carbon cycle. The task will initially identify in a systematic fashion what high resolution data sets exist (from SPOT, Landsat, MOS-1, ERS-1 and other similar satellite sensors) at various archives, including regional ground receiving stations. Subsequently, it will provide coordination between the data providers and the science community, so that the data sets required by IGBP researchers can be made available at reasonable cost.

Task 2 *IGBP test site data.* Landsat, SPOT and other high resolution data are being acquired for the IGBP large transect test sites (initiated by GCTE, now with IGAC, BAHC, LUCC and LOICZ involvement). These data sets are being made available at the cost of copying or at very reduced prices.

Task 3 *Land cover validation data set.* This task is being conducted through collaboration with the NASA Landsat Land Cover Pathfinder Stream 3, Global Land Cover Test Site Activity. Landsat data are being obtained from a number of locations around the world representing a range of land cover conditions.

Task 4 *Liaison with high resolution satellite ground stations.* This task is being undertaken in conjunction with Activities 2.1 and 3.1. It involves searching the archives of the various ground stations and assessing the availability of the data for Tasks 1, 2 and 3, and negotiating a pricing structure appropriate for scientific use by the global change research community. The current situation requires an international science coordinating body to help organize the global archive of high resolution data. To date, each ground station has been archiving and distributing high resolution data independently, without any coordinated policy, pricing structure, catalogue, or standard means of distribution. Formats and processing methods vary considerably. IGBP-DIS will help to identify what data sets exist at ground stations and individual archives, and thereby assist the global change research community in efficiently obtaining consistent high resolution data.

Activity 1.3 Global land cover data base generation

Rationale: Improved land cover characterisations are required for global and regional modelling of the biosphere. Requirements for such data bases were identified at the Toulouse meeting on Core Project Data Requirements (IGBP-DIS Working Paper 2) and outlined in IGBP Report 20 (1992). Three tasks have been identified which will be phased to provide the data needed for model parameterization.

Task 1 *"Conventional" land cover stratification.* This task is to provide improved global land cover classifications from satellite data, initially at 8 km resolution and subsequently at 1 km, as the IGBP global 1 km data sets become available. The validation of these data sets is being investigated by a sub-group of the IGBP-DIS Working Group on Land Cover Change.

Task 2 *Direct land cover parameterization.* The limitations of land cover classifications for parameterizing models are recognised. This task will be to promote the development of research to derive parameters "directly" for models. Such parameters include leaf area index (LAI), albedo, vegetation structure, APAR (absorbed photosynthetically active radiation), and NPP (net primary production).

Task 3 *Functional vegetation types.* This task is being set up to generate global distributions of functional vegetation types. There is close liaison with GAIM and GCTE, to take account of the needs of their global modelling groups.

Activity 1.4 Global soils pedon data set

Rationale: Global data on the physico-chemical attributes of soils are needed by IGAC to assist estimation of trace gas exchanges, by GCTE for soil depth, texture and type, by BAHC for water holding properties, and by GAIM for modelling the global carbon cycle and climate-vegetation interactions. In addition to new mapping studies, soil profile data needs to be incorporated into existing soil maps, and soil classification systems need to be translated into physical and hydrological properties (for further details, see IGBP-DIS Working Paper 7).

Task 1 *Development of a soil pedon data set.* To be achieved by integration of existing soils pedons into a homogeneous, internally consistent format with contributions from the global change and soils communities. A four-stage process is in progress:

(i) based on existing soil data holdings of the organizations developing international data bases

(ii) as above, supplemented with data from national holdings which are already in digital form

(iii) as above, supplemented with non-digital, archival sources, from national soil surveys, PhD dissertations, the scientific literature, and other sources

(iv) as above, supplemented with data obtained through strategically-sited new *in situ* samples, located to fill key gaps in the data base.

Task 2 *Development of a lexicon and IMS link,* to access the soils pedon data bases at individual laboratories.

Task 3 *Development of pedon transfer functions,* using existing parameters in the soil pedon data base to produce derived products, such as carbon stocks, water retention capacity, rooting depth, etc.

Task 4 *Spatial extrapolation of pedon/point data,* to derive maps of important soil parameters, such as carbon.

Activity 1.5 Development of global fire data base

Rationale: Fire is a major source of important trace gases and aerosol particles (of considerable interest to IGAC); it is also an important process in ecosystem structure and function, and land management (of interest to GCTE and LUCC). AVHRR and other sensors offer the opportunity for a global fire-monitoring system, closely linked to global data sets on fire emission characteristics, land cover/land use and meteorological variables. Research problems associated with biomass burning in African savannas were discussed at the Victoria Falls workshop, June 1993, with IGBP-DIS involvement (IGBP Report 31, 1994).

Task 1 *Global fire distribution.* An *ad hoc* working group was brought together in April 1993 at NASA's Goddard Space Flight Center to assess the current capabilities of remote sensing to provide a global fire distribution data base and to define the community consensus algorithms which could be applied to the global 1 km AVHRR data base. The report will be released in a future IGBP-DIS Working Paper. The working group is currently evaluating alternative algorithms which could be applied to the AVHRR data.

Task 2 *Global emission factor data base.* This task (not yet started) will gather together from the literature the existing information on emission factors for a wide range of vegetation, fire types and conditions. The aim is to produce a comprehensive data base on emission factors, and thus to develop comparative emission factors from the various existing sources.

Task 3 *Fire information system.* The IGAC Activity on biomass burning (BIBEX) includes the design of a system to combine fire detection by remote sensing within a geographic information system (IGAC Science Plan booklet series, 1992). The aim is to derive parameters of interest for atmospheric chemistry, fire ecology and land use planning. A prototype system is currently being developed, jointly with IGBP-DIS, as part of the BIBEX Southern African Fire-Atmosphere Research Initiative (SAFARI).

Activity 1.6 Estimation of areal extent and characteristics of global wetlands, from remote sensing and other sources

Rationale: Improved estimates are needed of the properties, global distribution, extent, and seasonal and annual variability of natural wetlands. These data sets are needed by IGAC and GAIM, in order to quantify the importance of wetlands as a source of methane and other biogenic trace gases. As noted in Section 1, two joint IGBP-DIS/ GAIM workshops are planned on this topic for late 1994/early 1995, addressing boreal and tropical wetlands prior to the assembly of a global wetlands database.

Task 1 *Estimation of extent of boreal wetlands*: algorithm development, validation and application, ground truth studies.

Task 2 *Estimation of extent of tropical wetlands*: algorithm development, validation and application, ground truth studies.

Task 3 *Estimation of extent and characteristics of global wetlands*: synthesis of Tasks 1 and 2, with additional studies as required.

Activity 1.7 Determination of terrestrial primary production by remote sensing and other sources

Rationale: Geographically-referenced estimates of net and gross primary production are key variables in the terrestrial carbon cycle and in the human exploitation of the biosphere. Significant advances should be possible by combining a modelling approach with satellite measurements of the Normalised Difference Vegetation Index (NDVI), relating NDVI to absorbed photosynthetically active radiation (APAR) and intercepted photosynthetically active radiation (IPAR). This Activity is being carried out jointly with GAIM, primarily through workshops; for further details see Section 1 and IGBP-DIS Working Paper 8, "Monitoring and modelling of terrestrial net and gross primary production" (Workshop at University of Maryland, January 1992).

Task 1 *Identification of problems and data requirements*: basic assessments of the scale and appropriateness of models and variables. (Task completed; IGBP-DIS Working Paper 8).

Task 2 *Testing of models, algorithms development, validation and application*. Now in progress, with a meeting held in Potsdam, Germany in June 1994.

Task 3 *Improved global estimates of terrestrial NPP and GPP*, with establishment of long-term monitoring protocols (1995 onwards).

Activity 1.8 Global topographic data sets

Rationale: The objective of this activity is to generate global topographic data sets to meet the needs of IGBP researchers, primarily within BAHC and GCTE. Three levels of required data have been identified: (i) a 1 km data base for improving the processing of global satellite data; (ii) a global data base for improved SVAT modelling; and (iii) local high resolution data for site level process modelling and a regional data base for hydrological modelling. The horizontal and vertical resolutions are different for these different data bases. There are several on-going efforts to generate global topographic data bases: IGBP-DIS will work closely with these initiatives rather than duplicate existing programmes.

Task 1 *Improved definition of topographic requirements for IGBP Core Projects.* This task is currently in its design phase. A series of tests of selected models will be carried out, using a range of topographic data at different resolutions.

Activity 1.9 Global land biomass data base

Rationale: The global distribution of terrestrial biomass is an important variable in nearly all global models. Biomass maps are crucial for models of primary production, carbon balance, and surface water and energy fluxes. It is possible to compile a data set of individual point estimates of biomass or surrogate measures such as stemwood volumes. These point measures (usually tabulated on a country basis) exist, but need to be catalogued into a single global data set if they are to be of use to the global change research community. In addition, research is required to take advantage of the many timber stand estimates of wood volumes which have been routinely collected for forest management purposes.

Task 1 *Organization of a global land biomass data base.* This task requires an initial workshop to identify the available biomass measurements (following a similar approach to that used previously by IGBP-DIS for the organization of a global soil pedon data set).

Task 2 *Development of appropriate biomass transfer functions.* The global change community needs information on more than biomass. Such parameters as carbon stocks in vegetation can be obtained through suitable expansion factors. The problem is potentially complex, however, since most *in situ* measurements are not for biomass *per se* but for surrogates such as stemwood volume. A workshop will be held to develop suitable methods for using existing data on stemwood volumes.

Task 3 *Spatial extrapolation of point estimates.* The data set developed from Tasks 1 and 2 would be used in conjunction with land cover maps derived from the IGBP-DIS 1 km AVHRR data set (see above).

Focus 1 priorities and future plans

Currently the highest priorities for data set development in 1994 - 1998 are as follows:

(i) Continue production, on a routine basis, of 1 km AVHRR products (10-day composites) on CD-ROMs available to IGBP scientists on marginal costs (Activity 1.1, Task 3).

(ii) Test methodologies for land cover classification from AVHRR and other satellite and ground data (Activity 1.3, Tasks 1 and 2).

(iii) Develop a set of databases of soil parameters such as carbon content, pH, hydraulic properties, soil depth, derived by combining global pedon data with new FAO maps, such as 1 km vegetation data, global topography, and others (Activity 1.4, Task 1).

(iv) Develop a fire information system (jointly with IGAC) which will also include a consensus algorithm for deriving biomass burning data sets (Activity 1.5, Task 3).

(v) Derive a 1 km global topography data base in cooperation with CEOS, based on the most reliable of existing sources, and possibly including remotely sensed data such as SAR and SPOT-Stereo (Activity 1.8).

In the areas of atmosphere, oceans, the coastal interface, and palaeo- studies, a series of comprehensive reviews of global data sets needs (and current deficiencies) would assist in developing pilot data sets, in a similar way as has been done for the terrestrial biosphere.

Focus 2: Data Management and Dissemination

(Leader: to be appointed)

This Focus has not yet been fully defined. A more complete specification will be developed by the IGBP-DIS Strategy Working Group (see under *Structure and Organization* below) which will define the generic and specific planning elements with respect to the Data System Plan for IGBP. An account of existing Activities and Tasks follows.

Activity 2.1 Data management

Rationale: As discussed previously, the various components of IGBP all need their own data management capabilities. This activity is designed to assist the implementation of the required capabilities. Close links with Focus 3 will be developed, particularly for Tasks 3 and 4 below.

Task 1 *Development of an IGBP-DIS Information Management System.* A number of sub-tasks are involved, several of which are now underway:

(i) Identify in each Core Project a Data Coordinator responsible for data-related issues and contact with IGBP-DIS

(ii) Ensure the provision of appropriate data handling tools including a Geographic Information System at each Core Project Office. This sub-task is nearing completion with the acquisition of Arc/Info licences, obtained with the assistance of ESRI.

(iii) Develop a metadata Information Management System, to be provided to each Core Project Office and run inside Arc/Info. This system will:

- Provide GIS-based metadata, products, and browse system for IGBP-DIS sponsored data products in a single source, to include: AVHRR orbits, 10-day composites, and derived products (e.g., land cover, soil pedons, emission factors); high resolution metadata, from Landsat and Spot; palaeo-climate records for GAIM etc.

- Provide information to Core Project scientists on how to obtain data from the implementation laboratories, e.g., the EROS Data Center of the USGS.

Task 2 *Implementation: inputs from Core Projects.* Provide a template in the Information Management System and a "handbook" for each Core Project to enter metadata, describing the data and data products which the Core Projects are developing. This information would then be distributed into other Core Projects' systems.

Task 3 *Implementation: data set "imports".* Develop links to other systems, primarily through the CEOS International Directory Network (with Asian, American and European coordinating nodes), and develop the means to access other data sets which have been identified as needed by the IGBP community; e.g., obtaining a copy of WCRP climate data sets, that could then be located in the IGBP-DIS Information Management System.

Task 4 *Implementation: data set "exports".* Develop the protocols for getting IGBP data assemblies and data products (e.g., the IGBP-DIS global soils data base) into the non-IGBP community, linking with WCRP, HDP-DIS, EOS-DIS, GCOS, GOOS, GTOS, etc.

Activity 2.2 Networks

Rationale: The collaborative research undertaken within IGBP requires open lines of communications between Core Project Offices, research centres and individual scientists. The organization of the necessary data links between institutes will require international support. Currently there are considerable regional differences in the ability of IGBP researchers to communicate by electronic means. Now that the IGBP community is growing, and includes more regionally-based programmes (linked through START), the requirement for improved communications, both within the IGBP structure and with external bodies, is becoming increasingly important.

Task 1 *Inventory.* Identify existing connections on Internet and host/node names and e-mail addresses.

Task 2 *New connections.* Liaison with the telecom and network community/industry to assist in placing lines (where lacking) into key Core Project and START locations, for e-mail and Internet connections.

Task 3 *Initial network development.* Assist in setting up high speed data networks between the IGBP-DIS Office and key Core Project and START locations.

Task 4 *Full network development.* This task will provide the international coordination required to establish full networking capabilities between IGBP scientists and other global change researchers throughout the world.

Activity 2.3 Assist in the development of standards and data formats for the archiving and distribution of data and metadata

Rationale: Effective use of data sets requires agreement on standards and data formats. In some areas there is little experience in such activities and it is important to establish appropriate standards and formats. In other areas, as in many aspects of the marine sciences, there is considerable experience. Unless attention is given to this matter across IGBP as a whole, substantial preparatory work could be needed before Core Project results can be used in an integrated fashion (e.g., by GAIM).

Task 1 *Develop metadata template*, and notify Core Project Offices.

Task 2 *Define appropriate standards* for IGBP-DIS products.

Task 3 *Participate in international standards and format development*, linking to organizations such as CEOS (in collaboration with Focus 3).

Activity 2.4 Development of an improved data base of IGBP data sets

Rationale: There is a need to keep Core Project scientists aware of the availability and current status of data sets being developed by IGBP-DIS, and providing access to these data sets. This activity (to be closely linked to Activity 2.1 above) will provide Core Projects with information about the data sets being developed by other Core Projects, and the availability of data sets residing in non-IGBP data systems; it will also provide information to other data systems on the IGBP data sets. Specific tasks have not yet been defined for this activity.

Focus 2 priorities and future plans

The development of an effective data management approach for the IGBP Core Projects is regarded as the highest priority objective within Focus 2. Given the distributed nature of data and information responsibilities within IGBP, implementation of data management activities will largely be carried out within the Core Projects, START and GAIM rather than in IGBP-DIS itself. The strategy of IGBP-DIS must therefore largely be directed at creating mechanisms (as identified in the above Activities and Tasks) that will assist other components of IGBP to develop their own Data System Plans and Information Management Systems, with an emphasis on inter-project complementarity.

Focus 3: Data Coordination in an International Context

(Leader: S. I. Rasool)

The global nature and scientific inter-dependency of IGBP research makes it necessary to give special attention to coordination with other bodies and organizations. The Focus 3 activities outlined below address that need for data-related issues; they are being developed in close liaison with representatives of other groups, agencies and committees. The results of this work then feed into Foci 1 and 2.

Activity 3.1 International coordination associated with data set generation and validation

Rationale: This activity will assist in providing information on current data availability and data generation activities within other national and international organizations. It will also assist in the initial coordination of the various international organizations required generation of a specific data set; and the coordination of international (and national) funding for data set generation. Whilst primarily providing support for Focus 1, close collaboration with Focus 2 will also be involved. The coordination of remote sensing data has been identified as a separate task (Task 2) because of their unique value in providing spatially comprehensive and up-to-date global data sets. In addition: i) the high cost of generating global data sets, often at the expense of other scientific activities, makes it important to ensure that the resulting data serve the science community; and ii) research access to some of these potentially useful data sets has, in many cases, been severely constrained by commercialisation of the data.

Task 1 *Liaison with other national and international data initiatives.* In addition to contacts with the ICSU Panel on World Data Centres, and its component centres, IGBP-DIS will maintain close liaison with many other data initiatives. At the national level, these include United States Global Change (USGC-DIS) and US Earth Observing System (EOS-DIS), and at the international level, WCRP, ISLSCP, HDP-DIS, WMO, UNEP-GRID and CEO (see Appendices for expansion of acronyms).

Task 2 *International coordination of remote sensing data activities.* Two sub-tasks have been identified:

(i) Current sensing systems. This involves: securing access to data from current sensing systems by the IGBP community; coordinating the required data acquisition for the IGBP scientists; and promoting the research and development needed to provide the derived data products necessary for IGBP science. To date, such coordination has been achieved through IGBP-DIS liaison with the Space Agency Forum for the International Space Year (SAFISY); interactions with several AVHRR-HRPT stations, as part of the global 1 km data initiative; participation in the CEOS Working Groups on Data Calibration and Validation; and representations on the ISLSCP Steering Committee. Future activities include representation at the Landsat Ground Station Operators Working Group (LGSOWG), the CEOS SAC Calibration Working Group, and the ESA ERS-1 results conferences.

(ii) Future sensing systems. This sub-task involves promoting the IGBP Core Project requirements for data in the planning and definition of new satellite sensing systems. It is being achieved through participation in such activities as CEOS and its affiliates workshops, the US Earth Observing System (EOS) planning groups, and the GCOS Joint Scientific and Technical Committee.

Activity 3.2 International coordination associated with data availability and networks

Rationale: Considerable international efforts have been directed towards the development of networks, directories and meta-data systems during the past few years. It is important for IGBP to coordinate its efforts with this work and to participate in its future development. The promotion of two-way movement of information from and to IGBP is a key objective for IGBP-DIS, since this relates directly to data supply and the maximising of data utilisation.

Task 1 *Liaison with non-IGBP information management systems.* This task involves establishing linkages between the various national and international information management systems which provide guidance on the availability of data sets pertinent to IGBP scientists. It also involves ensuring that the broader global change community has access to data sets generated within IGBP. Past activities have included establishing the NASA Master Directory at the IGBP Paris Office; also accessing and searching various international satellite data holdings, e.g., those in the USGS Global Land Information System. Future activities will include representation on the NASA EOS Focus Teams on Data Organization.

Activity 3.3 Linkage to other international coordinating bodies on data

Rationale: In the past five years several international bodies have been established with major involvement in the coordination and integration of data on global environmental change. It is important for IGBP data-related interests and requirements to be brought to the attention of these organizations. The definition, addition (and possible deletion) of Tasks within this Activity will be kept under close review.

Task 1 *Liaison with GCOS, GOOS and GTOS.* The Global Climate Observing System is being defined by a group representing WMO, UNEP, IOC and ICSU. The current chair of the IGBP-DIS Standing Committee, Dr J. Townshend, is one of the two ICSU representatives. The proposed GCOS monitoring system is intended to detect global change by a combination of space and surface networks. IGBP-DIS input will be to ensure that such a monitoring system includes a calibrated and consistent series of measurements, not only of "classical" climate variables but also of biotic parameters (e.g., vegetation density) which affect long term climate and are impacted by climate change. It is expected that similar interactions with the Global Oceans Observing System (GOOS) and the Global Terrestrial Observing System (GTOS) will be developed as these programmes become better defined.

Task 2 *Liaison with IPCC.* The Intergovernmental Panel for Climate Change (IPCC) provides periodic assessments of the state of our knowledge of climate change, of its possible impacts and response strategies. IGBP-DIS assisted in providing input to the 1990 Scientific Assessment, and the 1992 Supplement, identifying key data sets needed to improve model prediction. Together with other parts of IGBP, similar interactions are expected to continue for future assessments.

Task 3 *Liaison with OECD.* The Organization for Economic Cooperation and Development (OECD) has initiated data base development activities starting with global greenhouse gases emissions on a country-by-country basis. IGBP-DIS has provided expertise in the methodologies used in computing greenhouse gas emissions from data on land cover change. Such data sets, when developed, should substantially improve our understanding of carbon cycle in the land-ocean-atmosphere system.

Focus 3 priorities and future plans

Interactive working relationships with international and national agencies like CEOS, WDC, ESA, NASA/EOS-DIS should be routinely functional by 1995. High priority will also be given to the following items, with their full and successful implementation expected relatively early in the period 1994-1998:

(i) Completion of CEOS/IGBP-DIS pilot project for obtaining high resolution data from SPOT, Landsat and MOS for IGBP research at minimum cost.

(ii) Routine involvement of IGBP scientists in NASA EOS/DIS-DAACs.

(iii) Close working relationships with ESA and EC established, particularly to study the usefulness of microwave sensing of surface properties (by ERS I and II).

(iv) Use of the WDC system for data archiving and distribution on a regular basis.

Structure and Organization

To fulfil the functions and develop the approach outlined above, the IGBP-DIS organizational structure has a Standing Committee, an IGBP-DIS Office, Working Groups on specific activities, and various laboratories, research groups and institutions directly involved in meeting IGBP needs for global data sets. These elements are linked to the Scientific Committee of IGBP, to other components of the programme, and to the agencies and organizations responsible for producing, assembling, processing and distributing other data sets of interest to IGBP. Figure 7 shows the main connections between these bodies.

IGBP-DIS Standing Committee and Project Office

The IGBP-DIS Standing Committee was established in 1990. It replaced IGBP Working Group 1, on Data and Information Systems, that had been responsible *inter alia* for Chapter 9 in IGBP Report 12 (1990). Members are appointed for three years, on the basis of their scientific expertise. Dr S. I. Rasool was chairman of the Standing Committee until December 1993, when he was succeeded by Dr J. R. Townshend; other members of the current committee are listed in the Appendices.

The terms of reference for the IGBP-DIS Standing Committee are to develop and assist the implementation of IGBP policy on data and information for the programme, reporting to the IGBP Scientific Committee. Meetings of the IGBP-DIS Standing Committee are held at approximately nine-month intervals.

The IGBP-DIS Office (Director: Dr S. I. Rasool) was established in early 1991 at the Université Pierre et Marie Curie, Paris, with current support from CNRS and CNES (France), the European Commission and NASA. Its role is to assist the Standing Committee by providing day-to-day management of IGBP-DIS activities, and, with the (relatively limited) software and hardware at its disposal, to carry out data handling tasks and facilitate access of readily-available data sets to data users. There is the opportunity for other organizations to establish direct working links with IGBP-DIS through secondments to the Project Office in Paris: the attraction of suitably qualified personnel will be given high priority.

It is envisioned that as the scope of IGBP-DIS expands, separate Focus Offices may be created. Such offices have been established within some of the IGBP Core Projects: they broaden international involvement in the project, whilst also providing an efficient way to manage distinct elements of the project.

Management structure for IGBP-DIS Activities

The role of IGBP-DIS is functionally different from other IGBP components, since its activities are primarily directed towards support of the Core Projects. Its existence is

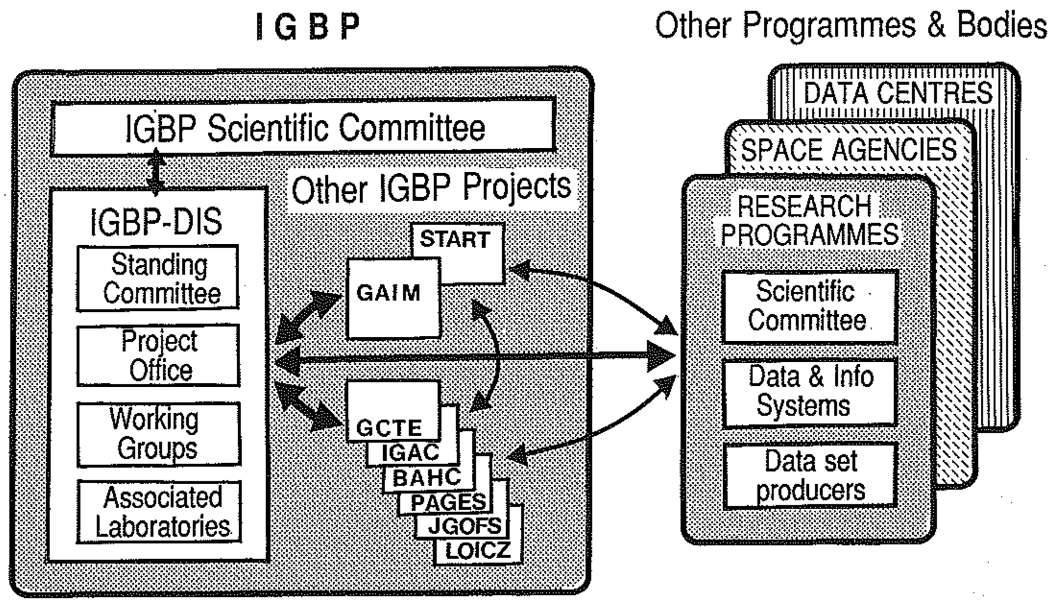

Figure 7. Structure of the IGBP Data and Information System and its main functional links, within and outside IGBP.

essential because of the fundamental importance of data and information manipulation to global change research. IGBP-DIS must therefore attract its own international team of researchers and information specialists, addressing data acquisition, processing and management issues – and thereby providing coherence and added value to the work of other IGBP scientists. Whilst some data-related problems can be relatively easy to solve, many others are more long-term, taking considerable effort over 2-5 years before a satisfactory outcome can be obtained.

In addition to the Focus Leaders, as previously identified in Section 2.3, IGBP-DIS Working Groups have been established to supervise the development and implementation of the main Activities and their component Tasks. The Chairman of each Working Group currently has the role of Project Manager for the relevant Activity, reporting on progress to the IGBP-DIS Standing Committee; however, there may be cases where a separation of responsibilities is appropriate, and another individual may then take on that role. Working Group members are appointed from laboratories that are well experienced in the processing and management of environmental data sets, or have other relevant expertise or facilities. Laboratories, research groups and other institutions that contribute significant effort to addressing Activity objectives will be designated IGBP-DIS Associate Laboratories by the IGBP-DIS SC.

In cases where the Associate Laboratory is involved in the production of a specific data set, that research group would be responsible for the quality and formatting of the data. However, its further distribution, would, in most cases, be the responsibility of the Working Group or the IGBP-DIS Project Office.

The important function of Core Project Data Coordinators in developing interactions within IGBP has been discussed in the section *Strategy Development* above, and the individuals who currently have that responsibility are identified there.

Strategic planning

IGBP-DIS is an evolving organization, and much work remains to be done in planning its future development, both with regard to IGBP-wide issues and its relationship to Core Projects and other components of the programme. A timeline for the implementation of IGBP-DIS is given in Fig. 8. A Working Group for strategic planning was established in 1993, with the following terms of reference:

(i) Develop a generic framework for a Core Project Data System Plan, so that all topics needing to be considered are included. Assistance should be drawn from those Core Projects who already have well developed plans and experience in implementing them, such as JGOFS and PAGES. The purpose of this exercise is to reduce effort levels required by Core Projects and others in the next task.

(ii) Work with each Core Project, START and GAIM to ensure that they have a detailed Data System Plan specific to their needs. (The section *Strategy Development* of this Report indicates the main topics that need to be included).

(iii) Develop a Data System Plan for IGBP as a whole. This requires decisions on what issues should be generic to IGBP and which should be left to the separate parts of IGBP.

(iv) On completion of items (i) - (iii), redefine as necessary the role of IGBP-DIS.

Work on the above items is currently underway, with expected completion by late 1994/early 1995. Although closely linked to several Activities within Focus 2, these planning items do not exactly match the tasks identified there, because of the wider issues under consideration. The following are members of the IGBP-DIS Strategy Working Group: S.I. Rasool, Christopher Justice, Berrien Moore III, David Skole and John Townshend. These individuals have also been responsible for the preparation of the IGBP-DIS Section of this Report.

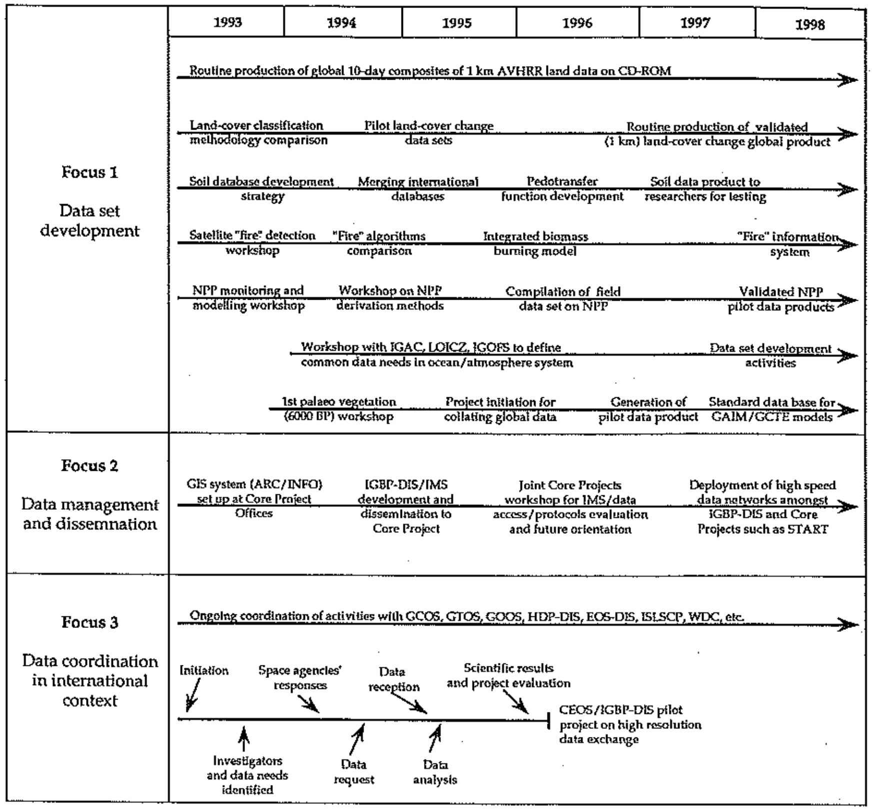

Figure 8. Implementation timelines for the main IGBP-DIS activities, 1993 - 1998.

APPENDICES

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Acronyms and Abbreviations

AGCM	Atmospheric General Circulation Model
AMIP	Atmospheric Model Intercomparison Project
APAR	Absorbed Photosynthetically Active Radiation
ATM	Atmospheric Transport Model
AVHRR	Advanced Very High Resolution Radiometer
BAHC	Biospheric Aspects of the Hydrological Cycle (IGBP)
BIBEX	Biomass Burning Experiment (IGAC)
CD-ROM	Compact Disk-Read Only Memory
CEO	Centre for Earth Observation
CEOS	Committee on Earth Observation Satellites
CNES	Centre National d'Etudes Spatiales (France)
CNRS	Centre National de la Recherche Scientifique (France)
CODATA	Committee on Data for Science and Technology (ICSU)
COHMAP	Cooperative Holocene Mapping Project
COSPAR	Committee on Space Research (ICSU)
DAAC	Distributed Active Archive Centre
DIS	Data and Information System
EC	European Commission
ECMWF	European Centre for Medium Range Weather Forecast
ENSO	El Niño - Southern Oscillation
EOS	Earth Observing System (USA)
EROS	Earth Resources Observing Satellite
ERS	ESA Remote Sensing Satellite
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization (UN)
GAIM	Global Analysis, Interpretation and Modelling (IGBP)
GCIP	GEWEX Continental-Scale International Project
GCM	General Circulation Model
GCOS	Global Climate Observing System (ICSU/IOC-UNESCO/UNEP/WMO)
GCTE	Global Change and Terrestrial Ecosystems (IGBP)
GEWEX	Global Energy and Water Cycle Experiment (WCRP)
GIS	Geographic Information System
GISS	Goddard Institute for Space Sciences
GOOS	Global Ocean Observing System (ICSU/IOC-UNESCO/WMO)
GPP	Gross Primary Productivity
GRID	Global Resource Information Database (UNEP)
HDP	Human Dimensions of Global Environmental Change Programme (ISSC)
HRPT	High Resolution Picture Transmission
CSU	International Council of Scientific Unions
GAC	International Global Atmospheric Chemistry Project (IGBP)
GBP	International Geosphere-Biosphere Programme (ICSU)
GBP-DIS	IGBP Data and Information System
NPE	Instituto Nacional de Pesquisas Espaciais (Brazilian Space Agency)
OC	Intergovernmental Oceanographic Commission (UNESCO)
ODE	International Oceanographic Data and Information Exchange
PAR	Intercepted Photosynthetically Active Radiation

IPCC	Intergovernmental Panel on Climate Change (WMO/UNEP)
ISLSCP	International Satellite Land-Surface Climatology Project
ISSC	International Social Science Council
JGOFS	Joint Global Ocean Flux Study (SCOR/IGBP)
JSC	Joint Scientific Committee (WCRP)
LAI	Leaf Area Index
LAMBADA	Large Scale Atmospheric Moisture Balance of Amazonia using Data Assimilation (BAHC/GEWEX)
LEMA	Long-term Ecological Modelling Activity (GCTE)
LGSOWG	Landsat Ground Station Operators Working Group
LOICZ	Land Ocean Interactions in the Coastal Zone (IGBP)
LUCC	Land Use / Cover Change (IGBP/HDP)
MOS	Marine Observational Satellite (Japan)
NASA	National Aeronautics and Space Administration (USA)
NASDA	National Space Development Agency of Japan
NCAR	National Center for Atmospheric Research (USA)
NDVI	Normalised Difference Vegetation Index
NMC	National Meteorological Centre (USA)
NOAA	National Oceanic and Atmospheric Administration (USA)
NPP	Net Primary Productivity
OCCM	Ocean Carbon Cycle Model
OECD	Organization for Economic Cooperation and Development
PAGES	Past Global Changes (IGBP)
PILPS	Project for Intercomparison of Landsurface Parameterization Schemes (WCRP)
PMIP	Palaeoclimate Model Inter-comparison Project (PAGES)
RRC	Regional Research Centre (START)
RRN	Regional Research Network (START)
RRS	Regional Research Site (START)
SAFARI	Southern African Fire-Atmosphere Research Initiative (BIBEX)
SAFISY	Space Agency Forum of the International Space Year
SC	Scientific Committee (IGBP)
SCOPE	Scientific Committee on Problems of the Environment (ICSU)
SCOR	Scientific Committee on Oceanic Research (ICSU)
SeaWiFS	Sea-viewing Wide-Field of view Sensor
SPOT	Satellite pour l'Observation de la Terre (France)
SSC	Scientific Steering Committee
SST	Sea Surface Temperature
START	Global Change System for Analysis, Research and Training (HDP/IGBP/WCRP)
SVAT	Soil-Vegetation-Atmosphere Transfer
TBM	Terrestrial Biogeochemical Model
TOGA	Tropical Ocean and Global Atmosphere project (WCRP)
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGC	United States Global Change
USGS	United States Geological Survey
WCRP	World Climate Research Programme (WMO/ICSU/IOC)
WDC	World Data Centre (ICSU)
WMO	World Meteorological Organization (UN)
WOCE	World Ocean Circulation Experiment (WCRP)

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