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

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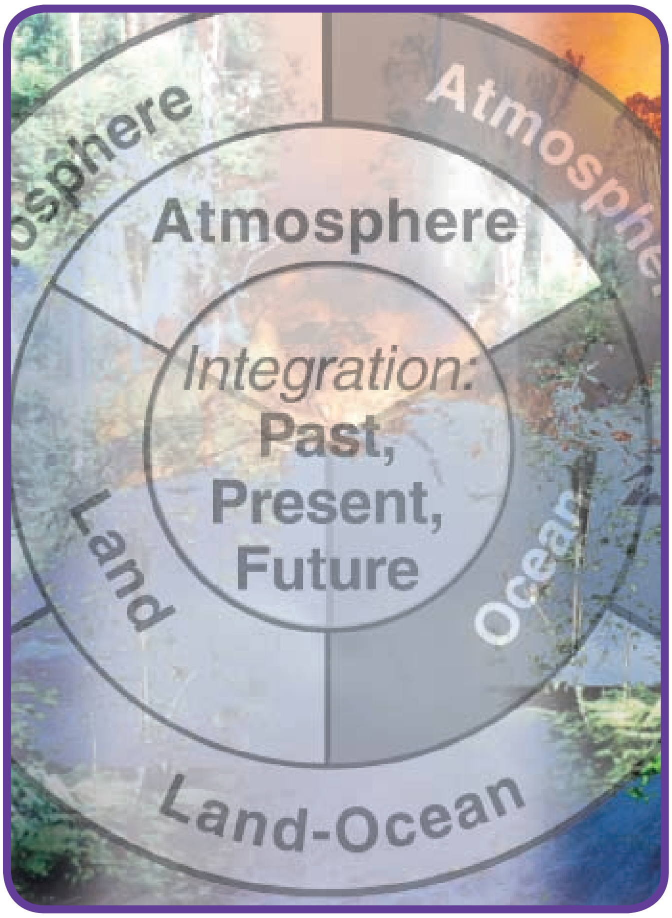
IGBP II - Special Edition

After 15 years of significant scientific achievements, IGBP is evolving into a exciting second phase, presented here in this special edition of the Global Change NewsLetter. Each new IGBP project describes the progress made in its field in the last decade and looks ahead to future challenges. In the coming years, IGBP II will collaborate ever more closely with its sister programmes IHDP, WCRP and DIVERSITAS: together, the four programmes comprise the Earth System Science Partnership (ESSP). Articles on the ESSP and the new 'joint projects', as well as a final article from the funding agency IGFA, put the science of IGBP in a wider context. In the centrefold you will find a central reference point, summarising the new structure and spelling out the acronyms that are commonly used in the articles.

The new and evolving IGBP



The International Geosphere-Biosphere Programme (IGBP) was initiated about 15 years ago, at a time when it became clear that human-induced perturbations would have a global impact on the Earth's environment. Several Program Elements were developed within IGBP to provide a fundamental understanding of the processes affecting the ocean, the continental biosphere and the atmosphere. Some preliminary attempts were made to understand the coupling mechanisms occurring between these components of the Earth System and to assess how they are being perturbed as a result of economic development and population growth. A decade of intensive research by a large international community of scientists has led to a comprehensive picture of the mechanisms that determine the fate of our planet. Even 10 years ago, the full extent of the impact of human activities on the Earth System was uncertain; now it is measurable. We can now distinguish natural variability from human-induced change due to remarkable proxy records of past climate. We have better

Summary of the new IGBP Structure in the centrefold

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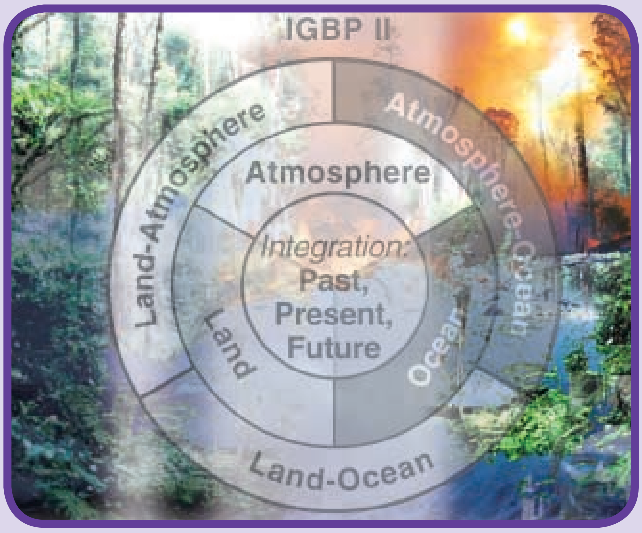

models and predictive tools to help us build scenarios of the future. We understand more fully the linkages between land, oceans and atmosphere, and between biological, physical and chemical processes, particularly the vital role of the biosphere in the Earth System. These findings were highlighted at the Global Change Open Science Conference held in Amsterdam in July 2001 and are being synthesised in a number of volumes to be published imminently as part of the IGBP series [1].

Significant scientific accomplishments in understanding the Earth System have been realised over the past decade, but much more needs to be done. The issues are of immense importance. If the full scope of scientific challenge is to be met, then it must be addressed in a more coherent and more aggressive manner in the next decade, than it was in the past decade….The linked challenges of confronting and coping with global environmental changes and addressing and securing a sustainable future are daunting and immediate for all cultures, but they are not insurmountable. The challenges can be met, but only with a new and even more vigorous approach to understanding our changing planet and ourselves.

Over the past two decades, DIVERSITAS, IHDP, WCRP, and IGBP have established and documented the scientific foundation on which we can now face these challenges head-on.

This is requiring us to focus and further develop IGBP, and to strengthen and expand our relationships with DIVERSITAS, IHDP, and WCRP. This has been a central activity over the past two years, and we have been advancing through a sequence of four iterative steps:

- Clarifying and articulating the critical system-level characteristics and associated core scientific questions. These questions are clearly both disciplinary and trans-disciplinary

- Developing research strategies for characterising better the Earth System and addressing the critical core scientific questions. This development has and will include specific research programmes, with priority on those theoretical investigations, observational systems and products, and focussed studies that are most needed. Prioritisation is not easy, but it is necessary.

- Defining, creating, evolving, and implementing the organisational structures that are appropriate to execute the emerging new research strategies. This has been and will continue to be an evolutionary process, and therefore, it will have some rough edges and that is good. One does not learn to ride a bicycle by reading an instruction book, and it is not without some bruises. But the shared vision and cooperative spirit of all has brought us forward; we are ready to ride.

Finally,

- Building and supporting an expanding international community of scholars, who are willing to commit to meeting these responsibilities, challenges, and expectations, is being realised. We have achieved much in terms of capacity-building in the past decade. But even more is needed—we must with greater urgency increase capacities throughout the world and thereby, *create* the necessary scientific resources most needed to meet the "linked challenges of confronting and coping with global environmental changes and addressing and securing a sustainable future."

We believe that we now need to move quickly and aggressively; we must capitalise on our collective successes, and we must not let the tide turn. We need, *this year,* to forge the new plans for the next evolutionary step of IGBP. The time is ripe: the new vision for the next steps in understanding the Earth's atmosphere, ocean, and land and the linkages between them is emerging; the Earth System Science Partnership is developing and its three joint projects on food, water, and carbon are moving ahead with clarity and purpose. But we can not wait until every "i" is dotted and every "t" crossed; we must begin to cross the scientific chasms in order to learn how to cross even wider ones in the future.

This will require all of us to contribute our ideas; to share our thoughts with one another; to offer constructive criticisms; and most importantly to listen to what our colleagues are trying to say. It may at times become frustrating; this is not an easy journey, but it is an essential enterprise. We simply must move forward and meet these challenges.

Fortunately, the evolution towards meeting these new challenges is gaining momentum. IGBP is now well into a transition phase. The new IGBP, starting in 2003, will be different from its predecessor. Disciplinary aspects (including process studies) will remain a central and important part of the scientific agenda. We will however, expand our efforts and address scientific questions through a more integrated approach. This system-level focus formally recognises that the Earth is a nonlinear system with chaotic behaviour, feedback mechanisms, bifurcation points, etc., and that the prediction of its future evolution is not always deterministic.

As noted earlier, collaborative research with our partners will be an increasingly important feature of IGBP II. Attempts to better understand the couplings between the physical climate system and the biogeochemical system will be made through a stronger cooperation with the WCRP. Including the human aspects in our traditional analytic approaches will be a challenging task, but it will be attempted through a closer relation with IHDP. Clearly, the future of global change research will be driven by the Earth System Science Partnership (ESSP) involving IGBP, WCRP, IHDP and DIVERSITAS, a new programme focusing on biodiversity.

Perhaps one of the most efficient ways to address interdisciplinary issues is to articulate the questions at the regional level. The Earth System Science Partnership, and IGBP specifically, will therefore develop a number of integrated regional studies in cooperation with local scientific communities. START will also play a key role. This approach may, in addition, facilitate the implementation of new educational efforts to be developed by IGBP in the future. It becomes increasingly clear everywhere in the world that scientific research cannot anymore be dissociated from educational activities. Educational curricula will have to account for scientific progress in global change research.

We have entered a new and exciting period for IGBP. We are developing new research foci and innovative methodologies. We will conduct research in very different ways, by highlighting interdisciplinary questions, by working through networks involving centres of excellence distributed over the six continents, and by connecting scientists with very different educational backgrounds. The use of information and of modern communication technologies will be of primary importance. The success of IGBP II will, however, depend primarily on the quality and the originality of the research. This research will be driven by the recognition that the Earth is a dynamic system, whose evolution may be full of surprises.

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Forward to the past: the future of PAGES

by K. Alverson

The Earth System is characterised by variations on all timescales. Dramatic changes in the global environment, due to a combination of external forcing and internal system dynamics, are known to have occurred on timescales from decades to hundreds of thousands of years. Furthermore, Earth System history is replete with examples of nonlinear dynamics, wherein various system components demonstrate large, abrupt or irreversible changes in response to forcings that are both small and smooth. Instrumental climate and ecosystem related data, on the other hand, are characterised by a short and, at least in relative terms, uneventful history. Meteorological data from a global network of stations has been available for about a century and satellite measurements of Earth System properties date back only a few decades.

PAGES (Past Global Changes) seeks to bridge the vast gulf that looms between these two extremes - the long and rich record of actual Earth System history on the one hand, and the short and comparatively uneventful instrumental record on the other. Closing this gap is the only way to illuminate the quantitative past record in a way that is relevant to regional and global resource sustainability. A quantitatively calibrated, chronologically well-constrained record based on multiple lines of empirical evidence alongside a hierarchy of dynamical models is the foundation for such understanding.

Figure 1

Instrumentation installed on a *Pinus hartwegi* tree to measure radial changes both above and below the bark as a means of better calibrating tree ring growth as a function of climate variables. [5] Photo: P.C. Harsough

A cautionary note

Over the past decade palaeoscience has come a long way. Mucking about in mud in search of very small dead things with long Latin names is now widely recognised as being of great relevance to societal concerns. Based solely on such proxy records of the past, we can make some fairly strong statements about the present. Greenhouse gas levels are higher than they have been for hundreds of thousands of years. Global average temperatures are higher now than they have been for the past millennium. Rapid, large amplitude environmental change can occur in response to smooth, small amplitude forcing. These are all messages that the past decade of palaeoresearch has brought to light. As palaeoresearch plays an even more central role in Earth System science, the challenges become even greater. The palaeocommunity is meeting the challenges through enhanced interaction with other Earth System science communities – through provision of freely available and carefully archived data, clearer and more consistent chronologies and increasingly quantitative results.

The Earth System is enormous and complex, while our data remain sparse and our models crude. The system is vastly underdetermined. As every first year college mathematics student knows, there are infinitely many solutions to an underdetermined problem. Thus, explanations which appear to fit our data, though often plausible and exciting, are not necessarily conclusive or sig-

Figure 2. An automated weather station at 3760 m elevation on Nevado de Colima, Mexico, providing the climatic timeseries against which data on ring growth can be calibrated. [5] Photo: F. Biondi

Box 1: Was the Medieval Warm Period as warm as the 1990s?

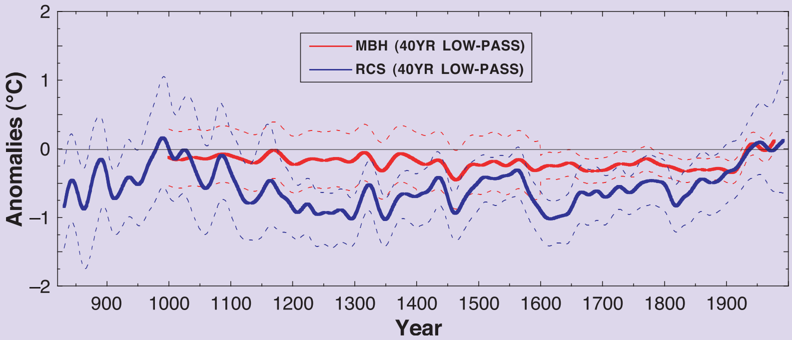

Figure 3. Two proxy-based reconstructions of mean Northern Hemisphere Temperature changes over the past millennium including uncertainty levels [1,2]. Reprinted with permission from Esper et al (2002) Science 295: 2250-2253. © 2002 American Association for the Advancement of Science.

Long tree ring chronologies are one of the most important sources of information on past climate variability over the last millennium. Figure 3 shows a recent, extra-tropical, tree ring based reconstruction [1] compared with an earlier hemispheric, multiproxy reconstruction [2] and their respective uncertainty estimates. The differences between these curves have been the subject of an active debate in the community [3, 4]. Of particular interest has been the question of whether the Northern Hemisphere average warming measured in recent decades is indeed greater than that associated with the peak of the Medieval Warm Period approximately 1000 years ago. The amount of cooling that occurred several centuries later during the Little Ice Age, and whether this cooling was geographically restricted to certain regions in the extratropics, is another issue of considerable debate. Notable among many differences in the construction of these curves, the former [2] contains records from multiple proxies and from the tropics while the latter [1] makes use of a novel technique (Regional Curve Standardisation) designed specifically to obviate the inherent loss of centennial scale variability in long chronologies constructed from a series of short, detrended records spliced together. Rather than highlighting the differences between these two curves, one might consider their similarities. They capture many of the same decadal scale events and lie at least 95% within each others' 95% confidence limits. They both show the remarkable power of long proxy-climate records to put modern changes in the perspective of the past and to use this perspective to better understand natural and anthropogenic drivers of global change. Together, they also indicate some of the most promising areas for future research: better calibration of the growth response of trees to climatic forcing (Figures 1, 2); the need to quantify the range of frequencies that can be reasonably expected to be captured by given reconstructions of past climate variability; and the need to develop long, annually-resolved, quantitative, palaeoclimatic proxy records from the tropics.

nificant. The palaeocommunity is moving beyond the storytelling mode of research of collecting data and then interpreting them. Rather, it is adopting a hypothesis-driven approach which explicitly seeks out certain data in order to confirm or rule out specific scenarios. Moreover, a single core, a single proxy, a single model or a single researcher cannot possibly answer questions about the evolution of the Earth System with the degree of sophistication with which we wish to address them. More than ever before, palaeoresearch must be grounded on quantitative calibration against instrumental data (e.g., Figures 1, 2, 3, Box 1) and a multiproxy approach.

Relevance for the future

Since the Industrial Revolution, the Earth System has become increasingly affected by human activities. Some might suggest that anthropogenic change has been so dramatic as to render dynamics of the past irrelevant to the current Earth System. This is not the case. Natural processes are now woven together with human induced changes in a complex tapestry of forcings, responses, feedbacks, and consequences. However, the past record remains of great significance for the future. For example, there is much evidence to

Box 2: PAGES in IGBP II

The PAGES remit includes the physical climate system, biogeochemical cycles, ecosystem processes, biodiversity and human dimensions. Thus, PAGES activities are not restricted to IGBP, but overlap substantially with IGBP's sister programs WCRP, IHDP and DIVERSITAS. PAGES thus expects to play a role in the developing joint projects on food, carbon and water. Facilitating public access to palaeodata, engaging with the climate modelling community, strengthening the engagement of scientists from developing countries, and interdisciplinary, international community building continue to be the foundation of all PAGES activities.

PAGES will continue to operate as a central, synthesising element within the structure of the second decade of IGBP (centrefold this issue). Thus, the reorganisation associated with the transition to IGBP II will be minor compared to that of most IGBP projects. Nonetheless, PAGES is taking the opportunity to reassess and streamline. In this process, three criteria are paramount:

1. Maintaining and building on the interdisciplinary, international community that has grown, over the past decade, to identify with PAGES projects;
2. Remaining a bottom-up organisation driven by the insights of individual scientists while bringing together otherwise disparate national or disciplinary efforts;
3. Ensuring that PAGES activities lead to clear and tangible benefits for the worldwide palaeoscience community.

Beginning with the next phase of IGBP, PAGES will support five foci encompassing various aspects of palaeoresearch. They are:

1. PANASH (Paleo-environments of the Northern and Southern Hemispheres) which comprises the three terrestrial PEP (Pole Equator Pole) transects and their intrahemispheric linkages, focusing on climate processes such as ENSO and monsoons;
2. IMAGES (International Marine Global Change Study), which with 24 member nations serves as the international palaeoceanographic flagship of PAGES;
3. The CLIVAR/PAGES Intersection, in which the recent CLIVAR past overlaps with the longer timeframe of PAGES;
4. Polar Programs, which comprises international efforts at very high latitudes in both hemispheres; and
5. Past Ecosystem Processes and Human-Environment Interactions, in which historical climate-society interrelationships are being assessed.

The activities of each focus will be overseen by a chair and a small steering group. These building blocks serve the important task of providing tangible elements on which to build grass roots scientific community association with PAGES programs.

How to get involved

The 30 or so tasks and activities which currently underlies PAGES foci are mostly being phased out, although all are welcome to request to remain in PAGES as cross-cutting initiatives driven by scientific questions. These questions are not prescribed by PAGES committees nor the PAGES office. Rather, PAGES maintains the required flexibility in our budget and our structure to respond to initiatives that arise from the community. The PAGES scientific steering committee critically ascertains if proposed initiatives should qualify for PAGES endorsement and support. This could include enhancing the profile of the initiative, advertising it to the international community and providing partial funding for workshops. The required qualifications for any initiative are a question which is tractable within a 3-5 year timeframe, a high potential to advance the field and a clear reason why PAGES should be involved, for example to facilitate new international or interdisciplinary bridges.

For more information on PAGES, see http://www.pages-igbp.org

suggest that global anthropogenic climate change may be expressed in terms of changes in naturally occurring climatic modes. Another example is biodiversity. The degree and range of modern biodiversity is not explainable with current climatic conditions alone. Rather it has arisen in response to the conditions in the past. Understanding the basis for the persistence of biodiversity in the face of past disturbances is the key to ensuring its future survival in the face of modern change. A globally inclusive, coordinated effort to decipher the complexity of natural climatic variability and ecosystem change relevant to the future remains PAGES primary goal.

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GAIM in 2002 and beyond: a benchmark in the continuing evolution of global change research

by D. Sahagian and J. Schellnhuber

As IGBP enters a new phase, building upon what has been learned in the twentieth century and especially in the last decade, it is timely for GAIM to reaffirm its goals in the context of Earth System analysis in IGBP II. GAIM was established within IGBP to "promote the development of a suite of global biogeochemical Earth System models." As such, GAIM is charged with constructing an integrated whole from the various parts of the Earth System being explored by each of the IGBP projects. This presents some challenges. Firstly, GAIM must be able to identify the most critical links between subsystems and any gaps in our understanding within and between parts of the Earth System. This introduces a "think-tank" character that necessitates a comprehensive vision of the Earth as a unit, and an integrated approach to GAIM activities. Moving to the Earth System level required expanding the scope of GAIM's activities beyond the strictly biogeochemical, and into the physical, on the one hand, and the socio-economic on the other. As such, GAIM acts as a "lighthouse" for the broader global change research community to ensure that it does not overlook any key issues that will prove to be important at the system level. Secondly, GAIM must be able to effectively link the efforts and results produced by the IGBP Projects as well as interface with the other ESSP programmes.

In order to achieve its goals, GAIM is faced with posing, and in part attempting to answer, the most fundamental questions that challenge the global change research community. For instance, one may ask: "What are the critical elements (thresholds, bottlenecks, switches) in the Earth System?" The planetary machinery is an externally forced, dissipative system operating quasi-resiliently far from thermodynamic equilibrium. A linear and homogenous system could never exhibit such features. Therefore, a number of non-linear processes and non-uniform structures must prevail, i.e. major thresholds, bottlenecks and switch elements exist (Figure 1). As a consequence, the Earth System is susceptible to critical perturbations which may either trigger repetitions of behaviour observed in records of the past or even novel modes of operation.

As another example, consider the question: "What is the carrying capacity of the Earth?" Carrying capacity can

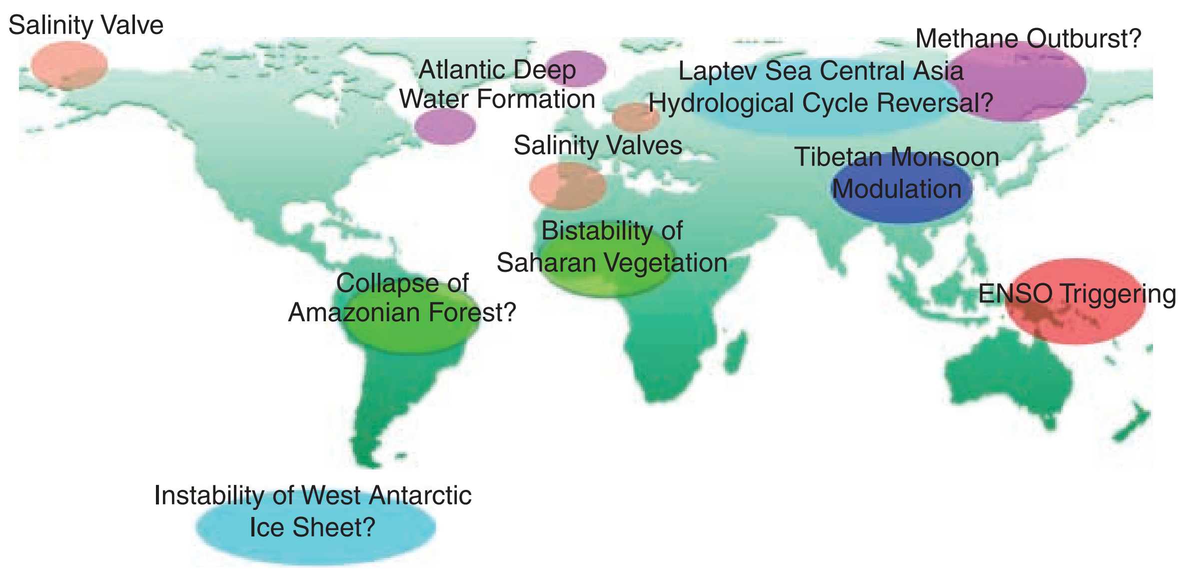

Figure 1. There are a number of potentially critical points in the Earth System, where major thresholds, bottlenecks and switch elements exist. Perturbations to the system may trigger abrupt changes, either repeating conditions that have existed in the past, or even causing shifts to new modes of operation.

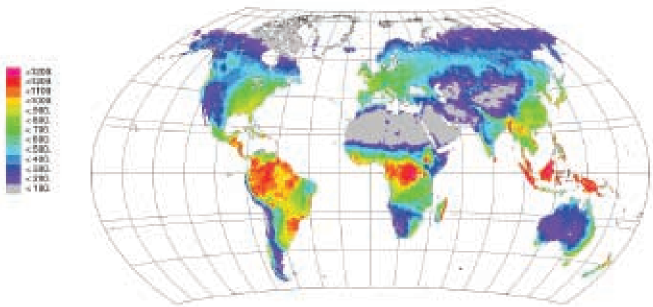

Figure 2. Global averaged annual net primary productivity (NPP) (gCm^{-2}) on the basis of 17 models participating in the NPP model intercomparison. Although the average of all models is in reasonable agreement with expectations and limited observational data, there was significant variation between models. These differences led model developers to revisit their formulations and explore the representations of ecosystem processes in a new light. The model refinements and sensitivity of the system to each of a number of important processes thus came into clearer focus as a result of the intercomparison.

be defined by the number of humans that can be supported by the Earth's life support system that consists of interlinked biological, chemical and geophysical subsystems. Carrying capacity can only be estimated within the context of long-term sustainability of the delivery of ecosystem goods and services. The carrying capacity will in fact be a multidimensional surface influenced by the technology, lifestyle, social organisation, distribution of wealth, and other socioeconomic factors. It is important to determine the Earth's carrying capacity to identify the multidimensional range of thresholds which, when exceeded, will trigger the depletion of the stock from which the Earth's life support system is derived.

Answering these questions and many others of comparable scope will entail developing a deeper understanding of the operation of the Earth System on the basis of observation of modern and palaeo systems, and modelling across a spectrum of complexities. These are the greatest challenges that face GAIM and the broader global change research community.

The new GAIM approach

In early 2000, GAIM met in Hawaii to revisit its mission, and so established the ("Waikiki Principles") regarding the scientific foci of GAIM and its role in IGBP. These provide an overarching structure within which to organise GAIM's activities:

Analysis

In its Analysis role, GAIM poses inspiring questions and challenges the broader community to explore them in ways that will ultimately contribute to Earth System level investigations (i.e. the GAIM Earth System Questions; Box 1). This means, in particular, to play the role of a trans-project topics scout and a feasibility assessor. This will require interaction with a broad range of scientists, agencies, and other institutions.

Integration

GAIM will advance the integration of knowledge inside and outside IGBP. This means both making available the best integrative methodologies and including the systems and problems dimensions primarily investigated by the sister programmes WCRP and IHDP and DIVERSITAS. As this is both conceptually and practically complex, GAIM focuses on those integrative activities in which it can pave the way for others to join in integrated Earth System analysis.

Modelling

GAIM will implement Earth System analysis by organising the construction, evaluation and maintenance of a hierarchy of Earth System models. In particular, it will help to generate models of different degrees of complexity and to employ the resulting complementary ensemble for conducting virtual planetary experiments with respect to past, present, and future global change. These kinds of models must be based on a solid foundation of analysis of the critical issues and integration of disciplinary science. The development of protocols for model intercomparison is one of GAIM's most notable achievements to date (Figure 2).

Earth System analysis relies on a hierarchy of simulation models that are being developed across a range of complexity. Depending on the nature of questions asked and the pertinent time scales, there are, on the one extreme, conceptual models like those in the "Daisyworld" family. At the other extreme, three-dimensional comprehensive models are under development in several research labs internationally. GAIM is

Box 1: The GAIM Earth System Questions

In 2001, in response to the evolving science, structure and results of the IGBP, GAIM developed a new set of overarching questions as a challenge to the scientific community concerned with global change. These questions are not limited in scope to those that can be answered by individual research projects, programmes, or even communities. Rather, they are meant to help define the overall context of global change science regardless of our present ability to address the issues articulated therein. In many cases it will be necessary to develop a dialogue with communities far beyond IGBP and the ESSP.

Analytic Questions:

1. What are the vital organs of the ecosphere in view of operation and evolution?
2. What are the major dynamical patterns, teleconnections and feedback loops in the planetary machinery?
3. What are the critical elements (thresholds, bottlenecks, switches) in the Earth System?
4. What are the characteristic regimes and time-scales of natural planetary variability?
5. What are the anthropogenic disturbance regimes and teleperturbations that matter at the Earth System level?
6. Which are the vital ecosphere organs and critical planetary elements that can actually be transformed by human action?
7. Which are the most vulnerable regions under global change?
8. How are abrupt and extreme events processed through nature-society interactions?

Operational Questions:

9. What are the principles for constructing “macroscopes”, i.e., representations of the Earth System that aggregate away the details while retaining all systems-order items?
10. What levels of complexity and resolution have to be achieved in Earth System modelling?
11. Is it possible to describe the Earth System as a composition of weakly coupled organs and regions, and to reconstruct the planetary machinery from these parts?
12. What might be the most effective global strategy for generating, processing and integrating relevant Earth System data sets?
13. What are the best techniques for analysing and possibly predicting irregular events?
14. What are the most appropriate methodologies for integrating natural-science and social-science knowledge?

Normative Questions:

15. What are the general criteria and principles for distinguishing non-sustainable and sustainable futures?
16. What is the carrying capacity of the Earth?
17. What are the accessible but intolerable domains in the co-evolution space of nature and humanity?
18. What kind of nature do modern societies want?
19. What are the equity principles that should govern global environmental management?

Strategic Questions:

20. What is the optimal mix of adaptation and mitigation measures to respond to global change?
21. What is the optimal decomposition of the planetary surface into nature reserves and managed areas?
22. What are the options and caveats for technological fixes like geoengineering and genetic modification?
23. What is the structure of an effective and efficient system of global environment & development institutions?

For some questions, GAIM is already in a position to begin to address the issues involved. In other cases, close collaboration will be necessary with IGBP projects, and with WCRP, IHDP, DIVERSITAS and others. There are additional questions whose answers will depend not on scientific research, but rather on social or philosophical considerations.

Programmatics: GAIM evolution and IGBP II

The GAIM Earth System questions were recognised by IGBP's Scientific Committee at its 2002 meeting in Stockholm as a useful overarching basis for the developing science plan for the next phase of IGBP, as well as a good context for collaboration with the other Earth System Science partners. In this way GAIM initially provides a comprehensive description of some crucial topics concerning the Earth System. Given the broad and comprehensive nature of the questions, GAIM itself cannot carry out the entire set of activities required (such as extensive data generation campaigns). Thus, GAIM will develop strategic partnerships to address well-defined problems within the question context through well-orchestrated research projects.

Further programmatic discussion, fuelled particularly by the deliberation of the GAIM questions, will generate new project and research activities as IGBP II evolves. Thus, GAIM activities are driven by a top-down strategy. At the same time, the IGBP project research activities themselves will produce new insights and new scientific riddles that will influence the formulation of the questions in a bottom-up fashion.

For more information on GAIM, see http://gaim.unh.edu/

promoting the development of models of both full and intermediate complexity - each has its uses and provides needed insights regarding the operation of the Earth System.

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Working towards a new atmospheric project within IGBP

by T. Bates and M. Scholes

The chemical composition of our atmosphere plays a crucial role in determining our planet's climate and the health and well-being of the biosphere. As human activities play an increasingly dominant role in shaping the composition of the Earth's atmosphere, it is imperative that we develop a prognostic understanding of our atmosphere and the linkages between atmospheric composition and other components of the Earth System. The past decade of research within the International Global Atmospheric Chemistry (IGAC) project has greatly increased our understanding of the chemical composition of the troposphere, the fluxes of chemical species into and out of the troposphere, and the processes controlling the transport and transformation of chemical species within the troposphere. IGAC has been particularly successful in several key areas including biosphere-atmosphere trace gas exchange (GEIA, Biomass Burning, TRAGNET), the production and reactivity of oxidising gases (NARE, APARE, EXPRESSO, MILOPEX, BIBLE), and the chemical, physical and radiative properties of aerosols (ACE-1, TARFOX, ACE-2, ACE-ASIA; *see end of article for definitions*).

The project has recently completed an integration and synthesis of its research activities [1]. Some of the major findings include:

- In the early 1990s, it was suggested that pyrogenic emissions of certain atmospheric pollutants could rival or exceed those from fossil fuel burning and have a global effect due to long-range transport. It is now known that emissions from biomass burning represent a large perturbation to global atmospheric chemistry, especially in the tropical regions of all continents. Smoke aerosols also perturb climate by scattering and absorbing sunlight and by influencing cloud microphysical processes. Burning has further significant effects on post-fire trace gas emissions from plants and soils. Interan-

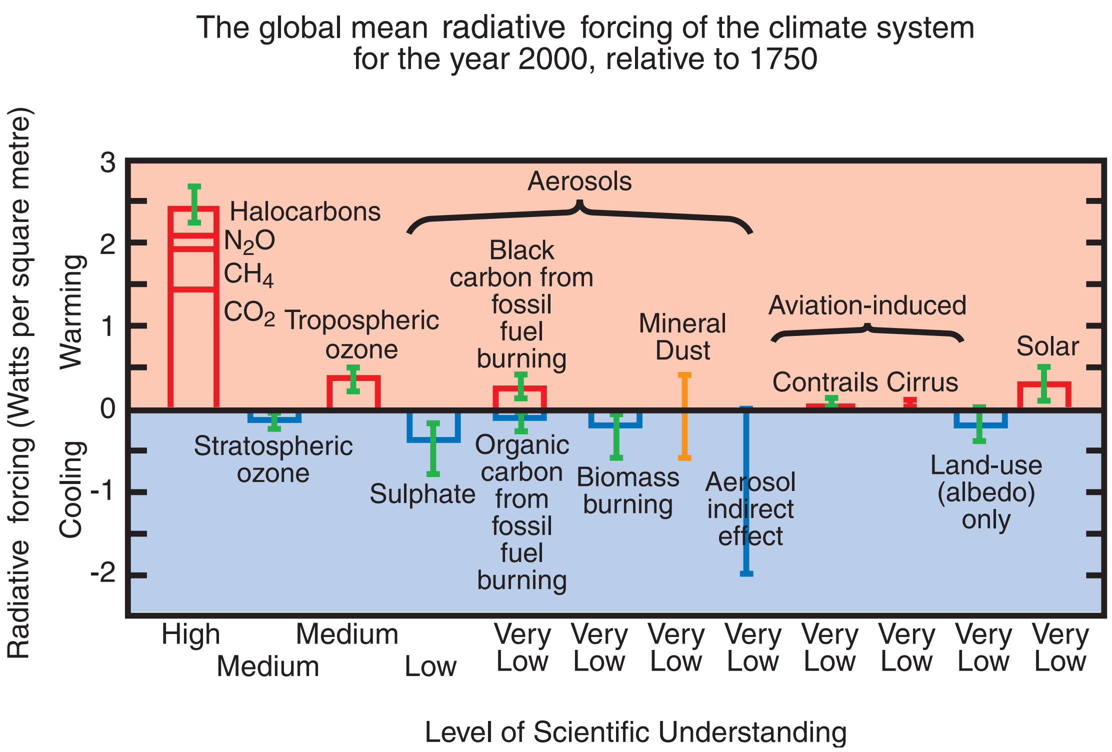

Figure 1. During the past decade the atmospheric chemistry research community has identified and quantified the distributions of a number of radiatively-active substances. However, in most cases, the level of scientific understanding in the calculated radiative forcing of these various substances is still extremely low. A major theme of IGAC-II will be to reduce the uncertainties in the calculated radiative forcing of the climate system and to understand the role of atmospheric chemistry in amplifying or damping climate change.

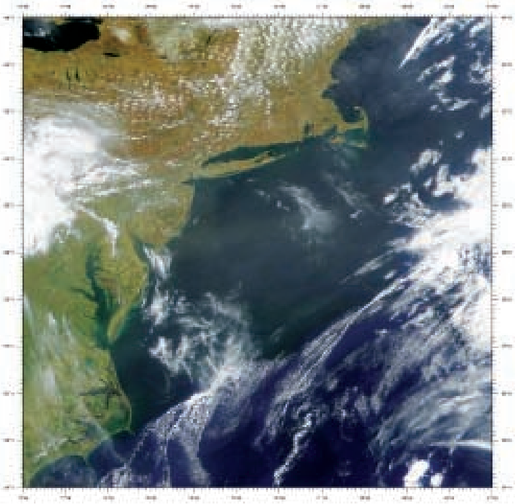

Figure 2. Research during the past few years has shown that even short–lived substances such as aerosols and ozone can be transported intercontinentally. This transport is easily seen in satellite images of dust transport. On 7-8 April 2001 strong winds swept across the Taklimakan Desert in western China, the Gobi Desert in eastern Mongolia, and the industrial regions of Eastern Asia lifting dust and pollutants into the troposphere. The plume was tracked by satellite cross the Pacific Ocean and can be seen here as a haze over the mid-Atlantic United States and Atlantic Ocean on 22 April. A major theme of IGAC-II will be studying the intercontinental transport and chemical transformation of short lived species and their affects on regional climate and air-quality thousands of kilometers downwind of their sources.

Image provided by the SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE

nual and seasonal trends in tropospheric ozone correspond to the seasonal cycle and extent of biomass burning in Tropical Africa, Latin America and Asia.

- The oxidising power of the atmosphere has remained relatively constant since the pre-industrial era, with a decrease in the OH concentration, and hence in the lifetime of major primary pollutants, that has not exceeded 20%.

- Short-lived species, such as ozone (O_3), aerosols and their precursors, exist over the oceans in multi-layered structures as a result of long-range transport from the continents.

- Major field campaigns have provided critical data for incorporating the major aerosol components into global climate models. Although still highly uncertain, the direct and indirect radiative forcing by aerosols is of comparable magnitude but opposite sign to that of greenhouse gases (Figure 1).

Perhaps as importantly, IGAC has brought together the atmospheric and biospheric research communities over the past several years. The remote sensing community, atmospheric modelling community, and gas and aerosol *in situ* measurement communities are now working side by side in the field and in data workshops to better understand the chemistry of the atmosphere. The synergy and momentum from IGAC-I provide a good foundation on which to build a new atmospheric project (IGAC-II) under IGBP II.

IGAC-II research questions

IGBP II is focusing research at the Earth System level by bringing together scientists from across traditional boundaries. Understanding the Earth's systemic behaviour and the effects and feedbacks due to human perturbations clearly require this interdisciplinary research approach. While there are still many areas of atmospheric chemistry where advances can be made within the discipline, an understanding of the functioning of the Earth System will only be achieved if scientists are encouraged to cross disciplinary boundaries and work together in common research directions.

Discussions of future research directions for IGAC have generated several key themes that deal with issues of climate and air quality over large regional and global scales:

What is the role of atmospheric chemistry in amplifying or damping climate change?

- How will changing emissions and depositions of gases affect spatial patterns of climate forcing?
- What are the relative roles of stratosphere-troposphere exchange, anthropogenic and natural precursor emissions, and *in situ* photochemical processes in controlling O_3 and its effect on global change?
- What are the sources, sinks, distributions and properties of aerosols and their direct radiative effects on climate?
- What are the effects of aerosols on clouds, their optical properties, precipitation, and regional hydrological cycles?
- How will a changing climate affect the chemical composition of the atmosphere?

Within the Earth System, what effects do changing regional emissions and depositions, long-range transport (Figure 2), and transformations have on tropospheric chemical composition and air quality?

- What are the export fluxes of oxidants, aerosols, and their precursors from continents (e.g., megacities, biomass burning, desert dust) to the global atmosphere?

- What are the impacts of intercontinental transport on surface air quality?
- How will human activities transform the dynamical and chemical properties of the future atmosphere?

IGAC-II objectives

International coordination and collaboration are essential to address these global scientific questions. The required research efforts encompass three fundamental objectives that IGAC-II will pursue:

1. To accurately determine global distributions of both short and long lived chemical species in the atmosphere and to document their changing concentrations over time.

Research over the past few decades has clearly documented the changes in the atmospheric concentration of longer-lived greenhouse gases. Recent campaigns, many organised under IGAC, have also documented the regional composition, chemical processes, and radiative effects of shorter-lived species such as aerosols and ozone. However, current observational systems are not capable of producing global distributions of short-lived gases and aerosol species. Without such data we cannot reliably determine the total radiative forcing of the climate system [2] or document the changes in the chemical composition of these species over the coming decades. Satellite measurements are beginning to provide the capability to monitor aerosol and gas concentrations globally but must be combined with well-calibrated *in situ* measurements and chemical transport models (CTMs) to convert satellite-measured radiances to chemical composition. The only way to produce accurate global distributions of short-lived gases and aerosol species is through a combined satellite, *in situ* measurement and CTM approach. The World Meteorological Organization (WMO), through its Global Atmosphere Watch (GAW) program, coordinates a network of atmospheric monitoring stations and data centres. In addition, the Integrated Global Observing Strategy (IGOS) is developing an atmospheric chemistry theme that aims to integrate *in situ* and remotely sensed measurements of atmospheric composition and processes. IGAC can extend the utility of these initiatives and obtain global distributions of reactive gases and aerosols by:

- enhancing the WMO-GAW network of systematic long-term surface and vertical profile observations of reactive compounds (O_3, VOC, NO_x, CO, SO_2), aerosols (chemical, physical and optical properties of sub and super-micron particles), and thermodynamical parameters and contributing to the IGOS theme on atmospheric chemistry. The approaches must use common methodologies and standards in order to develop an intercomparable database.
- coordinating the measurements in time and space with satellite (e.g., TOMS, GOME, MODIS, MISER, CALIPSO, SCIAMACHY, TES, etc.) overpasses.
- assimilating the remotely sensed and *in situ* measurements into CTMs to evaluate the consistency of the data set and extrapolate the measurements over larger areas.

The integration of *in situ*

Box: IGAC in IGBP II

IGAC's goal is to promote and facilitate international atmospheric chemistry research that will lead to a better understanding of the Earth System. IGAC will also promote interaction among the atmospheric chemistry community through biannual scientific conferences held throughout the world to facilitate a broad geographical representation. Since IGAC does not fund research *per se*, research efforts within IGAC must come from pro-active scientists. Research will generally be organised on a task basis, directed towards a specific scientific question or as a component of a larger interdisciplinary programme, with the end product(s) published in peer-reviewed manuscripts or used in the synthesis of position papers. We anticipate that activities within IGAC-II will come and go and that the structure of the project must facilitate this to encourage focused international and interdisciplinary research efforts to better understand our Earth System.

For more information on IGAC II, see http://www.igac.unh.edu/

measurements, satellite observations and CTMs was extremely successful in recent IGAC intensive field studies (ACE-Asia, TRACE-P, SAFARI). This same integration must now extend to an ongoing long-term observational program.

2. To provide a fundamental understanding of the processes that control the distributions of chemical species in the atmosphere and their impact on global change and air quality.

To understand and ultimately manage the Earth System, the atmospheric chemistry community must contribute a prognostic capability to develop global distributions of atmospheric chemical species under different climate and emission scenarios. This requires a fundamental scientific understanding of the biogeophysical system in order to construct models that can simulate the life cycle (emission, transport, transformation and deposition) of chemical species in the atmosphere. The international atmospheric chemistry community will need to continue focused process studies with comprehensive chemical, meteorological, radiation, and aerosol physical and optical measurements to quantify processes controlling the evolution of chemical species in the atmosphere and their radiative effects. Models will provide important insight into where additional process studies are needed and what key measurements are needed to address the regions and processes of highest uncertainties. In the field, models can be run in a forecast mode to guide daily mission planning. A key strategy here again is to integrate satellite observations, *in situ* measurements, and models. The primary goal of these process studies is to constrain, improve, and couple a range of models from the local to regional to global scale.

A critical need for CTMs is emission inventories. To expand and improve the IGAC Global Emission Inventory Activity (GEIA), IGAC-II will need to work closely with the IGBP II projects studying the ocean-atmosphere (SOLAS) and land-atmosphere interfaces. Also important is the exchange of chemical species in the upper atmosphere. Here IGAC-II will need to work closely with SPARC (Stratospheric Processes And their Role in Climate), a WCRP project, to better understand the chemistry, dynamics, transport and microphysics associated with the upper troposphere and lower stratosphere.

3. To improve our ability to predict the chemical composition of the atmosphere over the coming decades by integrating our understanding of atmospheric processes with the response and feedbacks of the Earth System.

It is clear that the scattering of solar radiation by aerosols reduces the direct short-wave radiation reaching the Earth and that the absorption of solar radiation by aerosols and infrared radiation by greenhouse gases leads to a spatially uneven heating of the lower atmosphere. However, it is still difficult to quantify the response of the Earth System to these and other forcings. Quantifying the responses and feedbacks of the Earth System to changes in the chemical composition of the atmosphere requires the integration of chemical transport models and global distributions

Continued on page 30...

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Definitions of acronyms

ACE: Aerosol Characterization Experiment

APARE: East Asian/North Pacific Regional Experiment

BIBLE: Biomass Burning and Lightning Experiment

EXPRESSO: EXPeriment for Regional Sources and Sinks of Oxidants

GEIA: Global Emissions Inventory Activity

MILOPEX: Mauna Loa Observatory Photochemistry Experiment

NARE: North Atlantic Regional Experiment

SAFARI: Southern African Fire-Atmosphere Research Initiative

TARFOX: Tropospheric Aerosol Radiative Forcing Observational Experiment

TRACE-P: TRansport And Chemical Evolution over the Pacific

TRAGNET: United States Trace Gas Network

SOLAS - Surface Ocean - Lower Atmosphere Study

by P. Liss

The first pictures of Earth taken from the Moon by the Apollo astronauts in the late 1960s (Figure 1) changed many things about the way we view our home planet: its isolation in what is essentially empty space; its beautiful colours, arising in large measure from biological processes; the dynamic nature of the atmosphere, as shown by swirling weather systems; and the vast areas covered by the ocean. None of this constituted new scientific knowledge; what was important was the perspective that distance gave to the visual image. Time now provides an additional perspective: the now-familiar pictures reinforce the holistic nature of the Earth, and show the complementary roles of the atmosphere and ocean in determining the conditions on its surface.

Why then has it taken more than 30 years for the importance of studying the planet as an entity, now called Earth System Science, to be recognised, with high research priority given to the interactions of the globe's two dominant fluids? The answer, at least partly, is a painful one, involving the conservative and compartmental nature of the academic enterprise (comprising scientists, funders and policy makers). Yet barriers are being broken down. In particular, physical climate models need robust representations of ocean-atmosphere energy transfers just as much as internally-consistent descriptions of their separate dynamics. And we now recognise that long-term climatic change is primarily driven by large-scale biogeochemical transfers between the two systems, in turn dependent on small-scale processes and subtle, non-linear feedbacks occurring at the ocean-atmosphere interface.

SOLAS, the first new core project in IGBP Phase II, addresses these inter-compartmental connections, with the following goal:

To achieve quantitative understanding of the key biogeochemical-physical interactions and feedbacks between the ocean and atmosphere, and how this coupled system affects, and is affected by, climate and environmental change.

Although this is a very large objective and one that is central to IGBP, SOLAS will only provide some of the pieces of the Earth System Science 'jigsaw puzzle' being put together in the programme's second phase. The components that SOLAS will cover are illustrated in Figure 2.

DMS and climate

Emission of trace gases from the ocean can have a profound effect on the properties of the atmosphere. For example, dimethyl sulphide (DMS), formed as a result of biological processes in the ocean, can affect the composition and number of cloud condensation nuclei in marine air, with resulting change in cloudiness and temperature. Recent coupled ocean-atmosphere modelling studies at the Hadley Centre for Climate Prediction and Research [1] show that even a relatively small (factor of two) change in marine emissions may have a significant impact on global temperatures (plus or minus about 1°C for a halving or doubling of DMS emissions, respectively). Evidence from ice cores [2] and iron fertilisation experiments [3] shows that changes in DMS release at least as large as this

Figure 1. Image of the Earth from the Moon taken by Apollo 10 astronauts, May 1969. Source: NASA.

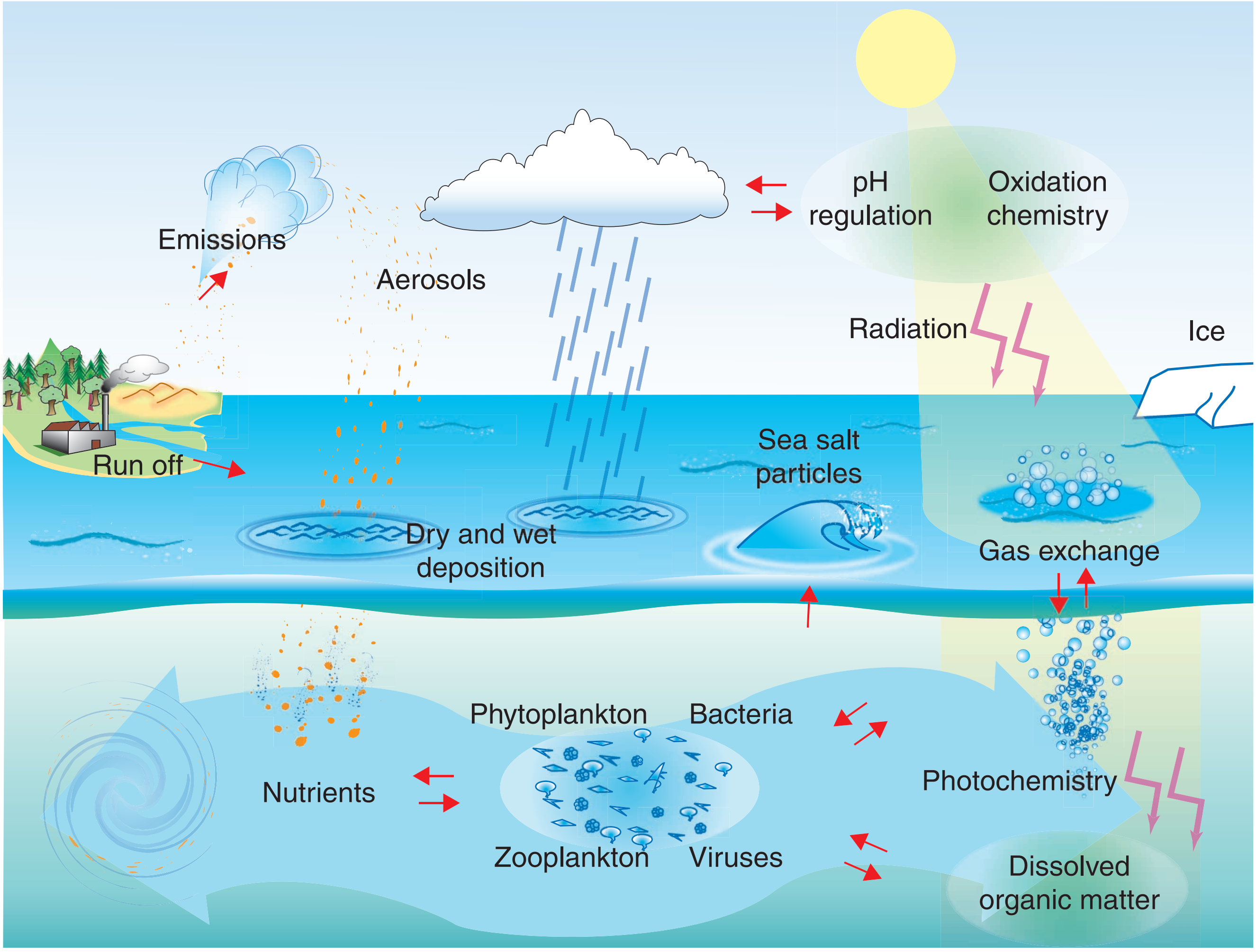

Figure 2. The domains of SOLAS, its interdisciplinarity and main operative processes. J. Bellamy and W. Broadgate, IGBP

have occurred in the past and may well occur under future global change scenarios (e.g. altered inputs of N and Fe from the atmosphere). Additionally, organo-halogen gases emitted from the ocean or ice-covered surfaces are potent controls on the levels of atmospheric oxidants such as ozone. Figure 3 shows 'clouds' of BrO, a product of organo-halogen breakdown in air, which can be seen by satellite over vast areas of both polar regions. These examples show the importance of SOLAS science for both climate prediction and air quality. They will be pursued in partnership with the upcoming IGAC - II and OCEANS projects, as well as with LOICZ, PAGES and GAIM, *inter alia*.

The above examples highlight some of the main topics to be studied in the first of three SOLAS foci:

Focus 1

Biogeochemical coupling between ocean and atmosphere. This includes topics such as oceanic emissions of trace gases important in atmospheric chemistry and climate, deposition of nutrients (N, Fe) that control marine biological activity and carbon uptake, as well as the production of chemically-active particles by gas-to-particle conversion in the atmosphere.

Focus 2

The development of quantitative understanding of processes responsible for air-sea exchange of mass (as gases, and wet and dry particles), momentum and energy, to permit accurate calculation of regional and global fluxes.

Knowledge of the rate at which gases cross the air-sea interface is central to calculation of their fluxes between the atmosphere and ocean and is a major topic in Focus 2 of SOLAS. However, there is considerable uncertainty as to how the exchange rate should be parameterised for calculation and modelling of the fluxes [4,5]. The equations used generally define the interfacial transfer rate in terms of wind speed, although the influence of waves, surfactant films and bubbles may be equally, if not more, important. Recently, experimental approaches from micrometeorology, using the technique of eddy correlation, have been successfully deployed at sea for CO_2 exchange [6]. Use of eddy correlation and related techniques have great potential to reduce uncertainties as to how gas transfer is affected by wind, in addition to other factors. In these approaches we will work closely with the WCRP and their Working Group on 'Air-Sea Fluxes'. Interaction between that group, with its expertise in energy and momentum transfer, and SOLAS scientists working on mass transfer should be particularly fruitful; such inter-programme collaboration will be a prominent feature of IGBP-II.

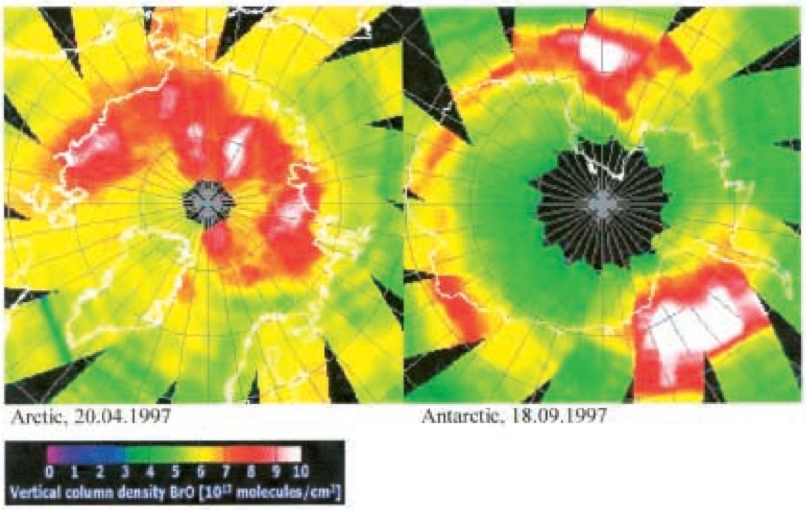

Figure 3. Satellite observations of tropospheric bromine oxide "clouds" in the Arctic and Antarctic. The clouds are associated with total loss of boundary layer ozone, occur only in spring, and have a typical lifetime of one to a few days. Reproduced by permission of the American Geophysical Union from Wagner T et al., (2001). Spatial and temporal distribution of enhanced boundary layer BrO concentrations measured by the GOME instrument on board ERS-2. J. Geophys. Res. 106: 24,225-24,235. © 2001 American Geophysical Union.

Focus 3

Air-sea fluxes of gases, especially their geographic and interannual variability and sensitivity of these to global change, in particular, gases that are long-lived in the atmosphere and are radiatively important therein, such as CO_2. In addition, Focus 3 covers air-sea transfer of other radiatively-active gases, particularly N_2O and CH_4, with emphasis on coastal and other areas subject to low dissolved oxygen levels.

With the ocean currently taking up 25-35% of the CO_2 put into the atmosphere as a result of fossil fuel burning, policy makers need to understand the regional, seasonal and interannual structure and variability of the ocean uptake, as well as how it may alter in the future as

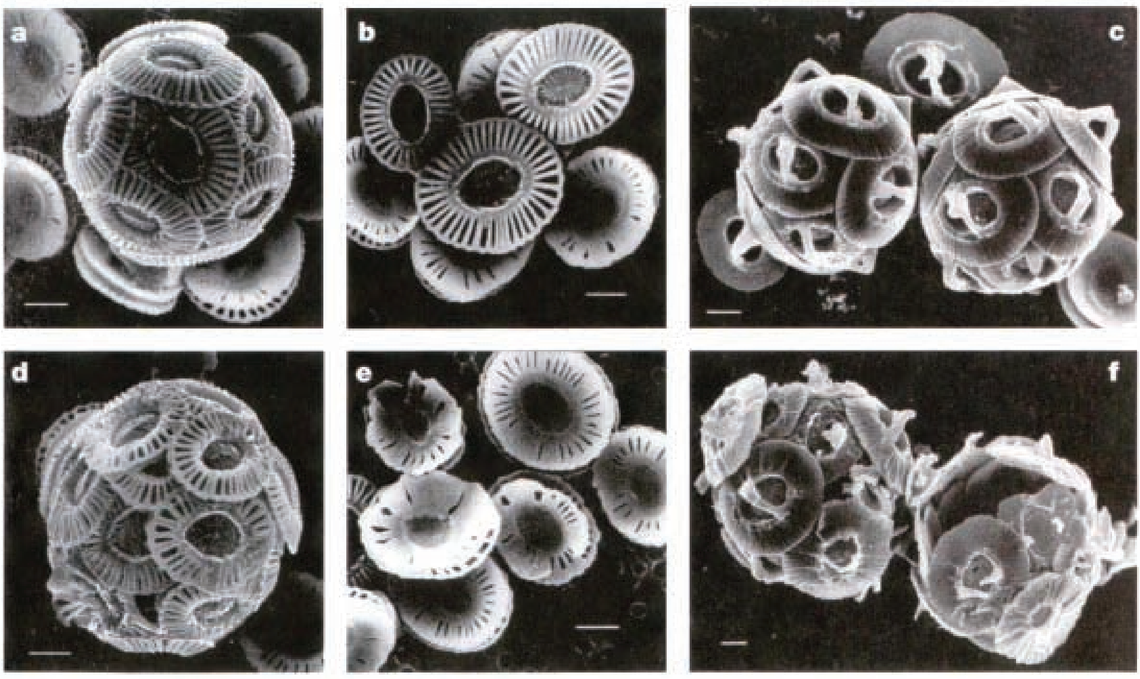

Figure 4.

Scanning electron microscope pictures of coccolithophorids grown under low and high carbon dioxide conditions, corresponding to dissolved pCO_2 levels of about 300 ppmv (a-c) and 780-850 ppmv (d-f). Note the difference in the coccolith structure (including malformations) and in the degree of calcification of cells grown at normal and elevated CO_2 levels. Reproduced by permission from Riebesell U et al., (2000). Reduced calcification of marine plankton in response to increased atmospheric CO_2. Nature 407: 364-367. © 2000 Macmillan Publishers Ltd.

Box: SOLAS in IGBP II

SOLAS was approved as a core project of IGBP last year and will be an integral part of the programme in its second phase. It is also sponsored by the Scientific Committee on Oceanic Research (SCOR), the Commission for Atmospheric Chemistry and Global Pollution (CACGP), and most recently by the World Climate Research Programme (WCRP).

As well as the 3 foci discussed above, SOLAS will also make much use of modelling, remote sensing, and time-series measurements in the atmosphere and ocean. The Science Plan will be published in early 2003, along with an Implementation Strategy for the work programme, which is being developed by the SOLAS SSC with input from SOLAS national representatives who met in Amsterdam in June 2002. As part of its capacity building activities, SOLAS will run a summer school in Corsica in 2003 (further details at http://www.bgc.mpg.de/~corinne.lequere/solas/).

global conditions change. A specific item is how the lowering of seawater pH by about 0.3 units over the next 100 years due to rising atmospheric CO_2 levels (Figure 4) will affect marine algae, particularly those with calcareous skeletons. Further, how will any change affect CO_2 uptake, as well as the production of trace gases such as DMS and organo-halogens and hence their fluxes to the atmosphere? SOLAS research on CO_2 will focus on its air-sea exchange. It will provide input to the OCEANS project on understanding how much of the carbon fixed at the surface by organisms is removed to deeper layers, and will work with WCRP on the implications of changed ocean uptake for climate and with IHDP on emission scenarios.

The examples given above are just a few of the science topics to be covered by SOLAS. They illustrate the scientific excitement, relevance to society and importance in IGBP-II, and elsewhere, of the research to be pursued. Through SOLAS and the other projects forming IGBP in its second phase, we have the opportunity to pursue the research agenda of Earth System Science made plain by those 30 year old pictures from the Moon.

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Footnote

It is not feasible in a short article to do justice to all the science to be pursued and the reader is referred to the following Web site where the full SOLAS Science Plan can be found: www.solas-int.org. This latest version of the Science Plan has been developed by the recently formed SOLAS SSC and derives from an Open Science Meeting held in Germany in February 2000 attended by more than 250 scientists from 22 countries, and the subsequent efforts of more than 30 contributing authors.

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Ocean research in IGBP II

by J. Hall, R. Harris, M. Barange and K. Lochte

The ocean is a key component of the Earth System, covering 70% of the Earth's surface and playing a major role in regulating the Earth's climate and the biogeochemical cycling of key elements. Its vast storage of heat and gases has an important impact on the climate, and it contains the most extensive and least known biosphere. Exploration of the ocean is still at an early stage in comparison to the land. In the next decade, more attention will be focused on the marine component of the Earth System, as it is the final large, relatively unknown realm, and the location of many resources.

The ocean usually reacts more slowly than the atmosphere to anthropogenic forcings, and is often considered as the part of the Earth System that buffers and modulates physical and geochemical phenomena. However, the ocean is also capable of amplifying atmospheric effects, and can act as a trigger for additional global change. (See Box 1). The atmosphere and ocean are intimately coupled, exchanging physical and chemical signals. These are not well quantified, particularly with respect to their feedbacks to the atmosphere.

The ocean, particularly the continental shelf, is also intensely exploited in response to human demand for food and resources. Fisheries and other human activities are leaving discernible footprints in marine ecosystems, influencing the dynamics of geochemical cycles and food webs, and compromising their capacity to respond and adapt to global change.

Ocean research in IGBP II will build on the achievements of JGOFS (Box 2) and other projects.

Future global change research in the ocean

Direct and indirect human perturbations of the ocean are increasingly important drivers of global change. Direct examples include overfishing, increasing nutrient and sediment loading in river runoff, coastal pollution caused by waste disposal and lowering of pH due to increasing atmospheric CO_2. Indirect examples arise mainly from the anticipated climate change due to human-induced changes in atmospheric chemistry, such as increasing emissions of greenhouse gases and aerosols.

Changes to ocean ecosystems, physical processes and biogeochemistry, whether as a result of human activities or natural causes, may have serious consequences. Not only do ocean ecosystems provide a great variety of goods and services necessary to sustain humans, but they also play a vital role in Earth System functioning.

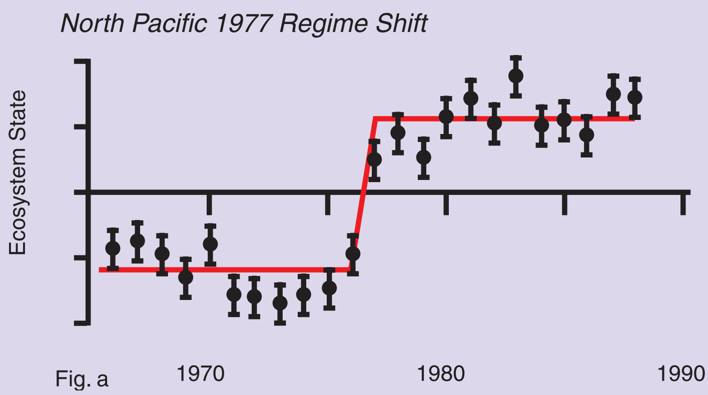
Future global change research in the ocean must:

- identify elements and processes relevant for global change and develop the capability to observe them on appropriate scales
- develop a predictive capability for the response of the ocean system to natural and anthropogenic perturbations
- assess and predict scenarios and options in order to enable society to make choices about sustainable futures.

Ocean research in IGBP II will be conducted by two closely integrated collaborative projects, GLOBEC (Global Ocean Ecosystem Dynamics) and OCEANS (Ocean Biogeochemistry and Ecosystems Analysis) (see Box 3) They will work together to develop an integrated understanding of the

Fisheries and other human activities are leaving discernible footprints in marine ecosystems, influencing the dynamics of geochemical cycles and food webs, and compromising their capacity to respond and adapt to global change.

Box 1: Regime Shifts



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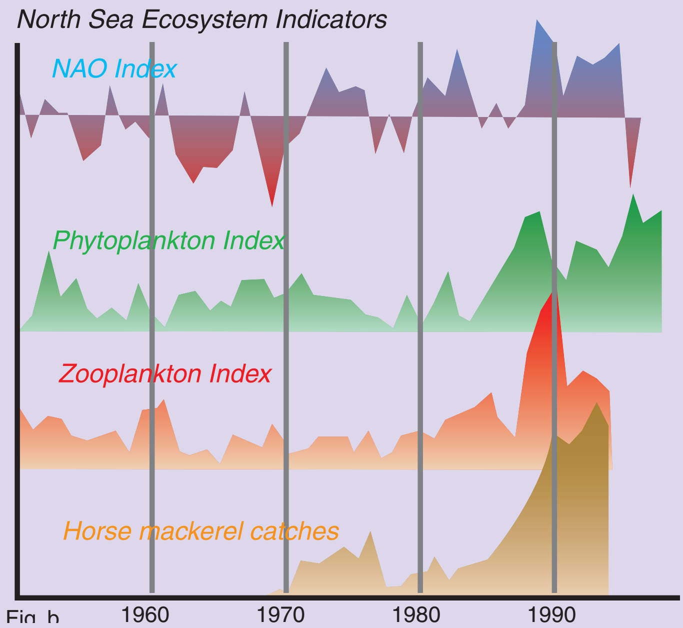
Recent studies have shown that ecosystems can switch states, triggered by small, often undetected, environmental changes. These states are commonly known as regimes. In the North Pacific, Hare and Mantua [1] identified temporally coherent changes in 100 physical and biological time series, demonstrating that a regime shift happened in 1977 (Figure a). They linked the shift to the Pacific Decadal Oscillation, a decadal pattern of climate variability. The shift coincided with an intensification of the wintertime Aleutian Low, year-round cooling of the Central North Pacific, and warming of the coastal Northeast Pacific and Bering Sea. Consequences were decreases in zooplankton off California, Alaskan shrimp and West coast salmon populations, and increases in most Alaskan salmon populations. A second regime shift occurred in 1989, but significantly this was not a simple reversal of ecosystem conditions established after 1977. Regime shifts have also been suggested in other regions. Aebischer et al. [2] observed parallelism between long-term trends in North Atlantic westerly winds and ecosystem components, concluding that this could not have been caused by trophic interactions alone. More recently, changes in the ecology of the North Sea around 1988, coincided with the highest positive North Atlantic Oscillation index for more than a century. Plankton abundances and horse mackerel catches increased sharply ([3]; Figure b). This suggested regime shift coincided with alterations in deep water convection from the Greenland to the Labrador Sea after 1988 and increases in the flow of oceanic water into the North Sea [4]. What causes ecosystems to shift state is unclear. Recently Scheffer et al. [5] postulated that ecosystems may have a reduced number of stable states (Figure c). A small change in environmental or biological conditions may produce an ecosystem collapse, which is not reversed through a simple reversal of the cause. This hypothesis seems to explain the dynamics of marine as well as several terrestrial ecosystems. Climate change, excessive resource exploitation and loss of biodiversity may facilitate such shifts, and will be investigated further during IGBP II.



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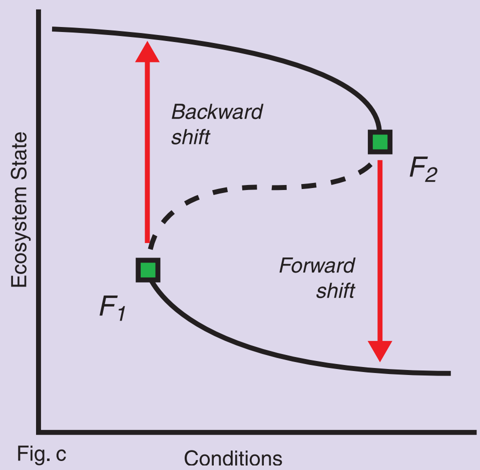

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linkages, interactions and feedbacks between physical forcings, biogeochemical cycles and food webs. They will also collaborate closely with the interface projects, SOLAS and LOICZ.

OCEANS

OCEANS will focus on biogeochemical cycles and marine food webs in the context of the Earth System and global change.

The overarching questions for the developing project are:

- How does global change, represented by changes in natural climatic modalities and anthropogenic forcings, impact marine biogeochemical cycles and ecosystem dynamics?
- How do these impacts alter the mechanistic relationship between elemental cycling and ecosystem dynamics?
- What are the feedback mechanisms to the Earth System from these changes?

OCEANS will seek a comprehensive understanding of the impacts of climate and anthropogenic forcings on food-web dynamics (i.e., structure, function, diversity, and stability) and elemental cycling (i.e., geochemical pathways, transfers, and cycling), including the impacts of underlying physical dynamics of the ocean. It will also strive for mechanistic and predictive understanding of how these linked systems respond to global change resulting from climate modes (e.g. El Niño Southern Oscillation, the North Atlantic Oscillation, etc.) and anthropogenic perturbations, and then feedbacks to climate, ocean physics, and marine resources (Figure 1). A key tool integral to this research is palaeoceanography, including the

Box 2: JGOFS

The Joint Global Ocean Flux Study (JGOFS), conducted during IGBP I, focussed on biogeochemistry and the lower trophic levels of the ocean ecosystem. JGOFS is currently completing its synthesis - the main achievements are:

- More reliable estimates of the global air-sea flux of CO_2.
- Determination of the global distribution, transport and inventory of anthropogenic carbon in the ocean and development of new models of the global carbon cycle.
- Identification of links between large-scale climate patterns, for example, the El Niño-Southern Oscillation (ENSO) and interannual variability in the air-sea flux of CO_2.
- Improved understanding of aspects of marine productivity, such as the role of iron as a limiting micronutrient,
- Improved understanding of the role of diatoms in episodic or seasonal blooms and in subsequent sedimentation
- Identification of the dominant role of microzooplankton in the grazing of phytoplankton.
- Quantification of the seasonal changes in primary production and the subsequent flow of carbon through food webs and export to the deep ocean.
- Detection of variability in plankton species on decadal time scales by long-term observations at time-series stations.
- Demonstration of the role of nitrogen nitrogen-fixing organisms in the nitrogen cycle of the subtropical ocean.
- Clarification of the role of dissolved organic carbon (DOC) in the ocean carbon cycle, its control by bacteria, and measurement of its contribution to export flux.
- Improved understanding of variations in the elemental ratios (C:N:P:Si) of organic matter, and alterations during transport within the ocean interior.
- Development and testing of new ecosystem models using time-series data and global observations from ocean colour satellites.

reliable calibration of proxies for nutrients, productivity, plankton composition, temperature, and other physical changes.

Hot spots and critical domains

Some areas of the ocean are likely to be particularly sensitive to gradual long-term changes in climate, and will be subject to intensive studies. These "hot spots" often occur in critical domains such as continental margins, the mesopelagic zone, intermediate waters, regions of upwelling and deep mixing, high-latitude areas and the sediment-water interface.

The continental margins are a critical boundary because they are most directly relevant to society. For example, input of nutrients, sediments and pollutants are large in these areas and fishing pressure can be intense. These regions are also responsible for significant draw down of atmospheric CO2, release of other climatically active gases and cross-shelf export of carbon with large, but unquantified, deposits of terrestrial carbon along the shelf slopes. There has, however, been little consideration of the role of marine food webs in continental margins that are heavily impacted by fishing activities, and how closely these relate to the biogeochemical cycles in this region. Continental margins are also characterised by a more intense nutrient cycling between the water column and shelf sediments, and can exhibit changes in oxygen concentrations with major effects on chemical and biological processes.

The mesopelagic zone is an important ocean region for decomposition of organic matter and the recycling of nutrients. This region has received little attention in previous research and was identified by JGOFS as a region that we need to study to understand the fluxes of carbon and associated elements in the ocean. It is also an important region for pelagic food webs.

Intermediate water masses of the world's oceans are major storage reservoirs for anthropogenic CO_2. Our understanding of the climate sensitivity of intermediate water mass circulation to climate change is therefore a key issue for future atmospheric CO_2 projections. Accurate representation of the circulation of intermediate-depth water masses and of the ocean's vertical circulation within ocean biogeochemical models represents a challenge for future IGBP/SCOR-WCRP collaboration.

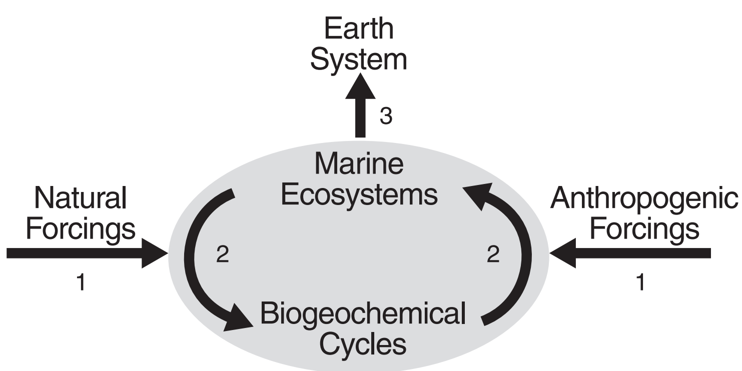

Figure 1. The scientific questions for OCEANS focus on the impacts of natural climatic and anthropogenic forcings on biogeochemical cycles and marine ecosystems (arrows 1), with particular focus on how these forcings alter the relationships between elemental cycles and ecosystems (arrows 2) the feedbacks to the Earth System (arrow 3).

GLOBEC

Closely linked to the objectives of OCEANS, the primary goal of GLOBEC is to advance our understanding of the structure and functioning of the global ocean ecosystem, its major subsystems, and their response to physical forcing so that a capability can be developed to forecast the responses of the marine ecosystem to global change.

The major overarching questions being tackled by GLOBEC are:

- How do multiscale physical environmental processes force large-scale changes in marine ecosystems?
- What are the relationships between structure and dynamics in a variety of oceanic systems?
- What are the impacts of global change on fish population dynamics using coupled physical, biological and chemical models linked to appropriate observation systems?
- How will changing marine ecosystems globally affect the Earth System?

GLOBEC will collaborate closely with the OCEANS project in investigating the impact of global change on food web structure and function. GLOBEC has developed a focus on zooplankton (the assemblage of grazers on phytoplankton), and the primary carnivores that prey on them. Both groups are

Box 3: OCEANS in IGBP II

Ocean research in IGBP II will be carried out by two closely integrated collaborative projects, sponsored jointly by IGBP and the Scientific Committee on Oceanic Research (SCOR). These are the already established Global Ocean Ecosystem Dynamics project (GLOBEC, also sponsored by IOC), which traverses phases I and II of IGBP, and the new project under development, Ocean Biogeochemistry and Ecosystem Analysis project (OCEANS).

Ocean research in IGBP II will also collaborate closely with the Surface Ocean-Lower Atmosphere Study [SOLAS] and the Land-Ocean Interactions in the Coastal Zone [LOICZ] project. Collaboration is being developed with the WCRP, DIVERSITAS and human dimensions communities, including GECAFS and GCP.

The development of OCEANS is well underway. The first meeting of the OCEANS Transition Team was held in April and the scientific background for the Open Science Conference (OSC to be held on 7-10 January 2003) is available on the web at www.igbp.kva.se/obe/. We invite your participation in the OSC, which is designed to gather community input into the development of the OCEANS project. Following the OSC, a Science Plan/Implementation Strategy will be written, so that OCEANS can be launched as a new research activity in IGBP II.

important prey for larval and juvenile fish. Zooplankton form an important route for the transport of carbon up the marine food webs to higher trophic levels and down the food webs in the form of faecal pellets and excretion products. Because of their critical role as prey for larval, juvenile and some adult fish, zooplankton cycles influence and are influenced by fish and fish population dynamics.

GLOBEC is undertaking retrospective analyses, process studies and innovative observational projects and modelling to achieve its objectives. Many of these techniques and their outcomes will be of wider applicability across IGBP II. GLOBEC has a strong regional approach, focussing on key systems in the world ocean, such as upwelling areas, high latitude regions, and the North Pacific and North Atlantic oceans. This approach recognises the different dynamics of each major oceanic area. For example, in upwelling regions the dynamics of lower trophic levels are very different from the interactions seen in spring bloom-dominated ecosystems like those of the North Atlantic and North Pacific oceans. The GLOBEC approach will eventually identify characteristic marine ecosystem types and understand their responses to global changes, highlighting similarities and divergences in their functioning. Identification of "early warning" indicators within and across ecosystem types will assist greatly in the prediction and possible mitigation of the effects of global changes, focusing particularly on zooplankton and fish.

The projects OCEANS and GLOBEC will jointly tackle the central questions of ocean research, which are a prerequisite for furthering our understanding of the whole Earth System. Whether the ocean is understood as a regulator or trigger for the state of the Earth System depends on the quantification and understanding of the connections and interfaces linking land, ocean and atmosphere. A major task of ocean research in IGBP II will be to develop an integrative approach to understanding the holistic dynamics of the planetary life support systems and to better link the future global change ocean research to other components of the Earth System.

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Land-ocean interactions - towards LOICZ II

by H. Lindeboom, C. Crossland and H. Kremer

The world's coastal zone is under extraordinary and increasing pressure from human use and habitation and from changes in global climate. The resources and amenities of the coastal zone are crucial to the societal and economic needs of the global population. While it represents less than 20% of the land surface, the coastal zone presently is: the location of more than half the global population; a major food source (most croplands and much agriculture, most of the global fisheries); a focus of transport and industrial development; a source of minerals and geological products including oil and gas; a location for most tourism; and an important repository of biodiversity and ecosystems that support the functioning of the Earth System.

One of the most important challenges facing society today is maintaining the continuity of human benefits from the goods and services of the coastal domain within the context of increasing uncertainty over the scale and nature of climatic and consequent human impacts on coastal systems (Box 1).

New scientific information is needed to fill critical gaps in our understanding of how coastal systems will react in response to changes in environmental processes and human management interventions. Natural processes and resources, human use and management, structure and transition all contribute to the dynamics of the coastal zone at regional and global scales. We have an urgent need for well-founded decision-making in coastal issues in the context of the Earth System.

Also we must make more effective use of available scientific knowledge to inform and support policy, investment strategies, and planning and management systems that govern human activities, if we are to help meet the allied management challenges facing us in promoting wise and durable use of our coasts.

LOICZ (Land Ocean interaction in the Coastal Zone) addresses these issues, and is currently being developed for a second phase.

LOICZ II

Resources, products and amenities are as heterogeneously dispersed at local and regional scales as the natural settings and processes they depend on. They are subject to changing patterns of availability, quality, limitations and pressures. We now understand that human dimensions and natural systems closely interact and are intimately bound together by the various pressures and resultant state of the coastal domain. Also, it is apparent that existing tools and concepts for measurement and analyses are inadequate to meet the needs for understanding human-nature interactions in these very complex ecosystems.

With these points in mind, LOICZ II should provide a framework for more integrated analysis of existing information and act as a means to focus on key issues concerning human uses of the coastal zone. An important action must be the transfer of information about what is being learned from science assessments that will benefit society.

River basins and human dimensions

Even a pristine coastal area is impacted by human activities that originate in the "hinterland". Activities in river basins change the flow of materials to the coast with impacts on coastal morphology (e.g., sediments) or ecosystems (e.g., nutrients and contaminants). A challenge is to bring together the combined expertise of 'Land' and 'Coast' scientists to study the river basin and coastal zone as one system. It must be recognised that while the major impacts are at the coast, part of the solution lies within the river basin. Also, while most of the benefits of appropriate science-informed management will be gained at the coast, many of the costs will be incurred within the river basin.

An additionally large challenge is disentangling the regional scale cause–effect relationships from those that are derived from much wider external pressures on the river-coast system, such as climate change, population pressure and the global economy. For example, climate-induced changes in hydrology will affect the flow of sediment and water whereas the changes in land cover and use will modify the flow of carbon and nutrients.

Future work will build on and extend the assessment framework (guidelines) for links between major anthropogenic and natural pressures on the coastal zone and the ecosystems changes in catchments. This could include the identification of critical thresholds in coastal systems, the development of "early warning" indicators of change, and model scenarios for basin-coast systems.

Coastal development and change: implications of land- and sea-use

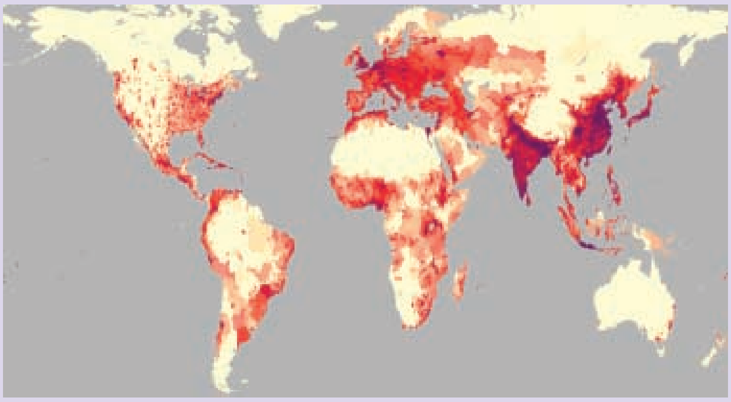
Coastal land is limited and under pressure from human development. With 75 % of the human population expected to be living in the coastal zone by 2025, it is already evident that extreme competition for space is occurring. Driving forces include population pressure, transport and tourism, resulting in increasing urbanisation and transport networks at the expense of natural ecosystems. Examples of spatial issues that have received extensive media coverage are fish farming in sensitive mangrove ecosystems and the local introduction of exotic species due to the increase in shipping. The human footprint on coastal areas will be quantified using natural science and ecological economics indicators including valuation methods.

In addition, thresholds and critical points in the coastal system will be identified. These will (for example) enable assessment of how close we are, through coastal habitat loss, to significant change in regional biogeochemical functions and be used in scenarios to 'design' robust and sustainable coastal systems.

Box 1. Human Influences in the Coastal Zone

The coastal domain of land and coastal seas is influenced by human activities in the maritime seaboard and in river basins where alterations to upland water resources are causing marked changes in the timing, the flux, and the dispersal of water, sediments, nutrients and contaminants. Human influences include:

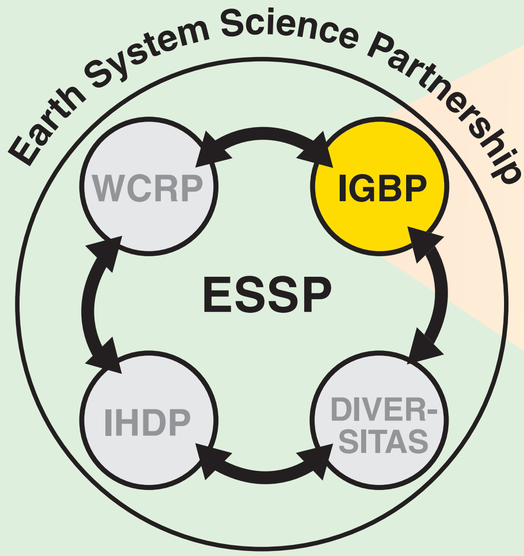
- changes in the timing of when water is transported to the coastal zone, through flood/wave mitigation, via reservoir storage, or entire water diversion schemes;
- changes in the amount of water transported to the coastal zone due to water use for urban development, industry and agriculture;
- regional decreases in the delivery of sediment to the coastal zone through sediment trapping within reservoirs;
- regional increases in the delivery of sediment to the coastal zone through increased soil erosion driven by agriculture, construction (urban development, roadways), mining, and forestry operations;
- changing the flux of nutrients to the coastal zone (e.g., storing carbon within reservoirs; elevated nitrogen flux through agricultural activities);
- building of shoreline engineering structures, ports and urban developments;
- harvesting and often over-harvesting of marine resources;
- increased competition for marine space;
- increased pollutants, contaminants and atmospheric emissions from industries and urbanisation;
- modification of the type and quantity of coastal discharges from surface and groundwater flows;
- alienation of coastal wetlands and ecosystems through land use change; and
- modification of habitat structure and functioning through introduction of non-indigenous species.

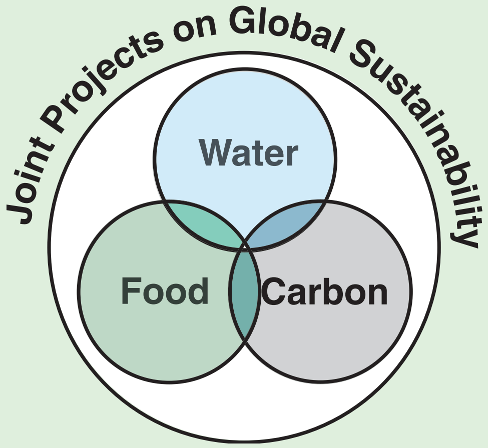


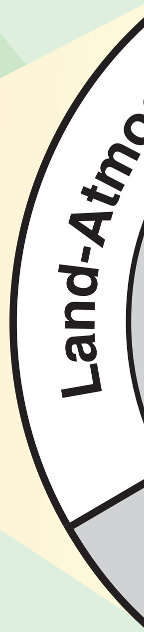
More than half the global population currently live in the coastal zone; this is expected to increase to 75% by 2025.

The consequences of the human impacts in the coastal zone are far-reaching and vital to societal and global functions. These include changes in: ecosystem health and diversity; vitality of coastal wetlands, mangroves, and reefs; coastal stability, biostability and shoreline modification; dispersal area of riverine particulate and dissolved loads; the fate and distribution of materials in coastal and shelf waters; yields of resources and products that sustain society and economies; and uncertainty or diminished options for sustainable development.

*Initial Suggestions







Earth System Science Partnership (ESSP)

The ESSP is a partnership of the 4 global change programmes (IGBP, IHDP, WCRP and DIVERSITAS) for the integrated study of the Earth System, the changes occurring to that system, and the implications of these changes for global sustainability.

Three new 'joint projects' on carbon, food and water – GCP, GECAFS and JWP respectively - are being developed by the programmes. Also under development are 'Integrated Regional Studies' which will be interdisciplinary studies each of which will focus on a region of global importance to Earth System functioning.

IGBP Structure

International Networks

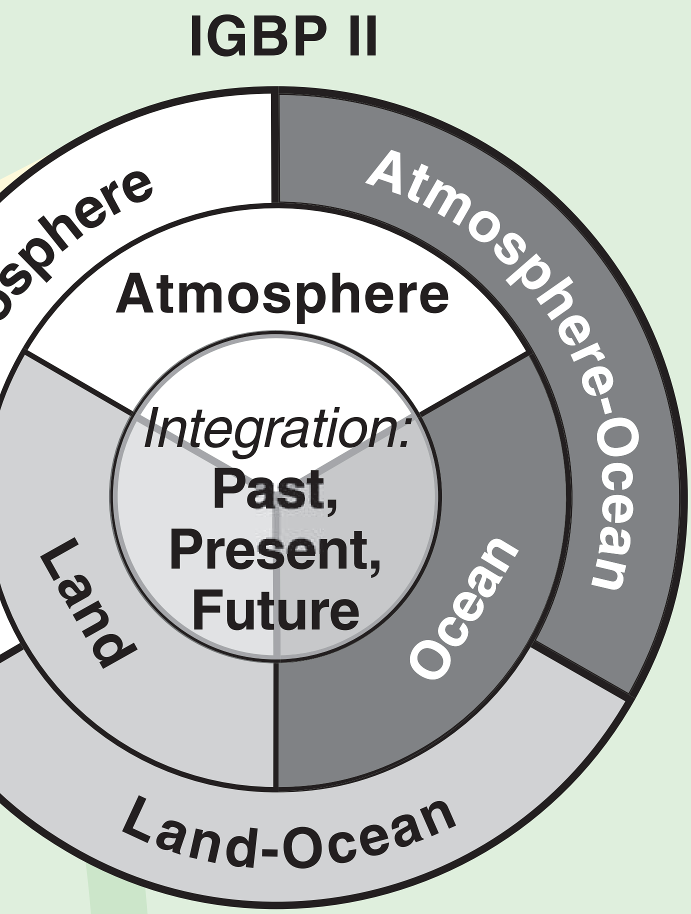
A large number of scientists around the world carry out the research on which IGBP is based. In addition, some provide voluntary support to the programme's research effort. These include scientists who serve on steering committees to guide the overall direction of the programme, researchers who serve as activity leaders to organise networks and implement other integrating activities, and post-doctoral and graduate students who work with IGBP scientists and IPO staff.

IGBP National Committees assist in the national co-ordination of relevant studies, facilitate linkages between national and international global change research, and often assist in the mobilisation of funds to support the central activities of IGBP. At present 80 countries have National IGBP or Global Change Committees.

Support Structure

The International Project Offices (IPOs) of the IGBP projects act as the integration, co-ordination and communication nodes for the individual projects. IPO staff help to initiate and support research networks, raise funds for core project activities, promote and communicate the core project's work, edit and write documents describing the project's achievements, organise workshops and conferences, and support the project's scientific Steering Committee.

The IGBP Secretariat in Stockholm, Sweden, acts as the central integration, co-ordination and communication node for the programme as a whole. The Secretariat implements the decisions of the IGBP Scientific Committee, works with the projects to provide support to the overall research effort, raises funds for



IGBP Organisational Structure

As described in detail in this newsletter, IGBP is moving from its previous scientific structure of eight core projects and two framework activities (including the jointly-sponsored START) to the new structure of 6 projects and 2 integrating activities shown in the figure. The six research activities will be centred on the three major Earth System compartments – ocean, land and atmosphere – and the interfaces between them, with PAGES and GAIM providing the integrative system perspective.

IGBP activities, communicates IGBP's research to a wide variety of audiences (e.g., science, observation, resource management and policy communities), liaises with partner organisations, and administers the IGBP central budget.

Overall scientific guidance and assessment

The Scientific Committee for the IGBP provides the overall scientific guidance for the research programme, develops specific scientific plans, oversees their implementation, and helps to publicise the results. Members are: the Chairs of the IGBP projects and of WCRP, IHDP and DIVERSITAS; a representative of the ICSU Advisory Committee on the Environment (ICSU-ACE) and 15 independent scientists, serving in their own capacity, appointed by ICSU.

A Glossary of Acronyms

BAHC	Biospheric Aspects of the Hydrological Cycle
CACGP	Commission on Atmospheric Chemistry and Global Pollution of the International Association of Meteorology and Atmospheric Sciences
DIVERSITAS	An International Programme on Biodiversity Science
ESSP	Earth System Science Partnership
GAIM	Global Analysis, Integration and Modelling
GCP	Global Carbon Project
GCTE	Global Change and Terrestrial Ecosystems
GECAFS	Global Environmental Change and Food Systems
GLOBEC	Global Ocean Ecosystem Dynamics
ICSU	International Council for Science
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere-Biosphere Programme
IGFA	International Group of Funding Agencies for Global Change Research
IGOS	Integrated Global Observing Strategy
IHDP	International Human Dimensions Programme
IOC	Intergovernmental Oceanographic Commission (of UNESCO)
IPCC	Intergovernmental Panel on Climate Change
JGOFS	Joint Global Ocean Flux Study
JWP	Joint Water Project
LOICZ	Land-Ocean Interactions in the Coastal Zone
LUCC	Land-Use and Land-Cover Change
OCEANS	Ocean Biogeochemistry and Ecosystems Analysis
PAGES	Past Global Changes
SCOPE	Scientific Committee on Problems of the Environment
SCOR	Scientific Committee on Oceanic Research
SOLAS	Surface Ocean - Lower Atmosphere Study
START	Global Change System for Analysis, Research and Training
UNESCO	United Nations Educational Scientific and Cultural Organisation
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation

Human influences in the coastal zone include harvesting and often over harvesting of marine resources.

The changing coastal footprint is also the result of global drivers and pressures and hence management can benefit from the LOICZ assessment across spatial scales, expressed through up-scaling and down-scaling approaches. Collaboration with LUCC and IHDP will greatly enhance the LOICZ effort.

Fate and transformation of materials in coastal and shelf waters

The changes in time and space of material loads (nutrients and sediment), especially from land and atmosphere, affect both the physical condition and function of the coastal seas. Knowledge of the transformation of materials on the continental shelf and the key locations of, for example, biological pumps for CO_2, is still limited. The volume and form (organic, inorganic; reactive, non-reactive) of the materials transferred to the ocean needs quantification, as does the impact of changing nutrient regimes (e.g., C, N, P, Si, Fe) on habitats and food web dynamics. This information is vital to understanding the resilience of and predicting changes in ocean chemical cycles.

The research focus will be on the horizontal and vertical fluxes and processes controlling material loads and transport, and how these are changing regionally and globally. Regional differences will be taken into account to assess why some shelf waters are more resilient or robust to change than others. A key challenge will be the quantification of processes undergoing change, including transport of materials within and across the continental shelf, transformation of materials within the water column and sediments, storage of materials in the coastal zone, and changes in energy levels. For example, the benthic (or sediment-water) interface of coastal seas and shelf waters is known to be a major site of material transformation, but is relatively poorly understood. Research will determine the function and resilience of the benthic interface and the implications of changes on associated trophic and biogeochemical processes, including the assessment of the time frames for material cycling, sequestration and mobilisation.

Towards system sustainability and resource management

Today's society faces a major challenge to maintain the continuity of human benefits from the goods and services of the coastal areas with the increasing uncertainty of climatic and human impacts on coastal systems. Solving the problems of sustainable resource use and access will likely become more difficult as human pressures and system changes progress.

Managing human influences (Box 1) and targeting of sustainable use, needs sound information on actual and predicted options and the valuation of change and options. The limits of marine sustainability, plans for combining goods and services in the coastal zone without irreversible damage to marine nature, and resolution of cross-boundary spatial conflicts associated with coastal zone management are major issues to be addressed.

A key consideration will be more effectively using scientific information to suggest practical solutions and regional-local scale products to fit management/policy needs. LOICZ II will explore the creation of probable “futures” via scenario-building structured around sustainability options, for example, by taking typology approaches further to predict outcomes. This will necessarily include attempting to separate human-induced and natural variability.

From its global perspective, LOICZ can assist in the assessment of coastal management interventions – their effectiveness and socio-economic cost-benefit. A challenge to LOICZ research in this area is to encompass links with management challenges and uncertainties (including models, legal/institutional arrangements and effectiveness). This includes the applications of high-tech tools and capabilities (including remote sensing) to meet advanced monitoring and assessment needs. The integration of policy, management and investment communities into assessment and option developments will also be important.

Risk and safety

Long-term fluctuations and cyclical events impinge upon the environmental and societal condition, going beyond climatic and meteorological forcing to include aspects of socio-economic globalisation. Long time scales need to be addressed, for example, by interpreting sediment cores to develop further ideas of periodicity of events. Moreover, it is becoming clear that we are not necessarily dealing with linear (cause and effect) systems and that our understanding of forcing and responses remains inadequate. Such analyses and approaches that encapsulate natural and human changes can support greater understanding of risk, uncertainty and predictability.

A critical issue in an analysis of the effects of global change on the coastal domain is the role of thresholds in maintaining ecosystem state, in the intensity and frequency of climatic and human forcing and their predictability. What are these thresholds? For a particular scenario, what is the likelihood that a threshold will be crossed? How do we aggregate scales? How long does it take for the effects of local processes to propagate into larger-scale systems (for example, land use practices translating into changed loads to the coastal zone)? Some key issues to be considered include: assessing the risks of environmental impacts caused by changes in socio-economic sectors and natural phenomena; assessing the risks to natural and human capital; the measurement and prediction of sea level change; and examining regional patterns of global climate change, such as trends in storm frequency and intensity.

In addressing these elements,

Box 2: LOICZ II in IGBP II

LOICZ II Structure

Learning from the experience of the current LOICZ, there will be some changes in the scientific objectives (outlined in this article), governance and management to form LOICZ II. There is need for flexibility in task coordination, adaptability to new research questions and approaches for funding, and improved “brokering” or communication of scientific information. Operationally, we need a structure that weaves into the vital scientific networks and regionally dispersed activities. A distributed IPO is planned with nodes in 5 or 6 regions to not only increase the visibility and effectiveness of LOICZ II but also to provide greater opportunities for regional funding in support of research and to increase networking (scientific and sponsors) within regions.

How to get involved

Building on the existing network of predominantly “natural systems” scientists and discussions at a recent international meeting in Miami, a Futures Discussion Document is being widely distributed for additional feedback of comments and ideas. We are particularly encouraged by the number of collaborative inputs from the social and economic scientists (mainly from the IHDP community) – and this expanding human dimensions expertise is crucial to the relevance and effectiveness of LOICZ II. We plan to establish a Working Group of a small and equal number of natural and socio-economic scientists later in 2002 to be the focal point in transforming the Discussion Document into a draft Science Plan. Please contact the LOICZ IPO (loicz@nioz.nl) if you would like to participate in the planning process and check our website (http://www.nioz.nl/loicz/) for immediate scientific linkage opportunities.

LOICZ II must embrace three major conceptual areas: a) that humans are an integral component of the ecology and function of ecosystems; b) that the water continuum of river basin catchments and the coastal ocean is a fundamental unit for coastal assessment and management; and c) that an ecosystems approach is required for coastal zone management.

Clearly, collaboration with IHDP, WCRP and DIVERSITAS is fundamental to the new project and should add an exciting dimension to the work and the networks of researchers needed to meet the coastal research challenges implicit in a LOICZ II project.

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(reflecting discussions of the LOICZ Scientific Steering Committee)

...continued from page 14.

of chemical species with coupled ocean and atmosphere general circulation climate models. Understanding these processes will require the atmospheric chemistry community to work closely with the dynamic meteorologists and programs such as Global Energy and Water Cycle Experiment (GEWEX). Understanding and predicting future emission scenarios will require the atmospheric chemistry community to work closely with the International Human Dimensions Program (IHDP). As our ability to parameterise the processes controlling the distributions of chemical species in the atmosphere improves and GCMs begin to include accurate distributions all the climatically important species, we will have increasing more reliable predictions of how our changing atmosphere is affecting the Earth System.

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Terrestrial human-environment systems: the future of land research in IGBP II

by D. Ojima, S. Lavorel, L. Graumich and E. Moran

Enormous progress has been made in terrestrial global change science in the first phase of IGBP. The projects LUCC and GCTE are at the centre of these achievements, substantially advancing our understanding of the role of land-use change and terrestrial ecosystems in the Earth System.

Over the last decade, LUCC has helped change our understanding of the patterns and drivers of land-use change in a major way. Often, these changes were seen in a fairly simplistic way - as recent, local, spatially homogenous alterations of previously pristine land (mostly forest) to agriculture, largely due to population pressures. We now know that a wide range of different landscape types have been altered by humans for millennia in a heterogeneous way, that driving forces are global and regional as well as local, and that they include socio-economic and political as well as population and biogeochemical triggers. The impacts of these changes are now also recognised as more far-reaching than previously thought, affecting biodiversity, albedo and human health as well as water and biogeochemical cycles.

Through combining research on ecophysiology, vegetation and disturbance dynamics, and land use change projections into the next 100 years, GCTE has shown that current terrestrial carbon sinks are not permanent features, and that they are likely to stop growing, probably diminish, and perhaps even disappear, some time this century. This finding is fundamentally challenging current policies and targets aimed to stabilise the accumulation of greenhouse gases in the atmosphere. In addition, GCTE has developed the mechanistic understanding underlying projections of food production under climate and atmospheric change over the next 100 years, and how changes in biodiversity, largely due to land use change, is altering ecosystem functioning and services critical to human well being.

A small set of joint LUCC-GCTE pilot projects is leading the way towards a unified Land project in IGBP II. For example the joint fire activity aims to foster a new integrated research approach for the study of global change effects and feedbacks in relation to fire regimes. Fire, and its use by humans as a management tool, causes dramatic changes in the structure and function of ecosystems and is now shown to significantly affect atmospheric composition.

Fire, and its use by humans as a management tool, causes dramatic changes in the structure and function of ecosystems and are now shown to significantly affect atmospheric composition.

Box 1: Terrestrial Futures

The Land Project has roots in a scoping document from the IGBP 'Terrestrial Futures' Meeting which took place at the Royal Swedish Academy of Sciences in Stockholm on 21-23 June 2000. The Terrestrial Futures meeting brought together more than 30 researchers representing a variety of disciplines (including geographers, economists, ecologists, and atmospheric scientists representing many of the current IHDP and IGBP projects) and a range of IGBP involvement, ranging from long-term project leaders to 'new blood.' The charge to the group was deceptively simple: imagine the next decade of terrestrial Earth System Science research. Participants were charged with identifying large framing questions which would define the trajectory of land-based research in its own right and to suggest ways that land-based research could contribute to the sustainability issues being tackled by the IGBP-IHDP-WCRP consortium, namely carbon, food/fibre, and water. The Terrestrial Futures document identifies three major questions, namely:

- What is the role of the structure of terrestrial ecosystems in the past, present and future functioning of the Earth System?
- How is the capacity of ecosystems to provide goods and services affected by global environmental change and
- What is the vulnerability of the human-environment condition? How does it change? What are the biophysical and human implications of human use?

The Terrestrial Futures report was an important stepping stone in providing a transition from the original projects to a more integrated study of the human-environment system.

Fire regimes and their effects on terrestrial ecosystems are highly sensitive to global change, particularly climate change and land-use change. For these reasons, the study of fire and how it did, does and will respond to global change will continue to be an important focus for research. The fire activity has already produced a global map of fire regimes synthesising regional information on fire frequency, type and causes. It has also highlighted research priorities for integrated regional research with coordinated socio-economic surveys, biophysical measurement campaigns and modelling exercises.

These research activities form a solid foundation on which to build the new, integrated land project in IGBP II, whose strategy critically emphasises changes in coupled human-environment systems. During the past decade of global change research of IGBP I, emphasis was placed on understanding the separate component processes of the Earth System. In IGBP II, we are better able to focus the research agenda at critical interactions and integrated studies of global change. The research planning thus builds upon the large heritage of IGBP I global networks of scientists, data, and largely disciplinary understanding, which will become the basic components of the evolving integrative science of IGBP II. In addition, this evolution of the research plan strongly promotes the linkage with the research approaches of the IHDP (Box 1).

The focus of the new project will be on land systems which includes the people, biota, and natural resources (air, water, and soil). In addition, the project also interacts closely with the projects studying critical feedbacks and interactions between the land and the atmosphere, and between the land and oceans. The research strategy is thus designed around i) a core of work built on the integration of the GCTE and LUCC projects (and parts of IGAC) of IGBP I and ii) close connections to the land-ocean (LOICZ) and land-atmosphere projects of IGBP II. The legacy of 10 years of research in IGBP I and IHDP core projects, recent efforts in integrated environmental research and methodological developments have opened the opportunity to undertake integrated human-environment system studies in ways not possible in the past.

The next decade of global change research on terrestrial systems will adopt the 'human-environment' paradigm. This implies considering the tight coupling between the functioning of ecological systems and the dynamics of human societies as the key process involved in the response of terrestrial systems to global change and in their feedbacks to the atmosphere and the oceans. The research of this project will primarily focus on the diversity of ecological and human systems on the land surface and on critical vertical and horizontal flows, within terrestrial ecosystems and across to the atmosphere and oceans. The overall objective of the Land project will be to identify, understand and evaluate changes in the tightly coupled system formed by these components, and its critical thresholds of vulnerability at local, regional and global scales. The prominence of vulnerability as an integrating conceptual framework will allow us to move towards understanding the processes of sustainability. To do this, we will address three nested questions (Figure 2) that represent progressive steps towards this urgently needed knowledge:

- What are the drivers and dynamics of variability and change in terrestrial human-environment (T-H-E) systems?
- How is the provision of environmental goods and services affected by changes in terrestrial human-environment systems?
- What are the characteristics and dynamics of vulnerability in terrestrial human-environment systems?

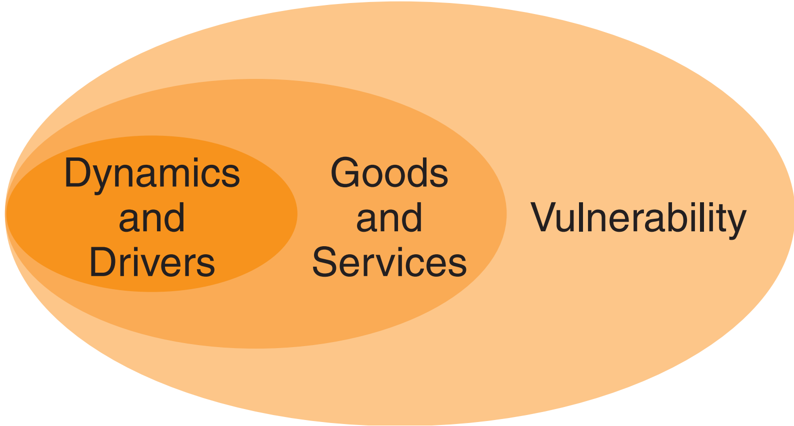

Figure 2. Three nested issues need to be addressed to understand and evaluate terrestrial-human-environment systems.

The novel approach of the project will reside in the integrative nature of the research, which will crystallise with the implementation of a set of integrative themes, regional studies and global syntheses, and a concerted effort in education and training on integrative science and synthesis. Most fundamentally, the guiding questions will consider the terrestrial human environment within a common integrated framework from the onset of project development rather than adding post hoc integration to separate human and biophysical questions. While specific questions will vary widely in the relative emphasis on human and environmental systems, all foci will begin with coupled or integrated questions. Integration will be achieved by involving simultaneously, or where necessary creating human and environmental research components in an interactive manner. Disciplinary research and networks will be the building components of the integrative framework and will be supported and encouraged as needed by the new project.

This approach will require the continued development of appropriate tools and knowledge to detect environmental change; to attribute the causes and underlying mechanisms of impacts and feedbacks, and to develop the capabilities to predict future trajectories of provision of ecosystems goods and services and of resulting vulnerability of T-H-E systems. These fundamental developments will be fostered by a series of research elements structured according to the main classes of processes in terrestrial human-environments, including biogeochemical cycling (e.g. N_2O fluxes to the atmosphere, nutrient loading on river systems), the response and effects of biodiversity (e.g., effects of functional diversity on ecosystem productivity), biophysical phenomena (e.g., landscape effects on mesoscale climate, soil erosion and changes in sediment delivery to the coastal zone), human decision-making (e.g., demographic and socio-economic dynamics). These elements will form the grass roots of the project and will also contribute towards integrating within IGBP and IHDP, and within the ESSP (e.g., the joint research projects on carbon, food and water), or with other programmes (e.g., Millennium Ecosystem Assess-

Box 2: Land research in IGBP II

The development of the new terrestrial system Science Plan continued at a meeting held in Fort Collins, 21-23rd January 2002. The objective of this meeting was to develop a draft set of scientific questions and an initial draft research strategy for the next 10 years of land-centric research that interfaces with the current research activities within IGBP II and IHDP. The meeting was attended by scientists associated with and/or having expertise on research related to GCTE, LUCC, IGAC, BAHC/GEWEX, and START. Four co-chairs have been assigned to lead the transition planning process: Dennis Ojima, Sandra Lavorel, Lisa Graumlich and Emilio Moran.

The new land project will largely rely on the body of research and international coordination networks established by IGBP I and other global environmental programs. In addition, it will create new structures to support the conceptual and tool development for the frameworks on integration, goods and services, and ecosystem vulnerability.

When established, the project will be driven by a SSC who will be made up of a combination of integrator scientists associated with the various research themes and scientists with critical links to the more disciplinary studies and networks that have been established during IGBP I, as well as scientists from other networks.

LUCC and its International Project Office will continue to operate until October 2005. The current GCTE will phase out by the end of 2003, though the IPO in Canberra will phase out by the end of 2002. Discussions are under way to establish a new IPO and research support office for the land project by the beginning of 2003.

ment). Within the project they will provide building blocks to tackle a series of research themes identified as critical challenges to T-H-E systems. The themes will form a dynamic set through time, selected according to scientific and stakeholder priorities and to feasibility. They will also be dynamic in focus, as research on each theme will have the opportunity to progress through the nested series of research questions. The selection of an initial list of research themes and process elements will be a critical part of the implementation of the project. Research themes may be selected to advance one or more of the three questions, to provide integrated knowledge about critical phenomena for T-H-E systems and vital components of sustainable development, or to supply results for joint research projects of IGBP. They will be investigated within a global scope, based on strong networks of individual sites at which genuine integrated research is conducted.

Several other aspects of integration will guide the project operationally. First, integrative-place-based research will form one of the cores of the program. Past successful experience shows the value of bringing together researchers from a range of disciplines to work together in a specific place. Simultaneously we will pursue global integration. While many questions will indeed be addressed through targeted local-regional studies, global integration will be achieved through networks, common protocols, models, workshops and data syntheses. While the maturation of process, place-based and network studies will occur at different rates, all projects will be encouraged to pursue strategies of continuous integration and synthesis. In addition, specific activities and research groups will be established to conduct synthesis and integration at the global level.

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Exploring the land-atmosphere system in IGBP II

by P. Kabat, M. Andreae and A. Arneth

Atmospheric processes, such as physical climate variability and chemical deposition, are major constraints on both natural and anthropogenic terrestrial biogeochemical cycles. For example, interannual variability in carbon uptake at ecosystem, regional, and global scales is strongly influenced by variation in climate and by the related feedbacks to physiology and productivity. The deposition of gases and aerosols from the atmosphere can also strongly influence ecosystem functioning, sometimes acting as fertilisers and sometimes as toxic substances.

Our understanding of the processes underlying the atmosphere-land interface has evolved rapidly during recent years. But what is perhaps more important in the context of IGBP II is that there is also a gradual shift in the broader perception of land-atmosphere interactions that is currently – and finally- taking place. The land biosphere itself, and the way humans are using it, that will strongly feedback to the physical and chemical composition of the atmosphere. Many processes taking place on land cannot be viewed independently from what is happening in the atmosphere. But indeed atmospheric chemical and physical properties themselves are directly determined by the terrestrial biosphere, including humans. Thus, the evolving perspective within the Earth System science community is to view the land-atmosphere interface as a system, defined by intricately linked processes and dependencies that have important implications for the functioning of the earth as a whole.

Goal of the new land-atmosphere project

Broadly speaking, the goal of a new project focused on the land-atmosphere interface is to answer the questions:

- How do interacting physical, chemical and biological processes transport and transform energy and materials through the land-atmosphere system?
- What are the implications for the dynamics of the Earth System?
- How are human activities influencing the land-atmosphere system (and vice versa)?

These broad questions encompass several more specific issues that provide stimulating challenges for the community in the years ahead.

The importance of land-atmosphere interactions

As shown in Figure 1, the main determinants of the coupled atmosphere – terrestrial biosphere system are energy partitioning, cloud processes, and aerosol and trace gas exchanges. For example, land cover type has been demonstrated to constrain the regional build-up of clouds and precipitation patterns [1] at the landscape scale and has even been implicated in the changing dynamics of the Asian Monsoon System [2].

The vegetation cover also may influence climate via atmospheric aerosols. Recent work in the Amazon shows that in the wet season the balance of natural sources and sinks of cloud condensation nuclei (CCN) is almost identical to marine values [3], which challenges our perception of continental regions normally to be ‘CCN-unlimited’. A large fraction of the CCN present over Amazonia turns out to be directly of biogenic origin. This implies that the vegetation itself may play a key role in influencing regional precipitation patterns, which in turn, of course, influences the distribution and functioning of the vegetation - classic systemic behaviour.

An even more intriguing example of land-atmosphere interaction also comes from the Amazon Basin, where the terrestrial biosphere plays an important role in governing the oxidation capacity of the tropical atmosphere. The budget of ozone and the main tropospheric oxidant, the OH radical, is controlled by the interplay of hydrocarbons and nitrogen oxides (NO_x), as well as by convection dynamics. The magnitude and direction of the fluxes of chemically active hydrocarbons and NO_x are determined by the type of ecosystem present and its physiological state; land

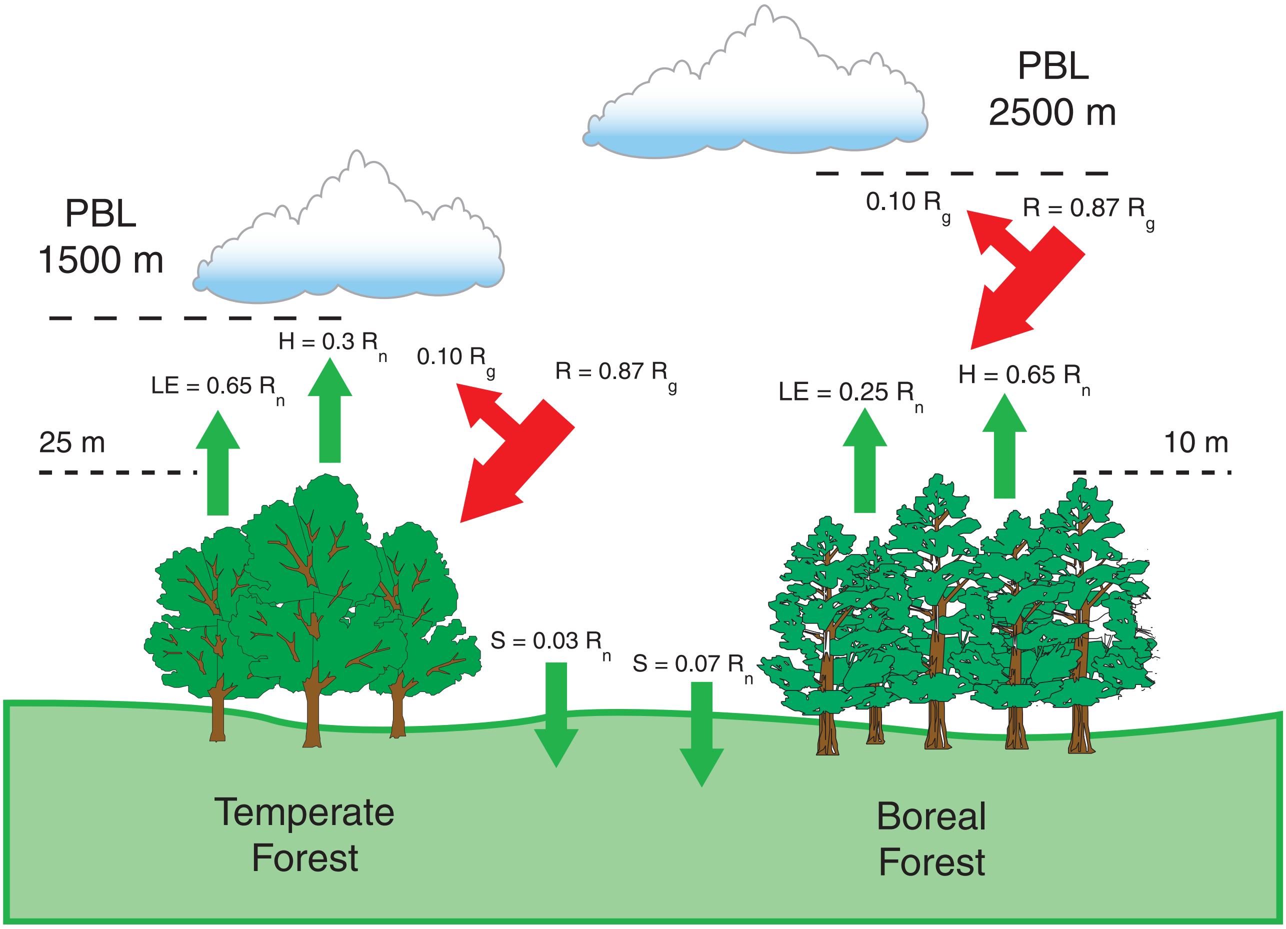

Figure 1a. A typical vegetation-atmosphere interaction via the surface energy balance: net radiation (R_n) is distributed towards latent heat flux (lE) + sensible heat flux (H) + soil heat flux (S); the relative magnitude of these fluxes depending on the vegetation (via canopy conductance, or canopy structure and roughness). In the given example (coniferous) boreal forests distribute ca. 25% of radiative energy towards transpiration whereas (broadleaf) temperate forests may use 65% for transpiration. The convective boundary layer developing over these surfaces reflects the, in turn the, higher sensible heat fluxes over boreal forest, which influences cloud activity and precipitation patterns and which will thus feedback onto the partitioning of energy into H and lE. The vegetation-atmosphere interaction is (at least) two-fold: short-term, via energy partitioning in response to weather (i.e., via stomatal control) and long-term (potential natural vegetation evolving with respect to the regional climate but also shaping the regional climate). Figure after Baldocchi, personal communication.

use change is thus expected to have a major impact on the photochemical functioning of the tropical atmosphere. Furthermore, moisture transfer between soil, vegetation and atmosphere strongly influences convection dynamics. Because of the strong non-linearity of the photochemical process chains, changing convection dynamics is likely to have a pronounced effect on the chemical state of the tropical atmosphere.

At larger scales, runs with fully coupled climate – carbon cycle models that contain dynamic vegetation modules indicate that there may be a positive feedback between climate change and CO_2 concentration, such that CO_2 concentration and global temperatures increase above the levels predicted with (select) IPCC scenarios when vegetation dynamics are considered [4]. These are, however, only preliminary results as the coupled models are not yet representative of the 'real' Earth System. The human component is, for example, not considered adequately with likely important implications for the model outcomes as all land-atmosphere interactions are modulated by anthropogenic land use changes and emissions.

Continued on page 45...

The Earth System Science Partnership

by A. Larigauderie

The need to understand our planet has motivated scientists to develop world-wide linkages and working partnerships. Four major programmes, linked through ICSU and its partners, identify scientific priorities and provide a framework for these efforts: IGBP, WCRP, IHDP and DIVERSITAS (Box 1). These four programmes have recently joined together to form a new partnership, the 'Earth System Science Partnership'.

The major findings carried out under the auspices of these four programmes have been summarised in the Amsterdam Declaration on Global Change, a statement drafted by the leadership of the four international global change research programmes at the Global Change Open Science Conference in Amsterdam (July 2001) and formally endorsed by a strong majority of the Conference participants:

- The Earth System behaves as a single, self-regulating system comprised of physical, chemical, biological and human components. The interactions and feedbacks between the component parts are complex and exhibit multi-scale temporal and spatial variability. The understanding of the natural dynamics of the Earth System has advanced greatly in recent years and provides a sound basis for evaluating the effects and consequences of human-driven change.
- Human activities are significantly influencing Earth's environment in many ways in addition to greenhouse gas emissions and climate change. Anthropogenic changes to Earth's land surface, oceans, coasts and atmosphere and to biological diversity, the water cycle and biogeochemical cycles are clearly identifiable beyond natural variability. They are equal to some of the great forces of nature in their extent and impact. Many are accelerating. Global change is real and is happening now.
- Global change cannot be understood in terms of a simple cause-effect paradigm. Human-driven changes cause multiple effects that cascade through the Earth System in complex ways. These effects interact with each other and with local- and regional-scale changes in multidimensional patterns that are difficult to understand and even more difficult to predict. Surprises abound.
- Earth System dynamics are characterised by critical thresholds and abrupt changes. Human activities could inadvertently trigger such changes with severe consequences for Earth's environment and inhabitants. The Earth System has operated in different states over the last half million years, with abrupt transitions (a decade or less) sometimes occurring between them. Human activities have the potential to switch the Earth System to alternative modes of operation that may prove irreversible and less hospitable to humans and other life. The probability of a human-driven abrupt change in Earth's environment has yet to be quantified but is not negligible.
- In terms of some key environmental parameters, the Earth System has moved well outside the range of the natural variability exhibited over the last half million years at least. The nature of changes now occurring simultaneously in the Earth System, their magnitudes and rates of change are unprecedented. The Earth is currently operating in a no-analogue state.

In what follows, I review some of the steps which have led to the establishment, in July 2001, of the Earth System Science Partnership (ESSP) as a follow-up to the successful Amsterdam meeting, and in the spirit of the Amsterdam declaration.

Towards a new contract between science and society

The establishment of the ESSP corresponds to a need to do science in a more integrative way, and to contribute to the design of science-base solutions to global environmental problems.

An example borrowed from marine microbiology illustrates my first point about the need for a more integrative approach to

Box 1: The four partners of the Earth System Science Partnership

IGBP - International Geosphere-Biosphere Programme

IGBP's overall scientific objective is focussed on improving our understanding of global biogeochemistry and the changes that are occurring to these cycles. It aims to undertake a systems analysis of Earth's composition and dynamics, focusing on the interactive biological, chemical and physical processes that define Earth System dynamics, the changes that are occurring in these dynamics, and the role of human activities in these changes. See the IGBP website at: www.igbp.kva.se

WCRP - World Climate Research Programme

WCRP's objectives are to determine to what extent climate can be predicted and assess the extent of human influence on climate. It carries out fundamental research into understanding the basic behaviour of the physical climate system, in particular: improving our knowledge of global and regional climates; assessing the evidence of significant trends in global and regional climates; developing and improving mathematical models capable of simulating and assessing the predictability of the climate system; investigating the sensitivity of climate to possible natural and human-induced stimuli; and estimating the changes in climate likely to result from specific disturbing influences. See the WCRP website at: www.wmo.ch/web/wcrp/wcrp-home.html

IHDP - International Human Dimensions Programme on Global Environmental Change

IHDP aims to describe, analyse and understand the human dimensions of global environmental change. IHDP's programme is designed around its three main objectives of research, capacity building and networking. Research on the human dimensions of global environmental change is concerned with the causes and consequences of people's individual and collective actions in terms of the ways in which human activities affect the environment, the socio-economic impacts of global environmental change and the individual and societal responses to those changes. All IHDP research activities and joint projects are guided by four overarching themes: vulnerability/resilience; thresholds/transitions; governance; learning/adaptation. See the IHDP website at: www.ihdp.org

DIVERSITAS - an international programme on biodiversity science

The mission of DIVERSITAS is two fold : (i) to promote integrative biodiversity science, linking biological, ecological and social disciplines in an effort to produce socially relevant new knowledge; and (ii) to provide the scientific basis for an understanding of biodiversity loss, and to draw out the implications for policies for conservation and sustainable use of biodiversity. DIVERSITAS achieves these goals by synthesising existing scientific knowledge, identifying gaps and emerging issues of global importance, promoting new research initiatives, building bridges across countries and disciplines, investigating policy implications of biodiversity science, and communicating these to policy makers and international conventions. See the DIVERSITAS website at: www.icsu.org/diversitas

global change issues [1]. W. Wilson, of the UK Marine Biological Association in Plymouth has isolated one virus which attacks *Emiliana huxleyi*, the algae causing the huge blooms which turn patches of the North Atlantic Ocean milky white. When infected algae cells die, they release dissolved organic matter, and could thus influence the microbial loop and the carbon cycle. When viruses kill off algal blooms, large quantities of dimethylsulfide (DMS) gas is released into the atmosphere. DMS stimulates cloud formation, increasing the proportion of solar radiation reflected back into space, which can have a dramatic cooling effect on climate. A millilitre of sea-water contains about 10 million of these viruses, and we do not know what most of them do. Yet, they may be crucial to revealing how our planet works.

This shows that as science progresses, new bridges need to be built across disciplines, to understand our life support system and how we are impacting it, from virus diversity to cloud formation. This is one important aim of the ESS-P.

This brings me to my second point, on providing science-based solutions.

Proofs of global change are starting to abound (loss of species, global warming, sea-level rise, etc.), and their consequences for human beings are becoming better documented in the media (eg economic losses resulting from invasive species). Yet, this has resulted in very few concrete actions at the international level (exception: ozone). This has made scientists realise that they must go beyond a description and understanding of natural phenomena, such as, for example, the impact of invasive species on ecosystem functioning or the impact of global warming on plant communities, and become involved in the design of science-based solutions. This is another important aim of the ESSP: designing economic and legal motivators for a more sustainable use of our resources, based on the best available science.

Past collaboration between the four partners

In addition to the successful Open Science Conference last year, a number of joint activities, described below, have developed in a "bilateral" way over the years between various pairs of these four programmes. The Earth System Science Partnership formalises these joint efforts, and moves the partnership further, towards integrated projects with jointly drafted research questions.

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The Global Carbon Project: linking the biophysical and human components of the carbon cycle

by K. Hibbard and M. Raupach and J. Canadell

The dynamics of the global carbon cycle have been driven by an increasingly complex array of drivers and controls over time. Before major human intervention, the carbon cycle was driven by climate variability and the internal dynamics of the linked land-ocean-atmosphere system (Figure 1). However, from about 200 years ago, industrialisation and accelerating land-use change increased the complexity of the carbon cycle by adding a new stock – fossil fuel. Although society was aware of the changes, it has not been until the last two decades that humans have begun to realise that changes in climate change and variability (through changes in the carbon cycle and other greenhouse gases) may significantly affect their welfare as well as the functioning of the Earth System. Now the development and implementation of institutions and regimes to manage the global carbon cycle adds a new set of feedbacks in the global carbon cycle.

The scientific community is now embracing the challenge of monitoring, understanding and predicting the evolution of the carbon cycle in the context of the whole Earth System with all its multiple physical, chemical, biological and human components. This demands new scientific approaches and syntheses that cross both disciplinary and geographic boundaries, with particular emphasis on the carbon cycle as an integral part of the human-environment system. The resulting combined IGBP-IHDP-WCRP project is called the Global Carbon Project (GCP).

The goal of the GCP is: to develop a complete picture of the global carbon cycle, including both its biophysical and human dimensions, together with the interactions and feedbacks between them.

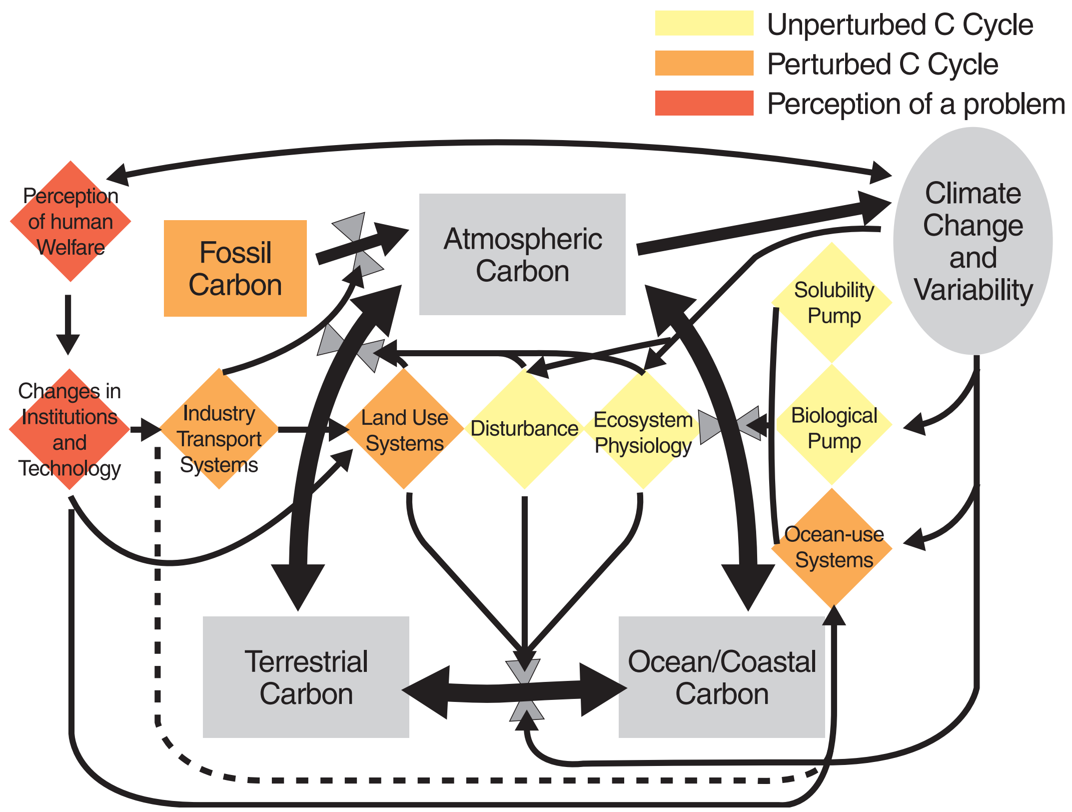

Figure 1. The global carbon cycle: (a) during the glacial-interglacial periods (unperturbed C cycle), (b) with industrialisation and rapid land use change, but no human perception of potential problem (perturbed C cycle), and (c) Human perception of a problem and measures are implemented to address it via scientific and institutional methods .

Carbon

The goal will be achieved by determining and explaining:

1. Patterns and variability: the current geographical and temporal distributions of the major stores and fluxes in the global carbon cycle.
2. Processes, controls and interactions: the underlying mechanisms and feedbacks that control the dynamics of the carbon cycle, including its interactions with human activities.
3. Future dynamics of the carbon cycle: the range of plausible trajectories for the dynamics of the carbon cycle into the future.

These scientific goals will be achieved by working in partnership with a number of existing national and international carbon projects, and sponsor programmes to:

- synthesise our understanding of the global carbon cycle;
- develop a multi-constraint research framework to utilise the many data-streams and process understanding generated by multiple disciplines;
- develop new methods and frameworks to couple the biophysical and human dimensions of the carbon cycle;
- identify gaps in the present research effort on the carbon cycle, and seek means to fill them;
- play a coordination role among the multiple national and regional carbon projects, and link them to the study of the global carbon cycle.

Over a time frame of 10 years, the GCP is planning to deliver:

- Improved knowledge of current patterns, mechanisms and future projections of carbon sources and sinks, at space scales from global to regional;
- A systemic framework, implemented in a suite of linked models, of the coupled biophysical and human interactions controlling the carbon cycle;
- Improved coordination between the research, monitoring and assessment communities working on the carbon cycle, leading to a capability for rapid assessments and responses to trends in the carbon cycle.

To start addressing this challenging research agenda, the GCP is organising a workshop on “Coupling biophysical and human dimensions of the carbon cycle” in Tsukuba, Japan, November 2002. The workshop will explore possibilities for coupling biophysical and human dimensions (including techno-

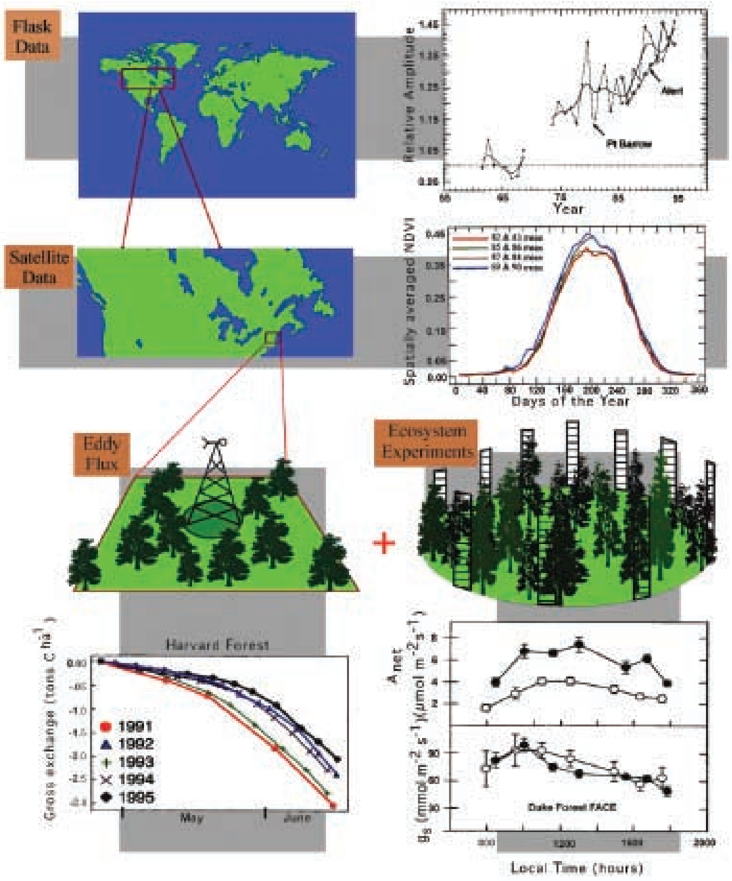

Figure 2. Understanding processes and patterns at multiple scales in space and time through observing systems, field experiments and modelling studies (Canadell et al. 2000. Ecosystems 3: 115-130)

Box: Planning and implementation

The GCP Scientific Steering Committee is: Mike Raupach (co-chair, Australia), Oran Young (co-chair, USA), Robert Dickinson (co-chair, USA), Mike Apps (Canada), Alain Chedin (France), Chen-Tung Arthur Chen (China), Peter Cox (United Kingdom), Ellen R.M. Druffel (USA), Chris Field (USA), Louis Philip Lebel (Thailand), Anand Patwardhan (India), Monika Rhein (Germany), Patricia Romero (Mexico), Chris Sabine (USA), Riccardo Valentini (Italy), Yoshiki Yamagata (Japan).

Organisation of the GCP to date has been supported by the IGBP/GAIM office and the Institute for Earth Oceans and Space in Durham, NH, USA; and the IGBP/GCTE office in Canberra, Australia. International Research Offices for the GCP will be located in Australia, Japan, Europe and the USA. The Australian office is already operating (shared with GCTE during 2002), with the remaining offices expected to be established over the next five months.

For further information e-mail Pep Canadell (pep.canadell@csiro.au.) or check the website http://www.globalcarbonproject.org

logical solutions) utilising low dimension models (e.g., intermediate complexity models) or simpler ones, and agent-based models to study interactions and the effects on atmospheric CO_2.

The GCP is also beginning work on the complex issue of carbon source/sink patterns and processes. Global biogeochemical research must increasingly address the problems of "detection" or quantification of changing fluxes to the atmosphere, and "attribution" or explanation of those fluxes in terms of specific mechanisms (Figure 2). Today, neither our measurement nor analysis capabilities are sufficient to meet the twin challenges of biogeochemical detection and attribution with sufficient accuracy and resolution. To tackle this issue, a summer school took place in May 2002 at the National Center for Atmospheric Research in Colorado, USA. The goal of the school was to advance both analysis techniques (inverse and assimilation modelling) and observing system design. This will be followed by a major state-of-the-art synthesis in partnership with SCOPE in January 2003 in Brazil, where major gaps and research needs will be identified and addressed by the GCP over the following years.

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on behalf of the GCP Co-Chairs and Executive Officers

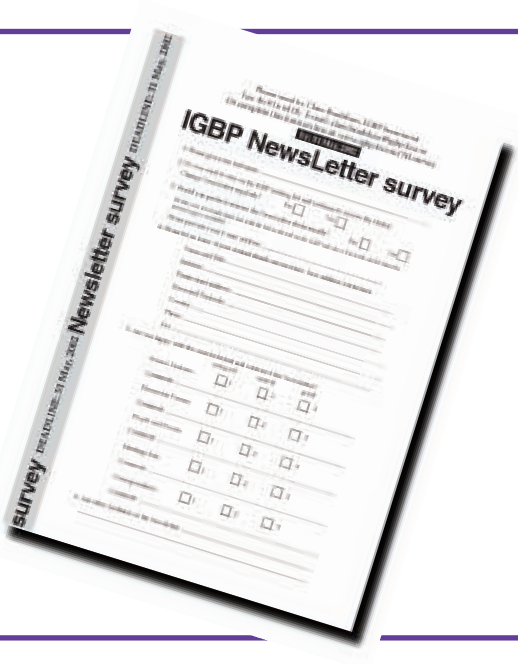
NewsLetter Survey

We have received over 1000 replies to NewsLetter Survey sent out in the March edition!

Thank you all for your overwhelmingly positive feedback. If you have not yet replied, it is not too late to fill in the online form at

http://www.igbp.kva.se/NLsurvey/

Those of you who requested electronic copies only will do so, starting with the next edition.



Global Environmental Change and Food Systems

by J. Ingram

Given changing demands for food, how will Global Environmental Change (GEC) additionally affect food provision and vulnerability in different regions and among different social groups?

How might different societies and different categories of producers adapt their food systems to cope with both GEC and changing demands?

What would be the environmental and socioeconomic consequences of adaptations to these changes?

Understanding the links between food systems and GEC captured in these questions is fundamental to societal well-being over the coming decades, and is thus of keen interest to policymakers and society at large. The research agenda they prompt is therefore of particular interest to IGBP II and its partner programmes, IHDP and WCRP, and will form a key aspect in the developing Earth System Science agenda.

Research by the Global Environmental Change community over the past few years has made many important advances in understanding how GEC affects food productivity. In IGBP, GLOBEC studies have improved our understanding of the effects of GEC on the abundance, diversity and productivity of zooplankton (the most important prey for the larval and juvenile stages of fish), and the consequent effects on fish stocks. GCTE studies in agroecology have provided key insights into global change impacts on the potential yield of major crops (notably the interactive effects of temperature and elevated CO_2). GCTE studies have also clearly identified where further research is needed on the interaction between these key GEC parameters and other factors which, collectively, dictate the harvestable yield (e.g., pest and disease issues, and crop management); exciting new approaches based on cropping systems are now being developed. WCRP-CLIVAR (Climate Variability and Predictability) studies have meanwhile given new insight into how climate and climate variability may change, and this work is now being linked with crop modelling by START-CLIMAG (Climate Prediction and Agriculture) and others to develop better ways of capitalising on the newly-forthcoming seasonal weather predictions to improve agricultural productivity. The social sciences have also made important progress in IHDP and the overriding effects of institutions, changes in food consumption patterns, the variation in vulnerability and adaptation capacity, and the influence of scale have been identified as key issues. These substantial advances have greatly increased our understanding of how GEC will affect food productivity and pave the way for broader analyses of GEC impacts on food production. In developing new areas of interdisciplinary research we however need to think beyond productivity and production – of ultimate interest is food *provision*, a concept which also considers notions of availability of, and access to food (see Box 1).

The three questions above, especially when couched within the broader concept of "provision", set the scope for three inter-related Science Themes which are being developed within Global Environmental Change and Food Systems (GECAFS), one of the new "Joint Projects" (see Figure 1). Collectively, the Themes address the overall GECAFS goal: **"To determine strategies to cope with the impacts of Global Environmental Change on food provision systems and to analyse the environmental and socioeconomic consequences of adaptation".**

Box 1: Food Provision

Food provision is more than food production; it also depends on the availability of and access to, food:

Production	=	*f* (yield x area)
Availability	=	*f* (production x distribution)
Access	=	*f* (availability x economic potential)
Provision	=	*f* (Production, Availability, Access)

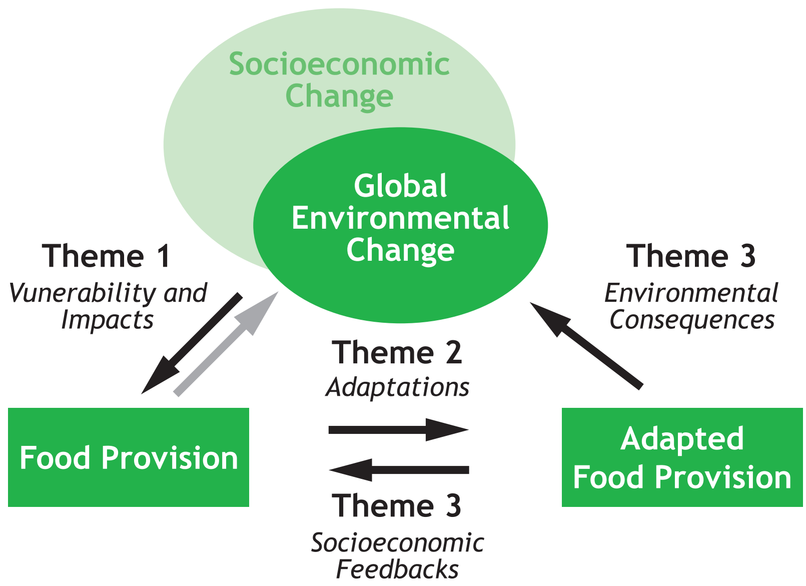


Figure 1. A diagrammatic representation of the three GECAFS Science Themes with respect to GEC and food provision systems. The context of changing socioeconomic conditions, and the feedbacks of current food provision systems to GEC, are depicted in grey with the main features of GECAFS shown in black.

Box 2. Examples of new areas of science

- Methodologies for policy analysis of environmental and socioeconomic tradeoffs in food systems.
- Analyses of changing human wealth and food preferences and interactions with biophysical models of GEC to produce new insights into regions where food provision may be sensitive to GEC.
- Methodologies that allow the appropriate level of aggregation of small-scale food production systems and disaggregation of global-scale scenarios and datasets to address regional- and sub-regional issues.
- Comprehensive scenarios of future socioeconomic and environmental conditions.
- Use of past records of societal adaptations to biophysical changes to provide inputs to scenario-based models of the future.
- New analysis and insights into the institutional factors that can reduce societal vulnerability to GEC.
- Developing indices of the vulnerability of food provision systems to GEC.

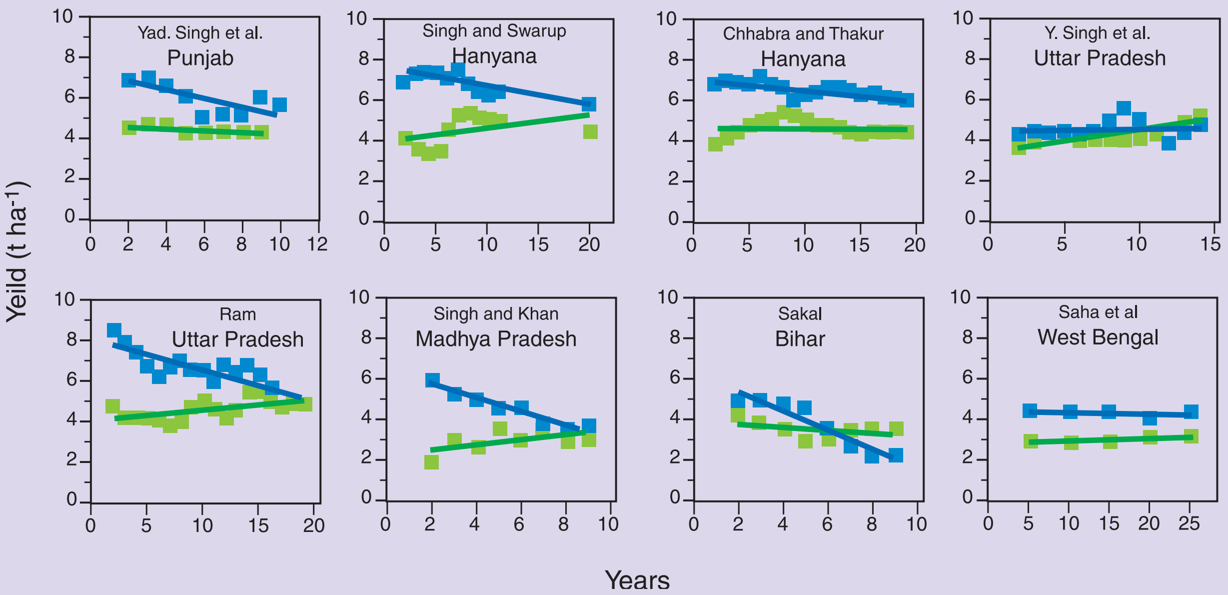
The interactions between GEC and the broader concept of food provision involve many complex issues spanning natural, social and climate sciences. Important though disciplinary studies of GEC impacts continue to be, GECAFS will be broader in scope, explicitly including studies on how food provision systems could be adapted to the additional impacts of GEC and the consequences of different adaptation strategies for both socioeconomic conditions and environment. By including consideration of both "impacts" and "feedbacks", there is a strong link to Earth System Science.

In addition, the juxtapositioning of social, economic, climate and biophysical sciences in GECAFS offers a fertile prospect for developing new areas of science as these often develop at the boundaries of supposedly "separate" sciences. Some examples of new areas of science likely to be developed by GECAFS have already been identified (see Box 2). The three inter-related science Themes provide an innovative framework that can develop and harness these new areas of science to address societal concerns. To this end GECAFS has begun to develop a set of complementary projects. Three topics are initially under development: (i) an arable food system principally established to satisfy local demand (the rice-wheat rotational cropping system typical of the Indo-Gangetic Plain: Box 3); (ii) a food system largely dependent on imports (the Caribbean food system); and (iii) a fisheries-based food system closely linked to both local and export markets (coastal fisheries). Further studies are envisaged.

The GECAFS framework offers a new approach to global change science. Building on work within the three sponsoring Pro-

Box 3. Example of possible research questions for the GECAFS project on GEC and the Food System of the Indo-Gangetic Plain

The rice-wheat rotational system is central to food provision across the Indo-Gangetic Plain (IGP). There is however growing evidence that there is overall yield stagnation and that productivity of the system (especially the rice component) is even declining in some areas; an assessment of 11 long-term rice-wheat experiments (ranging from 7-25 years in duration) from the region indicates a marked yield decline of up to 500 kg^{-1} ha^{-1} yr^{-1} in rice in nine of the experiments [1]. Continuation of these trends will have serious implications for food provision, local livelihoods and the regional economy. As a given season's weather is a major determinant of yield (due to both the direct effects on crop growth and indirect effects related to management), there is concern that changes in climate, especially related to changes in climate variability, will exacerbate the observed trend. Moreover, other analyses [2] show that the highly-intensive production approach currently practiced in large parts of the region is a major source of greenhouse gases, while the current irrigation practice is having serious negative effects on local water tables, ground water quality and quality of the natural resource base.



Yield trends for rice (■) and wheat (■) in long term rice –wheat experiments. Redrawn from Duxbury et al. (2000) [1].

As the IGP food system is both threatened by global change and contributes to further global change "forcing", research is needed to help develop policy and agronomic strategies to (i) sustain production, especially in the face of potential increased climate variability and degradation of land and water resources; and (ii) promote production systems which enhance environmental and socioeconomic conditions. Due however to the marked socioeconomic and biophysical differences across the region, a single approach is not appropriate.

The eastern region of the IGP is a food deficit region characterised by low productivity, low inputs of fertiliser and water, risk of flooding, poor infrastructure and an out-migration of labour. Interdisciplinary research will be developed to address questions such as:

- Theme 1: How will climate variability affect vulnerability to flooding within the region?
- Theme 2: What are the market opportunities and management options for diversifying crops (e.g., legumes, aquaculture) to make more effective use of flood and groundwater?
- Theme 3: How will this effect crop intensification, diversification, labour migration, the interregional movement of food grains and water quality and river flow?

In contrast, the western region is a food surplus region characterised by higher investment, high productivity, major use of fertilisers and ground-water for irrigation, and an in-migration of labour. Interdisciplinary research will be developed to address questions such as:

- Theme 1: How will climate variability affect change in water demand for irrigation?
- Theme 2: How can changes in water management (e.g., though policy instruments such as water pricing, and/or agronomic aspects such as alternative cropping, land-levelling) reduce vulnerability to climate variability?
- Theme 3: What will be the consequences of changed water management on the local and regional socioeconomic situation; and on GHG emissions, water tables and land degradation?

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Box 4: Research Design and Implementation

GECAFS will build on appropriate elements of the sponsoring Programmes to ensure strong links to their respective "core" sciences; and link these with inputs from other organisations as appropriate. It will not "replace" existing efforts at the Core Project level, but draw upon them, and set them in a broader context of coupled human-environment systems.

A three-way dialogue is being established between scientists, policymakers and donors (see Figure) to establish specific research agendas which are scientifically exciting and researchable, useful to aid policy formulation, and fundable. By designing GECAFS research in close consultation with both the science community and "end users", and maintaining this link throughout the research process, the adoption of research findings are more likely.

For more information see: http://www.gecafs.org

grammes, and developing new research partnerships with an innovative set of partners (Box 4), GECAFS offers prospects for significant scientific advances as a consequence of its interdisciplinary approach. In so doing, GECAFS will directly address the call for "a new system of global environmental change science" which lies at the heart of the Amsterdam Declaration.

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(This article is a summary of a document produced jointly by the four GEC programmes.)

...continued from page 36.

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Box: Land-Atmosphere in IGBP II

The above examples are just a few of the emerging science questions that will be addressed by a new land-atmosphere project (initially called i-LEAPS: interactive Land Ecosystem-Atmosphere Processes) during the coming years. The scientific excitement that comes with these issues will be accompanied by the close collaboration of different communities.

A joint working group from IGBP (BAHC, IGAC, GCTE, GAIM) will interact with WCRP (GEWEX) to form a project transition team and to oversee and coordinate the planning process of i-LEAPS. In October 2002 a workshop will be held to prepare a first draft of the Science Plan and the implementation framework. 2003 will also see the Open Science Conference and the new project will be launched in 2004.

For more information, please contact Pavel Kabat, Andi Andreae, or Almut Arneth (email addresses given below).

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The water challenge: Joint Water Project

by H. Hoff on behalf of the Scoping Team*

The global water system (Box 1) plays a central and integrative role in the dynamics of the Earth System as a regulator of biogeochemical and biogeophysical processes as well as for maintaining terrestrial and aquatic ecosystems. The global water system also is essential for sustenance of human societies – provision of drinking water, water for irrigation, sanitation and many other services.

Through water development, humans are affecting the global water system significantly, with profound effects on the quality of the world's rivers and water bodies, as well as aquatic habitats, but without adequate understanding of how the system works. Fragmentation and interference of natural water regimes have disrupted inland fisheries and other aquatic life forms. Reservoir siltation and reduction of sediment transport to estuaries and the coastal oceans have adversely impacted economic benefits of reservoirs, coastal development and biological resources. Nutrient enrichment of coastal oceans is a global problem, with anthropogenic fixation of nitrogen exceeding natural levels.

The overarching scientific question to be addressed by the Joint Water Project is:
How are humans changing the global water cycle, the associated biogeochemical cycles, and the biological components of the global water system, and what are the social feedbacks arising from these changes?

These issues are clearly complex and call for integrative, interdisciplinary, and comprehensive approaches, combining studies of the physical water cycle, the influence of human actions and water-related institutions, as well as biogeochemical and ecological processes. By focusing on the global scale, the Joint Water Project will evolve as a key contributor to improved knowledge of, and responsible interaction with, the global water system. In addition, improved understanding of the global water system will be used to analyse the response options available to humans in coping with water scarcity.

Regional - and global-scale synthesis

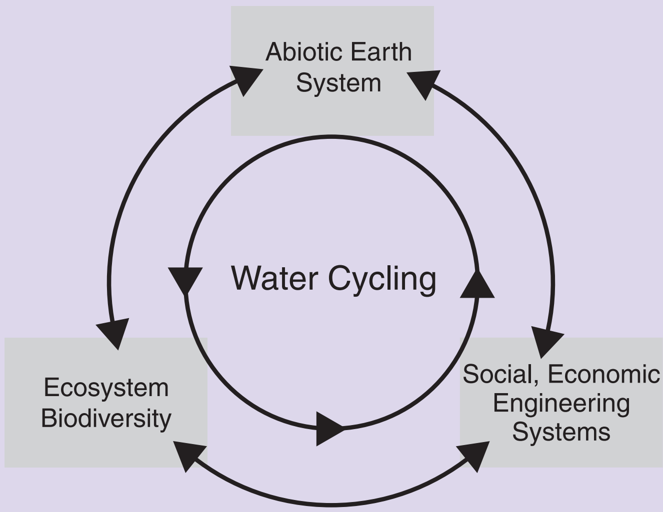
A growing number of studies employing continental and global-scale datasets and evolv-

Box 1: The global water system

The global water system involves physical, biogeochemical and socio-economic components:

- the physical water cycle (which is central to the system);
- waterborne substances;
- biological species; and,
- humans with their water-related institutions,

as well as the interactions between these components.



Global Water System

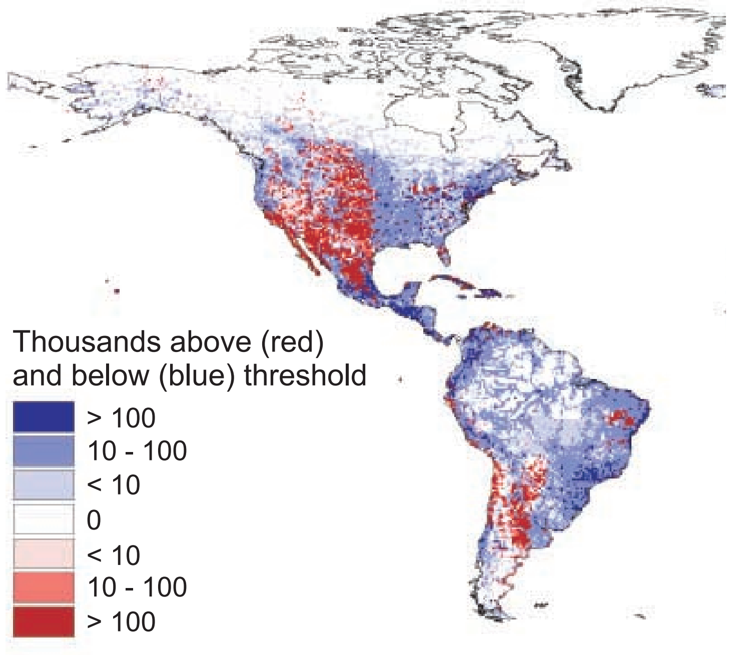


Figure 1. Contemporary relative water scarcity over the western hemisphere based on current withdrawals (defined as the ratio of agricultural and municipal and industrial water demand to local water supply). Western North America, La Plata River basin, northeastern Brazil, and west coast of South America are currently areas of high water scarcity. Reprinted from: Vörösmarty C, Green P, Salisbury J, Lammers R. (2000). Global Water Resources: Vulnerability from Climate Change and Population Growth, Science, 289: 284-288. © 2000 American Association for the Advancement of Science.

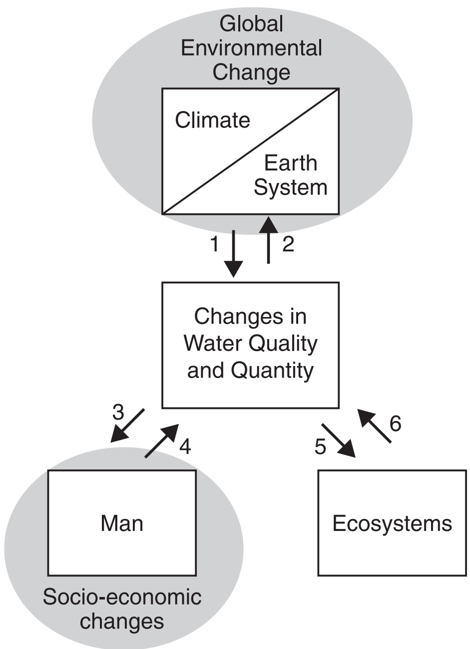
tics. Agricultural water demand was computed from irrigated land area and national use statistics.

Interdisciplinarity and integration

As previously mentioned, an important aspect of the Joint Water Project is the perspective that the global water system has both biogeophysical and human dimensions. Figure 2 illustrates that elements ranging across these thematic boundaries are joined by two-way interactions (numbered arrows). Change can occur in both directions, i.e., from or to the global environment and socioeconomic subsystems.

Three initial framing questions, consistent with the overarching science question, are proposed to provide some sense of the scope of activities that could be pursued by the Joint Water Project:

Question 1: What are the relative magnitudes of global-ing global modelling capabilities confirm that the effects of human development on the terrestrial water cycle are already truly global in scope. For instance, Figure 1 shows the extent of relative water scarcity (defined as the ratio of agricultural and municipal and industrial water demand to local water supply) over the western hemisphere – the situation in the eastern hemisphere is even more serious. The calculation uses a water balance model to compute contemporary runoff at 30 minute resolution as a basis for water supply. Water demands were determined by population (from 1 km data sets), per capita use and country level water withdrawal statis-



Example of interactions between the components of the global water system:

The potential for changes in drought severity or duration (1) could be caused by either natural climate variability or CO_2-induced climate change. The resulting anomalous scarcity of water in turn would create an impact on regional agriculture (3) and a response from the human population (4), which might embark on a program of reservoir construction. Such a strategy would affect the water budget (2) by altering evapotranspiration and runoff. Associated fragmentation of river systems might affect wetlands, and in turn fish populations (5). The decision to build reservoirs (4) also implies a reduction in sediment transport (2), which affects coastal ecosystems that are highly dependent on sediment and entrained nutrients.

Figure 2. Interactions among physico-chemical, ecological and socio-economic components of the global water system in view of global change

Box 2: Planning and implementation

After a number of initial activities towards a Joint Water Project, a planning meeting was held in May 2002 with representatives from the different water-related projects of IGBP, IHDP, WCRP and DIVERSITAS, and a scoping team* of the Joint Water Project has produced a draft prospectus (summarised in this article).

**The scoping team consists of Carlo Jäger (IHDP), Dennis Lettenmaier (WCRP), Christian Lévêque (DIVERSITAS), Harry Lins (WCRP), Madiodio Niasse (IHDP), Michel Meybeck (IGBP) and Charlie Vörösmarty (IGBP).*

Timeframe

In the near-term (0-2 years), a strong emphasis is expected on the identification of data needs, and early efforts to construct first generation global datasets, via synthesis and coordination with other programmes.

Examples would be data sets that identify the location and quantities of water applied globally for irrigation, the extraction of groundwater and surface water for human use, return flows to rivers, discharge of pollutants, eutrophication, hydraulic engineering, water demand, and other data sets representing the effects of human action on the global water system in an integrated and comprehensive manner.

In order to be successful, this effort at integrative data collection needs a strong conceptual component. Topics of clear scientific and practical relevance – like the issue of virtual water – could provide foci for synthetic modelling and analytic efforts that help to develop an adequate observation capability in the global water field.

Intermediate term (c. 2-5 years). Based on an evaluation of the first phase of work, the Joint Water Project would help to facilitate the development of first-generation models that would allow prediction of physical, chemical, biological, and socioeconomic aspects of human manipulation of the global water system, including explicit uncertainty representation as well as in analysing risks and opportunities involved in the dynamics of the global water system.

In the long-term (5-10 years), the Joint Water Project would promote development of interactive models capable of predicting possible responses and feedbacks of the global water system (and especially its terrestrial components) to human use and abuse, with reliable uncertainty estimates. Concurrently, models developed off-line in the intermediate term representing the physical and biogeochemical effects (but prescribing human behavioural aspects) would be tested in fully interactive mode with global models of the Earth System, including sophisticated representations of human dimension issues.

For more information on the Joint Water Project, please contact Wendy Broadgate at IGBP: wendy@igbp.kva.se

scale changes in the global water system that are attributable to changing human activities such as water use, water management, land use, and to environmental factors such as climate variability and change?

This will include the study of regional patterns of change; downscaling and upscaling between regional and global scales; trends in discharge of major rivers; precipitation type and timing as well as water availability for crops; and changes in nutrient and sediment transport and their impacts.

Question 2: What are the main mechanisms by which human activities are affecting the global water system?

This will include studies of: irrigation, agriculture and land use change; urbanisation, megacities and groundwater depletion; pollution and eutrophication of inland waters; overexploitation of fisheries, introduction of exotic species, thermal effluents; water engineering and dams.

Question 3: To what extent is the global water system (from the perspective of its living and social components) resilient to global change? How adaptable is the global water system and how capable are water management systems and ecosystems to cope with water issues, in particular when these arise in combination with further challenges like biodiversity loss or economic poverty?

This will include studies of: extreme events, especially flooding and drought; direct and indirect effects of water engineering, including habitat changes; changes in water quality, conservation strategies and rehabilitation of freshwater systems; consumptive water use, environmental dimensions of human welfare, health, and security; and virtual water (water in agricultural products) and water-related patterns of trade;

The Joint Water Project will have to provide a water-related global observation capability that integrates environmental and human dimensions. This is feasible, but only through a stepwise build up of regional samples with global relevance. A careful use of regional case studies for purposes of global water studies will be essential for this. Isolated regional studies will be of little use here, what is called for are *comparative* regional studies involving two or more heterogeneous regions from the outset, and explicitly placed into the service of continental and global-scale analysis. Remote sensing can play a key role in facilitating both comparability and spatio-temporal interpolation of *in situ* studies. Maximum collaboration will be sought with enhanced monitoring networks associated with the ESSP Programmes (e.g. WCRP-CEOP) and allied organisations (e.g. HELP, FRIEND).

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A funder's perspective

The Global Change Open Science Conference in Amsterdam July 2001 has brought the often demanded "periodic reexamination of the scientific goals and an alteration of science' course by the science community itself" (Jane Lubchenco's AAAS-Presidential Address 1997 on a new social contract for science [1]). It marked the "new direction" of global change research towards integrated strategies, turning more attention to regional problems and place-based solutions within the global context rather than to disciplinary and sectoral research agendas.

Implementing a New Contract between Science and Society – Support for the "Amsterdam Spirit"

The creation of the Earth System Science Partnership (ESSP) between WCRP, IGBP, IHDP, DIVERSITAS with START and the emerging Joint Projects of Global Sustainability are a clear sign that the global change research community is gathering to contribute to sustainable development, the goal of the World Summit for Sustainable Development (WSSD). There, under the leadership of ICSU, WFEO, and TWAS, the "reorientation of science towards higher priority to identifying solutions for pressing environmental and developmental challenges" is the focus of a "Science for Sustainability" [2].

The more the complexity of real life is approached in an integrated mode, the more science sees the "endless frontier" different from the traditional, serendipitous paradigm of science which Vannevar Bush had fixed for decades [3]. Science is now reflecting its role as the think-tank for humanity in a more "down to earth", and therefore more modest way, adhering to the precautionary principle – a turn not felt as imposed from outside, but emerging in a new research agenda from inside science which, for example, differently assesses chances and risks of the powerful tool technology. Normative implications and asking "Cui bono?" are finally accepted as legitimate foundations for doing sound science.

Previously, scientists have comfortably retreated to their ivory towers, yielding to the self-betrayal that objectivity is in reach, but that science should not talk before objectivity is achieved. This attitude has to change to consciously feeling responsible towards society for developing the research agenda in what is now called transdisciplinarity.

Such a policy-relevant, but not policy-driven science has changed the relation of science to politics fundamentally under the common understanding that uncertainty is unavoidable both in advising as well as in deciding. Science and policy finally run according to the same ethic, so aptly described by Sir Robert May as "uncertain scientific advice in an uncertain world" [4].

What imminent implications does this have for global change research? Everyone wishes research to be relevant and properly communicated to politics. In the past, the instrument of international scientific assessments on a politically contracted institutional basis has evolved as the main tool for this communication, IPCC being the evident success story. As the Fourth Assessment Report of IPCC is beginning and numerous other assessment initiatives emerge, such as the "Millennium Assessment" or those concerning the global marine environment (UNEP and WSSD) or agricultural research (World Bank), we should take a step back and rethink how to organise and relate these processes and their scope without over-stretching the capabilities of the institutions and scientists involved and at the same time not endangering the independence of the scientific work at the basis of any such effort.

It may be worthwhile to discuss whether the science community involved in the ESSP should make an effort to contribute to this dialogue between science and policy by independently defining focused questions on urgent problems ("hot spots"). This is not to say that science should run such assessments "academically" on its own, but that it may sharpen the discussion on what crossroads or guardrails are at the centre of those problems. This may be especially useful in cases where the analysis reveals that the special topic is not easily accepted in the political processes leading to intergovernmentally-agreed assessments like IPCC. To give examples, one could think of revisiting the forest- and sink-question, where the scientific preparation for Kyoto has perhaps not been clear enough to bar horse-trading with scientific results. Other examples include aquaculture in coastal zones where the Law of the Seas Convention provides a rather adverse framework for environmentally sound practices, the nitrogen-cycle as an independent factor of global change, or the re-emerging discussion on the "commons" (e.g., the "global common goods" initiative by UNEP) where social sciences "beyond economicism" [5] get a new role in global change research.

This way, its autonomy could be used by the ESSP to position itself in the vast array of policy-linked assessments. This is not arguing against cooperation with governments or political institutions, but for giving the international research programs a role in setting the agenda for "hot spots" independently if necessary. Defining the questions is at the centre of expectations from the independent science communities. This exercise inside science has also to address the looming divide on priorities in geosciences between integrated "place-based" strategies and falling back into "end of pipe" megaengineering like fertilising oceans or deep sea-sequestration of CO_2 (technological fixes).

What kind of support for the "new direction" is needed from the funding agencies? The integration across so many disciplines results in the involvement of a range of funding agencies of different policy sectors like agriculture, water and waste cycles, energy and their relevant technologies. In this array, with so many quarters properly demanding deliverables on urgent practical issues and at short notice, a stronghold for the necessary autonomy of such processes inside science is needed. There is a not yet well understood task for the science-dedicated funding agencies. They also have to leave behind the old perception of the "endless frontier" and the traditional distinction between basic (= free) and applied research and to foster the critical (= free) role of science in defining the crucial issues to be looked at and to overcome our ruling beliefs such as the blind trust in modernity, growth and development. Science funders should therefore enable this new community of engaged scholars to spend time on the necessary global coordinating and integrating tasks.

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...continued from page 38.

WCRP teamed up early with IGBP on a number of projects. For example, the BAHC (Biospheric Aspects of the Hydrological Cycle, established in 1992) and GEWEX (Global Energy and Water Cycle Experiment; established in 1988) projects of IGBP and WCRP, respectively, have worked together to better understand the complex and interactive nature of Earth's climate and hydrological cycle. A joint issue of the BAHC and GEWEX newsletters published in November 2001 describes some joint scientific accomplishments, which include CEOP and FLUXNET. Other examples include the collaboration between SPARC of WCRP and IGAC of IGBP on the coupling of atmospheric chemistry and climate. Also, the CLIVAR (Climate Variability and Predictability) project of the WCRP and the Past Global Changes (PAGES) project of the IGBP have launched joint worked - termed the 'CLIVAR/PAGES Intersection' - on the use of palaeo data to provide a longer term perspective on climate variability.

Human beings are of course at the centre of global change research, since they cause or contribute to global changes, are ultimately influenced by them, and have the capacity to mitigate and respond to these changes. IHDP, the International Human Dimension programme on Global Environmental Change was restructured in 1996. IHDP joined IGBP in a co-sponsorship of an international interdisciplinary project called "LUCC" (Land Use/Cover Change) aimed at improving our understanding of the dynamics of land-use and land cover change and their relation with global environmental change.

More recently, DIVERSITAS, the international programme on biodiversity science, and the latest born, or rather latest "restructured" programme, joined the partnership at the time of the Amsterdam conference. DIVERSITAS has been developing, with GCTE of IGBP, a set of activities on the link between biodiversity and ecosystem functioning.

Future collaborations

The ESSP has thought carefully about how their science could contribute to sustainable development. They have decided to launch three global-scale collaborative joint projects on water resources (the Joint Water project), food systems (GECAFS) and the carbon cycle (Global Carbon Project), described in this issue. Contrary to previous "bilateral" collaborations, the research questions are being drafted by all programmes, in an integrated way, and research will be collaborative.

The Earth System Science Partnership represents one important commitment from the scientific community towards achieving "global sustainability in terms of climate, biodiversity, food provision, coastal zone health and freshwater resources" [2].

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Note to contributors

Articles for “Science Features” should achieve a balance of (i) solid scientific content, and (ii) appeal for the broad global change research and policy communities rather than to a narrow discipline. Articles should be between 800 and 1500 words in length, and be accompanied by one to three key graphics or figures (colour or black and white).

Contributions for “Discussion Forum” should be between 500 and 1000 words in length and address a broad issue in global change science. A “Discussion Forum” article can include up to 2 figures.

Contributions for ‘Integration’ should be between 800-1200 words in length and highlight how IGBP or its core projects are integrating with other areas of Earth System Science. The article can include up to two figures.

“Correspondence” should be no more than 200 words and be in the form of a Letter to the Editor in response to an article in a previous edition of the Newsletter or relating to a specific global change issue. Please include author and contact details.

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