Earth System Focus for Geosphere-Biosphere Program

PAGES 209, 213–214

Global change is perhaps the greatest environmental issue facing humanity. The Earth's atmosphere and biosphere are undergoing profound change, due not simply to terrestrial or extraterrestrial geophysical forces, but to the numbers and activities of people.

Over the last 100 years the human population soared from little more than one billion to six billion, and over the last 50 years economic activity increased nearly tenfold. Half the Earth's land surface has been modified for direct human use, and nearly all is affected by humans in one way or another. Over two thirds of ocean fisheries are fully or overexploited, and scant pristine coastline exists outside of the high latitudes. The composition of the atmosphere—particularly greenhouse gases, reactive gases, and aerosol particles—is significantly different from a century ago.

The evidence that these changes are affecting the functioning of the Earth system, particularly the climate, grows stronger every year. Humans have become a global-scale force in their own right, comparable to the geophysical forces of nature.

This reality is the motivation for the International Geosphere-Biosphere Programme (IGBP), which was initiated in 1986 under the auspices of the International Council for Science (ICSU). From 2000–2003, IGBP reviewed and synthesised its preceding decade (1991–2000) of innovative research into atmospheric chemistry, terrestrial ecology and land-use change, marine biogeochemistry, the hydrological cycle, the coastal zone, and paleo aspects of global change [*Steffen et al.*, 2004].

Following the synthesis, IGBP transformed its existing suite of essentially autonomous projects into a more integrated study of the interactive physical, chemical, and biological processes that define Earth system dynamics, the changes that are occurring in these dynamics, and the role of human activities in these changes. This approach recognizes that the Earth is a nonlinear complex system characterized by chaotic behavior, feedbacks, and bifurcations, such that prediction is not always deterministic.

Human societies and activities are considered to be a part of the Earth system. To recognize this in practice, IGBP carries out much of its research in close collaboration with the International Human Dimensions Programme on Global Environmental Change (IHDP).

Within this integrative framework, IGBP is maintaining its focus on biogeochemical sciences, while increasing efforts to articulate and tackle key system-level questions. GBP has developed a new research structure that reflects the emphasis being placed on Earth system-level processes and the detailed dynamics between and within

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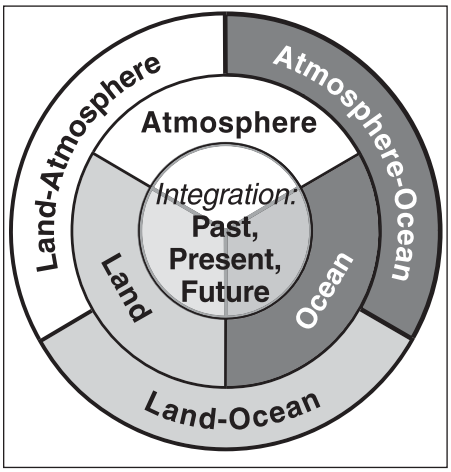

Fig. 1. Schematic representation of the structure of IGBP that indicates important project interfaces and symbolizes their integration into Earth system science.

Earth system compartments. This Earth system approach makes interdisciplinary research necessary and natural.

Eight Major Projects

The new IGBP research structure (Figure 1) is built around eight major projects. Three of them consider the major Earth system compartments of land, ocean, and atmosphere. Three Focus on the transport and transformations of matter and energy across the interfaces between these compartments. And two projects, represented by the central core of the Figure, study the changing dynamics of the entire Earth system, past, present, and future. These eight projects are described below in terms of their major themes.

Analysis, Integration and Modelling of the Earth System (AIMES): (1) Earth system analysis and modelling: the physical perspective (in collaboration with the World Climate Research Programme, WCRP) (e.g., Figure 2); (2) Earth system analysis and modelling: the human perspective (in collaboration with IHDP); (3) tools and techniques (for example, modular modeling and an Earth system atlas); and (4) fast-track initiatives: focused 2- to 3-year projects that tackle a "hot topic" in Earth system science and generate seminal papers on the issue. AIMES is based on the earlier Global Analysis, Integration and Modelling (GAIM) project.

Past Global Changes (PAGES): (1) Paleoenvironments of the Northern and Southern Hemispheres, organized around three pole-equator-pole transects; (2) collaborative research with the Climate Variability and Predictability (CLIVAR) project of the WCRP; (3) the International Marine Past Global Changes Study (IMAGES); (4) polar programs; and (5) a study of past ecosystem processes and human-environment interactions.

International Global Atmospheric Chemistry Project (IGAC): (1) The role of atmospheric chemistry in amplifying or damping climate change; and (2) the effects of changing regional emissions and depositions, long-range transport, and chemical transformations on air quality and the chemical composition of the planetary boundary layer.

Surface Ocean–Lower Atmosphere Study (SOLAS): (1) Biogeochemical interactions and feedbacks between the ocean and the atmosphere; (2) exchange processes at the air-sea interface and the role of transport and transformation in the atmosphere and in oceanic boundary layers; and (3) air-sea flux of carbon dioxide and other long-lived radiatively active gases.

The *Ocean Project* will be implemented by a partnership between the long-standing Global Ocean Ecosystem Dynamics (GLOBEC) project, and the new Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) project. Project themes include (1) the structure and functioning of the global ocean ecosystem, its major subsystems, and its response to physical forcing, toward the development of a capability to forecast the responses of the marine ecosystem to global change; and (2) the interactions between marine biogeochemical cycles and ecosystems and their response to, and forcing of, global change.

Land-Ocean Interactions in the Coastal Zone (LOICZ): (1) Vulnerability of coastal systems and hazards to human societies; (2) implications of global change for coastal ecosystems and sustainable development; (3) human influences on river basin–coastal zone interactions; (4) biogeochemical cycles of coastal and shelf waters; and (5) toward coastal system sustainability by managing land-ocean interactions.

Global Land Project (GLP): (1) The dynamics of land systems; (2) the consequences of land system change for the provision of ecosystem services (the stream of benefits derived from ecosystems, ranging from direct production of goods such as food to aesthetic and spiritual fulfillment) and for the functioning of the Earth system; and (3) integrating analyses and modeling for land sustainability. The long-standing Land-Use and Cover Change (LUCC) project, cosponsored by the IHDP, together with IGBP's earlier Global Change and Terrestrial Ecosystems (GCTE) project, provide the basis for the GLP.

Integrated Land Ecosystem–Atmosphere Processes Study (iLEAPS): (1) Land-atmosphere exchange of reactive and conservative compounds; (2) feedbacks between terrestrial biota, aerosols, and atmospheric composition in the climate system; (3) feedbacks and teleconnections in the land surface/vegetation/water/atmosphere system; and (4) measuring and modeling the transfer of materials and energy in the soil/canopy/boundary-layer system.

Research Implementation

Many of the above projects are developed and implemented with cosponsors, including the IHDP, the WCRP, the Scientific Committee on Oceanic Research, the Commission on Atmo-

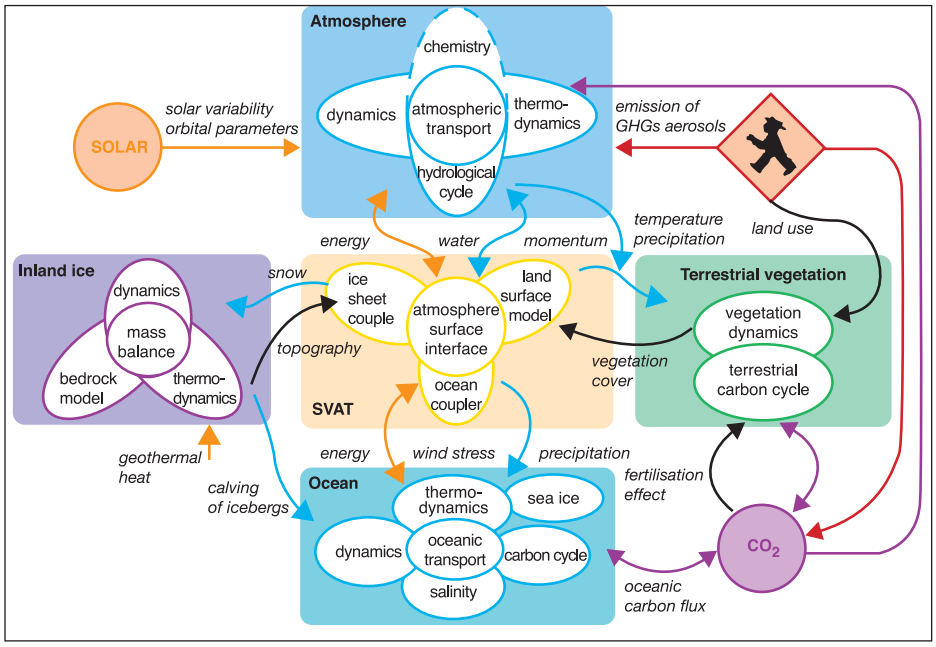

Fig. 2. Schematic diagram of the climate and biosphere (CLIMBER) Earth system model of intermediate complexity (EMIC). EMICs are part of a hierarchy of Earth system modeling approaches to be considered in AIMES. Adapted from Petoukhov et al. *[2000].*

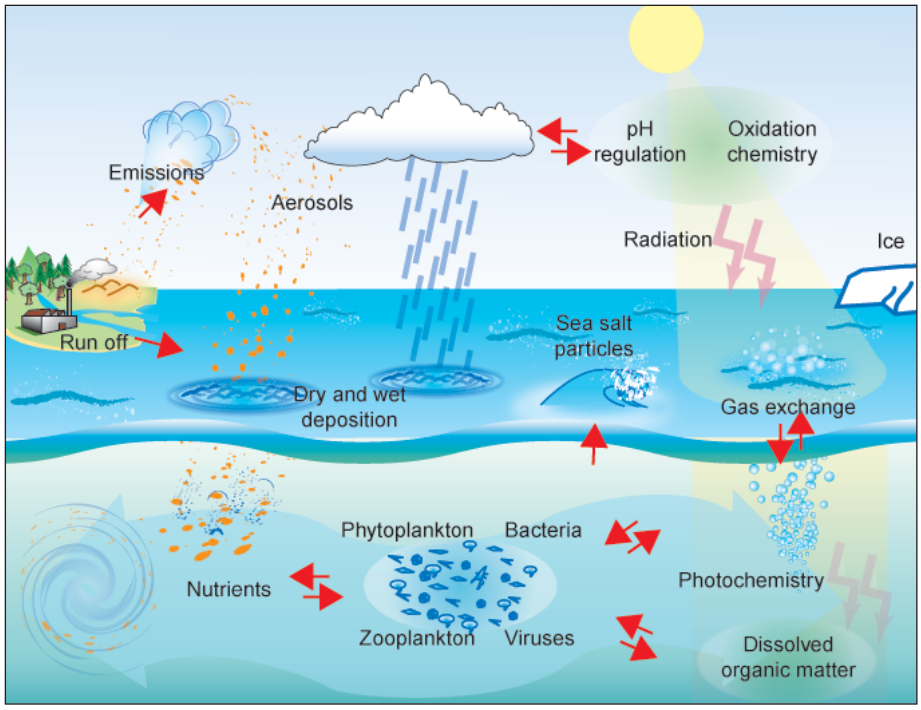

Fig. 3. Illustration of the areas of study of IGBP's SOLAS project as an example of the range of biogeochemical processes that IGBP projects consider. From SOLAS *[2004].*

spheric Chemistry and Global Pollution, and the Intergovernmental Oceanographic Commission.

IGBP addresses scientific questions that require an international approach. Its implementation strategy is built on interdisciplinarity, networking, and integration, which add value to the large number of individual, national, and regional research projects that contribute to the program.

IGBP is supported by close to 80 national committees whose role is to connect their countries' scientists to the IGBP effort and help develop the IGBP science agenda.

The individual projects that contribute to IGBP are funded by national and regional agencies around the world. The networking and integration activities of IGBP are funded largely through national contributions from about 50 countries, coordinated through the International Group of Funding Agencies.

IGBP integration activities aim to provide policy and resource management communities and the public with a better understanding of how the Earth system works and how it is changing. Interdisciplinarity and networking facilitate the international collaborations necessary to study Earth system processes and answer Earth system–scale questions. Typical value-adding activities of IGBP projects include:

- *Developing common international frameworks for collaborative research based on agreed agendas.* IGBP projects develop through a process of discussion among, and consultation with, hundreds of scientists from around the world. This allows many countries to influence project development, and helps orient national and regional research efforts to facilitate international collaboration.
- *Building research networks to tackle focused scientific questions.* An IGBP network typically shares expertise on experimental technologies, helps to spread this expertise to developing countries, interacts with the relevant modeling community to ensure the latest understanding is used in simulation tools, and carries out periodic syntheses on focused topics. IGBP's international approach strives to ensure that the broadest range of ecosystems or geographical locations are included, and that the networks are truly global.
- *Promoting standardized methodologies.* Earth system science often requires a large number of process or case studies at multiple sites in varying conditions, and their comparison and integration requires the development and application of standardized methodologies for conducting research.
- *Coordinating complex, multinational field campaigns.* IGBP projects offer a platform for planning and executing multinational campaigns, where airborne, shipborne, or specialized ground-based instrumentation is required, and where a high degree of coordination is necessary to maximize scientific benefit. International coordination provides further benefits by facilitating the cross comparison of several related field campaigns, for example, the Aerosol Characterization Experiments (the ACE campaigns) of IGAC.
- *Undertaking long time series observations.* Long time series, for example, monitoring atmospheric carbon dioxide concentrations, are important for detecting long-term trends, and for detecting when human activity pushes a system variable beyond the range of natural variability. Long time series also provide environmental baselines for the more intensive field campaigns or process studies.
- *Undertaking model intercomparisons and comparisons with data.* IGBP provides an international platform for model intercomparisons. These studies help define the strengths and weaknesses of different modeling approaches, share knowledge on modeling techniques and structures, and accelerate further model development.

IGBP research is enhanced by two partnerships. The first is the Earth System Science Partnership (ESSP) of DIVERSITAS, IGBP, IHDP, and WCRP. The partnership facilitates collaborative activities for the integrated study

Table 1. Web Addresses for IGBP Projects and ESSP Partners and Projects	
IGBP Projects	*Web Address*
AIMES	www.aimes.ucar.edu
PAGES	www.pages-igbp.org
IGAC	www.igac.noaa.gov
SOLAS	www.solas-int.org
Ocean Project	see GLOBEC www.globec.org and IMBER www.imber.info
LOICZ	www.loicz.org
GLP	www.glp.colostate.edu (and LUCC www.geo.ucl.ac.be/LUCC)
iLEAPS	www.atm.helsinki.fi/ILEAPS
ESSP Partners and Projects	*Web Address*
DIVERSITAS	www.diversitas-international.org
IGBP	www.igbp.net
IHDP	www.ihdp.org
WCRP	www.wmo.ch/web/wcrp
GCP	www.globalcarbonproject.org
GECAFS	www.gecafs.org
GECHH	no Web site as yet
GWSP	www.gwsp.org
START	www.start.org

of the Earth system, the changes that are occurring to the system, and the implications of these changes for global sustainability. The ESSP recognizes that the expertise of the four partners spans many disciplines required for a holistic approach to Earth system science; the partnership provides a mechanism for fostering the collaboration necessary for Earth system science.

The ESSP sponsors four projects on issues of global sustainability: the Global Carbon Project (GCP), Global Environmental Change and Food Systems (GECAFS), the Global Water System Project (GWSP), and Global Environmental Change and Human Health (GECHH). The ESSP also sponsors the global change SysTem for Analysis, Research, and Training (START), which fosters scientific networking and capacity building in developing countries.

The second enhancing partnership is the Integrated Global Observing Strategy (IGOS) partnership, which aims to provide an overarching strategy for observing the climate and atmosphere, oceans and coasts, land surface, and Earth's interior. The IGOS partners, which include space agencies, in situ observation programs, IGBP, and WCRP, build upon the strategies of existing international programs to improve observing capacity and to deliver more coherent and integrated observations in a cost-effective and timely manner.

IGBP's role within IGOS is to assess how well research requirements are currently being met and to suggest how they could be met in the future through improved integration and optimization of remote sensing and in situ systems. For example, IGBP led the development of the Integrated Global Carbon Observation (IGCO) theme and contributes to the themes on the hydrological cycle, atmospheric chemistry, the coastal zone, and the land.

For more information on IGBP (including on IGBP-sponsored open science meetings), contact the IGBP projects or the IGBP Secretariat via the Web sites listed in Table 1.

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NEWS

Subglacial Environments: Focus for a New U.S. Research Program

PAGE 210

Subglacial Antarctic lake environments (SALE) have attracted great scientific and lay public interest during the last decade. "Subglacial" is broadly defined as those localities under substantial (kilometer-scale) ice overburdens that cause long-term (at least thousands of years) isolation from direct subaerial contact. Subglacial environments are at or below the ice-bed interface of glaciers and ice sheets, including ice-water contacts above subglacial lakes and below ice shelves.

For the next decade or more, SALE exploration and research will be a focus of intense interest in Antarctica as one of the last remaining unexplored and difficult to access environments on Earth. SALE is also a primary focus for the International Polar Year (IPY) 2007–2008 scientific theme, "exploring new frontiers."

In the United States, a strong and diverse community interested in SALE exploration and research has developed over the last several years. Although several workshops and meetings have been convened, U.S. SALE interests need better coordination and advocacy. To this end, those involved in establishing the SALE agenda in the United States and internationally have joined together to form the U.S. SALE Program (see *Eos* article titled "Exploring Subglacial Antarctic Lake Environments, 86(20), 17 May 2005, p. 193).

To better organize U.S. efforts, Texas A&M University has established a SALE Program Office (SALE PO) (http://salepo.tamu.edu/) to provide focus and coordination for all aspects of SALE exploration and research. The program office serves the U.S. community and the recently approved Scientific Committee on Antarctic Research (SCAR) international Scientific Research Program. The Web site also serves an IPY coalition of six countries—the SALE Unified International Team for Exploration and Discovery (SALE-UNITED)—that will provide a focus for subglacial exploration in the IPY. The SALE PO will act as a clearinghouse for U.S. SALE interests, providing liaison with the international community through SCAR SALE and the International Council for Science/World Meteorological Organization (ICSU/WMO) Joint IPY Committee.

The U.S. SALE Program includes an Executive Committee (U.S. SALE ExCom) and a U.S. SALE Science and Technology Steering Committee (USSSTSC). The SALE ExCom and USSSTSC provide focus for advice, coordination, and leadership in all aspects of SALE exploration and research in the United States, while also coordinating education and outreach activities.

The U.S. SALE Program includes a series of science, technology, education, and communications/public relations committees. Science committees include genomics, glaciology, geology, and paleo-climate, geophysics, limnology and geochemistry, and planetary and terrestrial analogs. Technology committees include drilling and coring, methodologies and protocols, environmental affairs, data management and information systems, and