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THE NEWSLETTER OF THE GLOBAL ANALYSIS,
INTERPRETATION, AND MODELLING TASK FORCE

Volume three, number one
Summer 1999



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International Geosphere Biosphere Programme

AGU to Include Biogeosciences at Fall Meeting

By Dork Sahagian

The American Geophysical Union has traditionally been a premier society of geophysicists, spanning a range of disciplines from deep earth structure to space physics. In recent years, AGU has included publications (e.g. Global Biogeochemical Cycles) and meeting sessions centered on issues of global change. However, there has been no specific consideration of the biosphere in AGU despite its critical importance in the Earth System. This gap in AGU was recognized this Spring and an ad hoc committee was formed to recommend a course of action for AGU. The recommendation was to form a new section of AGU entitled "Biogeochemistry, Biogeophysics and Planetary Ecosystems" (or Biogeosciences, for short). The AGU Council has not yet decided on the issue. However, the **AGU Fall Meeting Program Committee decided to treat Biogeosciences as if it were already a section of AGU for the purposes of abstract submission and sessions at the Fall meeting in San Francisco.** It is called a "theme" for now. This is a great step, recognizing the importance of the biological aspects in global change and other Earth System research.

Consequently, the research community, as typified by IGBP, has an opportunity to use AGU as a venue for presentation of their research results. This initial meeting at which a "B theme" will be included will in part be a measure of interest of investigators from the com-

The Second IGBP Congress: From Collaboration to Integration *Some Personal Reflections*

By Will Steffen

Executive Director, IGBP

In an enterprise where meetings and travel have become so common that they are now often viewed as an unwanted intrusion in one's busy schedule, the IGBP Congress was a 'big ask'. We enticed, cajoled and perhaps even coerced over 300 top global change scientists from around the world to take over a week from their lives to come to a place that was, in most cases, far from their home. The primary objective was to contribute to the IGBP synthesis effort.

The meeting was successful beyond our expectations, in fact, in ways that we didn't really foresee. Yes, the plenary presentations profiled a programme which has matured considerably over the past three years and which is producing world-class, cutting edge Earth system science. And there is no doubt that the vigorous discussions and debates which went on inside and outside the synthesis working sessions will contribute many exciting new insights to the synthesis. This will become more apparent in the next 12-18 months as the various components of the synthesis effort are finalised and volumes go to the publishers.

But something more profound happened at Shonan Village. As the week progressed, it became apparent that a massive shift towards truly integrative science was occurring in the IGBP community. The move towards integration began with the first IGBP Congress, held at Bad Muenstereifel, Germany, in 1996. That was the first time that the scientific com-

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munities of ecological, biogeochemical, and other research which forms the basis of IGBP. As such, this should be considered a "call to arms" for the community to **send abstracts to the AGU meeting** (Abstract deadline, Sept. 9, 1999) indicating "B theme" and make a strong showing at this first invitation to AGU of the biological side of the Earth System.

Abstracts can be submitted on any topic related to biology and its interaction with any or all of the Earth System. In addition, a few sessions have been identified already for the Fall Meeting. These are listed in the adjacent text box. Abstract submission can be done on the web at <http://www.agu.org>.

Submission of Abstracts

Authors are encouraged to submit abstracts electronically via the Interactive Web Form on the AGU Web site. Abstracts submitted by postal/express mail must be received at AGU Headquarters by September 2, 1999. Abstracts submitted by the Interactive Web Form must be received at AGU by September 9, 1999. (These deadlines are firm and no exceptions will be granted.)

Abstract submission policies and instructions are available at <http://www.agu.org>

Important Dates

Abstract Submission Deadlines:
September 2, 1999 (Postal/Express Mail)
September 9, 1999 (Interactive Web Form)

1999 Fall Meeting: December 13-17, 1999 (Monday-Friday)

For More Information, contact:
AGU Meetings Department
2000 Florida Avenue, NW
Washington, DC 20009 USA
Tel: +1-800-966-2481 or +1-202-462-6900
Fax: +1-202-328-0566
E-mail: meetinginfo@agu.org (subject: 1999 Fall Meeting)
AGU Web site: <http://www.agu.org>

Or Contact the GAIM Office (gaim@unh.edu).



A number of Special Sessions have been formulated for the AGU Fall Meeting in the "Biogeosciences". In addition, there are a number of joint sessions for which "B" is co-listed. One session (Earth Sys-

tem Integration and Modelling) was chosen by the Program Committee to be a "U", or all-Union, session. Session descriptions are available at the AGU website or at <http://gaim.unh.edu>. 

Fall AGU Sessions in "B Theme"

Earth System Integration and Modelling

Biogeophysics of Land Cover Change, the Hydrologic Cycle, and Climate

Biospheric Interactions with Climate and Extreme Events: A Tribute to the Late Hans Oeschger

Global Terrestrial Ecosystem Modeling

Evolutionary Dynamics: The Evolutionary Play in the Geophysical Theater

Polyunsaturated Fatty Acids (PUFA) in Deep-Sea Sediments - Plankton Input or Bacterial Origin?

Isotopes in Biogeochemistry and Global Change

Wetlands

Transport of Microorganisms in the Subsurface Environment

Ocean Color and Biological Primary Productivity

Deep Biospheres: Where and How?

Balancing the Atmospheric Carbon Dioxide Budget

Hydrogen Biogeochemistry

Vegetation-Atmosphere Interaction: Synthesis from Field Experiments

Assessing the Range of Central North American Droughts and Associated Land Cover Change

Astrobiology

Roles of Atmosphere, Land Surface and Oceans in Determining the Monsoon Climate

Geophysics and Biogeochemistry of Gas Hydrates

Biogeochemistry of Forested Ecosystems (Poster only)

Coupled Hydrologic and Ecologic Processes in Arid and Semiarid Environments

Environmental Geochemistry (Poster Only)

Isotopic Tracers of Hydrologic and Biogeochemical Processes

Land Surface Characterization and Monitoring Using Airborne and Spaceborne Laser Altimetry

Land Surface Characterization and Analysis for Estimating Transport of Water, Sediment, Carbon and Nutrients over Large Areas (Poster Only)

Explaining Evolution

Spatial and Temporal Variability in the Gulf of the Farallones from San Francisco Bay to Beyond the Shelf Break

mittees of all IGBP projects, representing the broad range of global change science encompassed in IGBP, met together. It was an impressive 'getting to know you' affair, and it began the process of pulling the IGBP pieces together into a coherent, integrated research programme.

At Shonan the process accelerated markedly. We are now thinking not just of how we can learn more about the Earth's dynamics by comparing and contrasting different pieces of research (synthesis), but we are now planning to DO our research together so that integration is designed into the work from the start.

Here are just a few examples from the Congress of such integration:

Terrestrial and marine ecosystems.

Throughout much of the 1990s, research on the impacts of global change on terrestrial and marine ecosystems was carried out largely in isolation. Now, as interest in the effects of changes in the biological diversity of Earth's ecosystems on the functioning of the Earth system is increasing sharply, there are plans to integrate work on the structure, composition and functioning of marine and terrestrial ecosystems.

Water. Much earlier global change research has focused on the vapour phase of water and its vertical exchange between the Earth's surface and the atmosphere and its role in the physical climate system. More recently, there is increasing focus on the liquid form of water, and its role in the horizontal transport of materials across the land surface into the coastal zone, and the consequences for water availability and quality. This type of research is now starting to come together in an integrated form in the large-scale, regional integrated assessment exercise, and in the vulnerability approach to water resource issues being pursued

in BAHC and in the IHDP.

Food and fibre. The first generation of climate change impact studies on food production was based on a simple 'linear' approach in which a climate change scenario was used to drive crop models, and the results were used to infer various implications for food security. Now the paradigm is shifting to an approach focused on the dynamics of the food production/supply system being impacted, with climate one of several simultaneous biophysical and socioeconomic factors affecting the performance of the system.

IGBP. Integration across WCRP and IHDP is at least as important as integration within IGBP itself, and these linkages are now beginning to occur at an accelerating rate. They are almost entirely driven in a bottom-up fashion – for example, the consideration of atmospheric chemistry across the tropopause (SPARC and IGAC), the merging of work on the physical and biological aspects of the hydrological cycle (BAHC and GEWEX), collaborative research on the variability of the climate system on a number of time scales (PAGES and

CLIVAR), and the coupling of carbon cycle and climate models (GAIM and the WCRP modelling groups). But the most pervasive theme of the Congress, in terms of cross-programme integration, is the need to integrate human dimensions research throughout the entire range of global change science. This is now recognised as critically important for the future of global change research, and presents a considerable challenge not only to the programmes but also to the agencies around the world which fund international global change research.

Finally, there is another key component to the success of the Congress.

Meetings are surprisingly reliant on pleasant surroundings, a congenial atmosphere and efficient organisation. In every respect our Japanese hosts excelled in meeting and exceeding expectations in all of these areas. Shonan Village was a delightful venue with beautiful gardens and lovely views; the late afternoon receptions were a splendid opportunity to meet old friends, make new ones, and discuss the exciting science of the day; and the organisation of the Congress was as close to flawless as I have ever experienced in a big meeting.

Yes, the IGBP Congress was a big task. But as the Chair of IGBP, Berrien Moore, remarked in his talk during the concluding plenary session: 'When is too much time not enough?'



Ceremony for opening a barrel of Sake at the IGBP Congress by breaking the wooden cover. The opening was accomplished by the wielding of hammers by (left to right), Berrien Moore (IGBP Chair), Will Steffen (IGBP Executive Director), Isamu Kayane (Japanese National IGBP Committee Chair), Isao Koike (SC-IGBP Vice-Chair), and Sheila Lunter (IGBP Information Officer).

A very important aspect of this newer approach, from the IGBP perspective, is the emphasis on the consequences for the Earth system of feeding a rapidly expanding global population.

In addition to the more formally organised synthesis working sessions, there were literally thousands of side meetings and small group interactions. These were probably the most important product of the Congress. The meeting was a unique opportunity to explore new ways of approaching global change problems on a one-on-one and small group basis.

We should also not forget that, at the level of the international programmes, global change research is not confined to

TransCom3: Ready to Roll

by Scott Denning and Kevin Gurney

Since our official kick-off meeting last December in San Francisco, participants in the Atmospheric CO₂ Inversion Intercomparison Project (TransCom3) have been busy finalizing the protocol and data sets for the upcoming experiment. More than a dozen chemical tracer transport modeling groups are slated to participate in the third phase of TransCom, with the aim of quantifying the roles of transport, data selection, and inverse methods in inverse calculations of the CO₂ budget.

The experimental protocol has been nearly finalized after much active discussion and comment among participants. It is available in draft form at <ftp://transcom.colostate.edu/transcom/protocol.pdf>. Also available for participants are the input data sets required for the experiment, utility codes for regridding input data and writing model output, and many "helpful hints" to facilitate each group's work. The next step for TransCom is the heart of the experiment: the forward simulations with hundreds of tracers. Some of these runs are already in progress around the world, and results are expected to start coming in soon. We will hold another workshop to discuss preliminary inversion results in early 2000, probably in France.

Along with our counterparts from the NPP/EMDI and OCMIP intercomparison programs, we held a TransCom special session at the IUGG meeting (July 23, 1999 Birmingham, UK). Seven papers were presented on TransCom and related work by participants in various areas of carbon cycle inversion and tracer transport research. This provided a great forum for introducing TransCom to the international research community, and also to hear about exciting new work. Some of these new results included an interesting treatment of the sensitivity of CO₂ inversions to various sources of error; an exploration of the effects of spatial resolution; and a spectacular inversion of interannual land and ocean carbon cycle variability. Some of these studies have already been submitted for publication.

The TransCom experiment is open to all interested tracer transport modeling groups that can perform the required simulations. For more information, contact Kevin Gurney (keving@transcom.colostate.edu), or see our website at <http://transcom.colostate.edu>. 

OCMIP Mid-Project Workshop

by James Orr and Jean-Claude Dutay

The first workshop of OCMIP phase 2 was held in Gif-sur-Yvette, France May 27-28, 1999. During the workshop, participants discussed developments concerning (i) ground-work that has been laid for comparison, (ii) observational data sets that will serve as reference, (iii) model-data comparison for CFC's, and (iv) plans for the last half of OCMIP-2.

Between OCMIP phases 1 and 2, the number of models has increased from four to thirteen. The number of simulations to be compared has also increased. Rigorous protocols were developed during OCMIP-2 so that all modeling groups could make consistent. By the time of the OCMIP-2 workshop, these standard protocols were available on the OCMIP Website (<http://www.ipsl.jussieu.fr/OCMIP/>). These protocols are given in "HOWTO" documents with links to the necessary boundary conditions and model code.

Further need for consistency between all modeling groups has inspired the development of an analysis package, tailored for the needs of OCMIP. At present the package consists of a model output database, data treatment routines, and graphical presentation software. Model output is stored in standard format (netCDF, GDT). Model output can be processed with routines in Fortran, C, and Ferret. Model results are presented graphically with Tecplot, which has many useful features including the ability to present any of the OCMIP-2 models on their original grid.

Discussion at the workshop also focused on recent advances in synthesis of new global-scale data sets from WOCE and JGOFS. They provide unprecedented coverage of tracer data that is crucial to evaluating the performance of ocean carbon cycle models. Leaders of current data synthesis efforts for CFC-11, CFC-12, C-14, and CO₂ are also members of OCMIP. At the OCMIP-2 workshop, each of

these leaders reported on recent synthesis efforts. The new WOCE CFC data is starting to be used to validate OCMIP-2 model simulations for CFC-11 and CFC-12; other tracers will begin to be used to evaluate other OCMIP-2 simulations in the Fall of 1999. An integral part of data synthesis efforts is the emphasis on deriving estimates for anthropogenic CO₂ and nuclear-era C-14.

Workshop participants were encouraged by the presentation of the first OCMIP-2 model-data comparison. Standard simulations for CFC-11 and CFC-12 have been completed by all 13 participating model groups. The new WOCE data set, much of it which is yet unpublished, is being made available to OCMIP-2. The AJAX section for CFC-11 (Fig. 1), provides an example of the ongoing comparison. It reveals large differences between storage of that tracer in the Southern Ocean, e.g., south of 50S. The AWI model does best job at capturing the penetration of the tracer to the bottom in the far southern end of the AJAX section. The AWI model even captures the mid-depth low also at the far southern end of that section. But the AWI is an "adjoint" model, which uses hydrographic and tracer data in an inverse fashion to compute a mean annual ocean circulation. The other models are of the more classic "forward" type. Almost all other forward models struggle to get adequate CFC-11 vertical penetration in the south. Only the models with a coupled sea-ice model do a reasonable job. An interesting feature is the observed bump at around 40S which is characteristic of formation of intermediate waters: models with explicit mixing along surfaces of constant density (isopycnals) capture this feature.

The final half of OCMIP-2 will be intense. The remaining simulations are currently in progress and analysis subprojects are being adopted many of the different OCMIP participants. The next OCMIP-2 workshop will probably be held for one week during the summer of 2000, in the U.S. 

EMDI Update

By Kathy Hibbard

The Ecosystem Model/Data Intercomparison (EMDI) activity has been very active in the past couple of months. In April, a small working group was held at the National Center for Ecological Analyses and Synthesis (NCEAS) in Santa Barbara, California where the scientific questions and decisions for data input/output protocols were finalized. In late June of 1999, the model driver data (soils, vegetation-type, transient and long term mean climatologies, NDVI, CO₂, and disturbance histories) were released from the NCEAS server for the participating modeling groups.

To date, there are approximately 20 models ranging from land surface schemes, dynamic vegetation models, remotely sensed and biogeochemical ecosystem models participating in EMDI.

GAIM will host a working group analysis at the University of New Hampshire in the first week of December where participants will be able to present their models and results as well as discuss the future of EMDI. For more information, see the EMDI homepage at GAIM: <http://www.gaim.unh.edu/Projects/EMDI/> or contact Kathy Hibbard at: k.hibbard@unh.edu 

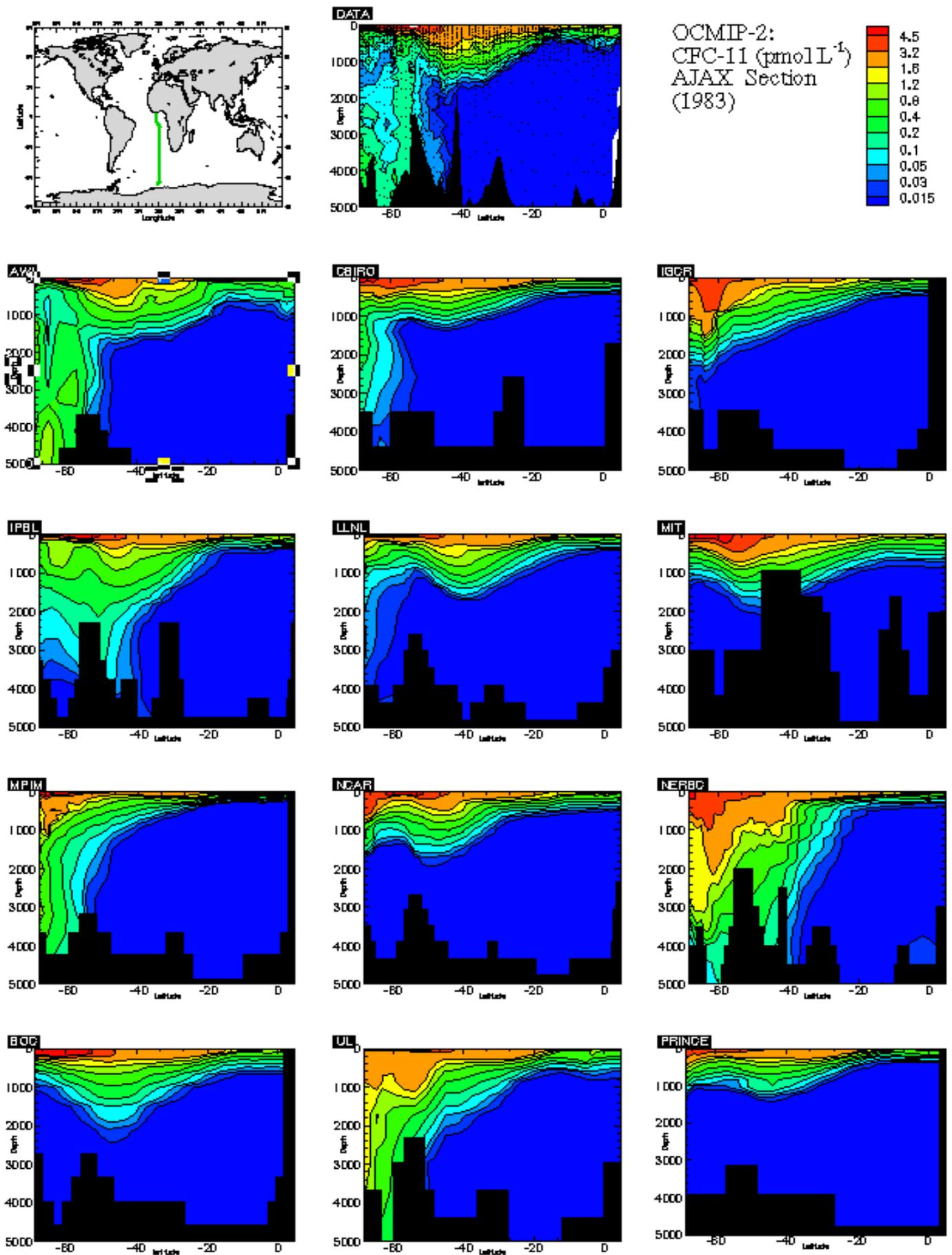


Fig. 1: OCMIP-2 Section for CFC-11 along the AJAX section in 1983. Concentration units are pmol/L.

Paleotrace Gas and Aerosol Workshop Jena, March 1999

By Colin Prentice, Sharon Cowling,
and Dork Sahagian

Understanding of the decadal to multi-millennial-scale regulation of chemical components of the atmosphere (CO_2 , N_2O , CH_4 , other reactive gases, SO_4^{2-} aerosols, mineral aerosols) remains a critical challenge to be addressed by global change scientists. Without a predictive understanding of the natural changes that have taken place over the past 200,000 years, we have little hope of foreseeing the consequences of human activities on global climate over the next several decades to centuries. Palaeodata from ice core, marine and terrestrial data sources provide information about former states of the ocean, terrestrial biosphere and physical climate. These diverse sources of palaeodata allow us to develop and test predictive, multicomponent earth system models, within a framework of known temporal and spatial constraints provided by natural atmospheric variations and their signatures on land and in the sea.

In view of this situation, it was decided that IGBP should act to promote interdisciplinary and international cooperative action, by mounting a concerted attack on the palaeotrace gas and aerosols problem using a combination of ice-core atmospheric composition data (the primary ‘target’ for explanation), state-of-the-art models, and the best available global palaeodata sets to constrain models. Hence, the IGBP launched its ‘Palaeotrace Gas and Aerosol Challenge’, a joint initiative of the IGBP Global Analysis, Interpretation and Modelling (GAIM), Past Global Changes (PAGES) and International Global Atmospheric Chemistry (IGAC) programs.

The workshop, assigned the acronym TRACES (Trace-Gas and Aerosol Cycles in the Earth System), brought together people from multiple research communities (terrestrial, marine, ice-core, atmospheric chemistry, palaeoclimate modelling) to discuss common research themes related to the regulation of atmospheric composition in the past. The aim of the workshop was twofold; first, to establish the current state of earth system modelling and data acquisition relative to this problem, and second, to identify future high priority needs which would require collaborative, international and interdisciplinary research activities.

At this workshop, TRACES participants were presented with the challenge of identifying outstanding research challenges which satisfied the following two criteria: 1) that our understanding of the processes and mechanisms underlying earth system feedbacks which control atmospheric composition, would be greatly enhanced by such proposed activities, and 2) that the activities could be completed within 5 years.

Sources of Palaeodata

(a) *Ice cores.* High resolution ice core chronologies now provide global change scientists with a detailed record of atmospheric trace gases spanning the last four glacial-interglacial cycles. Not only can concentrations of long-lived trace gases such as CH_4 , CO_2 and N_2O be measured in ice, but levels of gases with short residence-times such as CO and biogenic species including NH_3 , acetate and formate can also be traced through time. The detection and measurement of these biogenic gases in ice cores provides a new opportunity for re-

constructions of past terrestrial ecosystem processes.

Methane and CO_2 dynamics during glacial-interglacial cycles have become an important research focus because they are key components of the earth’s carbon cycle, and their concentrations do not always follow similar trends. Because of the observed positive relationship between atmospheric CO_2 and temperature, CO_2 levels during the Younger Dryas cooling event might be predicted to have been low, but ice records indicate that although CH_4 decreases during this period, CO_2 levels continue rising. Examples from the last glacial period where atmospheric CO_2 responds to prolonged periods of cooling, but not to rapid climate oscillations, help to illustrate the fact that as much as we might be able to reconstruct gas flux changes over the past 400 ka, we are still unable to explain the underlying processes and mechanisms triggering these changes.

(b) *Marine.* Palaeodata commonly address one of three key characteristics of surface ocean waters: temperature, pCO_2 , and alkalinity. Sea surface temperatures and the location and strength of coastal upwelling zones can be reconstructed for key time periods in the past (e.g. Last Glacial Maximum) from calcareous or siliceous phytoplankton, with methodologies based on species abundance transfer functions or a modern-analog approach, stable O-isotopes and alkenone ratios. Sr/Ca ratios in corals can also be useful. One potential limitation to the interpretation of marine palaeodata concerns the degree to which palaeoproxies truly describe surface water processes (e.g. many foraminifera live at some depth in the mixed layer, and changes in the structure of the mixed layer may change biological assemblages). There is a need for more synthetic work on marine palaeodata as well as continued attempts to develop better proxies and improved understanding of existing ones.

(c) *Terrestrial.* Global terrestrial databases include the Global Lake Status Data Base, which contains estimates of changes in lake level or area reconstructed from biostratigraphic or lithologic data, reflecting changes in the climate water balance; the Palaeovegetation Mapping Project (BIOME6000), which contains palaeovegetation data sets for 6000 and 18,000 years BP; DIRTMAP, which provides data on dust accumulation and fluxes as recorded in ice cores, marine cores and terrestrial (loess) sections, ranging over a period from the glacial maximum to the present; and the 21 ka tropical data synthesis project, which has used multiple proxies (pollen, plant macrofossils, noble gas thermometry, speleothems, lake-status changes). Continued collection and synthesis of terrestrial palaeoproxy data is essential, including an effort to improve chronologies, above all for the evaluation of model experiments focusing on rapid changes.

III. Palaeoclimate Modelling

Climate model complexity has rapidly expanded from the introduction of the first Atmospheric General Circulation Model (AGCM) over two decades ago. Sensitivity studies have demonstrated that land- and ocean-surface processes are important for accurate simulation of climate within the framework of the GAIM ‘6000 yr. BP Experiment’, building on the work of PMIP (Kutzbach *et al.*, 1996; Brostrom *et al.*, 1998). Vegetation changes (in composition and leaf area index) can significantly alter regional and global climates. By testing the sensitivity of climate models to differ-

ent coupling scenarios (atmosphere, biosphere, hydro-sphere), the strength of interactions between climate components can be quantified, and the type of interaction classified as either additive or synergistic. Fully coupled Atmosphere-Ocean-Vegetation climate models (AOVGCMs), however, do not yet exist, thus vegetation-climate feedbacks must be modelled separately, with changes to surface roughness, energy and heat budgets input to AOGCMs as surface boundary conditions (‘equilibrium asynchronous coupling’). Fully coupled models (AOVGCMs) need to be developed, tested and applied to palaeoclimate problems routinely. Intercomparisons need to be carried out for AOVGCMs (or subcomponents) in order to test the robustness of those simulations. Refining our basic ability to simulate past climate, including biogeophysical interactions, is a prerequisite for successful coupling of physical, chemical and biogeophysical components in Earth System models.

IV. Biogeochemical Cycles

(a) *Carbon.* Central to our evaluation of the earth’s carbon cycle is our understanding of the physical and biological processes modifying atmospheric CO_2 levels. We also must identify whether these changes are primarily glacial triggering mechanisms or secondary climate amplifiers. Answers may lie within the oceans, which are able to alter atmospheric pCO_2 through changes in the balance between CO_2 removal by deep water burial and CO_2 release by CaCO_3 -compensation. OGCM simulations indicate that marine bioproductivity tends to be initially limited by soluble Fe, and then eventually by PO_4 . Mechanisms in addition to biological-pump activity must be responsible for drawdown of atmospheric CO_2 because even when simulated ocean productivity is unlimited by Fe, N or PO_4 , the magnitude of simulated CO_2 decrease in coupled OGCM-ocean carbon models does not match that estimated during the last glaciation. The weak link in many marine bioproductivity models may be a lack of understanding of basic phytoplankton biology. On the other hand, the problems in simulating the low CO_2 of the glacial periods may force us also to reexamine some aspects of the physics of ocean models.

An alternate mechanism for explaining low glacial CO_2 levels may be the reduction in rates of CaCO_3 -compensation in the oceans. This could be brought about by variations in marine inventories of soluble Si, since studies show that high levels of Si reduce rates of CaCO_3 -pumping. The identity of the triggering mechanism for enhancement of soluble Si in the oceans is as yet unknown. Modelling studies indicate that to produce quantities of Si necessary to significantly inhibit CaCO_3 -pumping during the last glaciation, weathering rates must increase by a factor of four. What has still to be considered is the potential role of dust in increasing abundance of soluble Si during glacial periods.

As with ocean carbon cycling, many questions concerning the terrestrial component of the global carbon budget remain unanswered. Despite advances in all three of the methods presently used to reconstruct biospheric carbon (data-based reconstructions, global $\delta^{13}\text{C}$ -budget, climate-biosphere models), estimates of terrestrial carbon storage at the last glacial maximum have still to be determined within a reasonable margin of error. Continued research on the role of terrestrial ecosystems in influencing the global carbon cycle is a

high priority.

The controls on atmospheric CH₄ require further investigation through models and measurements. It is generally agreed that CH₄ source strengths must have changed in order to produce the large inferred variations in atmospheric CH₄. Surprisingly, most CH₄-source studies focus on northern temperate peatlands, despite indications that tropical wetlands are likely to have played a key role in altering CH₄ source strengths during glacial-interglacial cycles.

(b) Nitrogen. Nitrogen is an important component of the climate system and carbon cycle, in part because it is a limiting nutrient in the oceans, has a turnover rate of approximately 300 years (therefore sensitive to climate perturbations) and may be unbalanced in both glacial and interglacial periods. N₂O has marine as well as terrestrial sources. An internal source of nitrogen in the oceans is N₂-fixation by cyanobacteria, and one of the key unknowns in the marine N cycle is the extent to which N₂ fixation rates could have changed, e.g. through changes in the input of Fe from dust.

(c) Dust. Under current atmospheric conditions, mineral aerosols (i.e. desert dust) can have very large local effects on heat transfer (up to 25 Wm⁻²). Areas which are likely to be sources of atmospheric dust are those with little vegetation, and having pronounced seasonal changes in moisture. Mineral aerosol abundance is estimated to have been considerably greater during the last glacial maximum, therefore likely exerted an even stronger influence on radiation budgets than at present. Model simulations of dust accumulation during the last glacial maximum show that increases in wind strength and a decrease in the strength of the hydrological cycle are insufficient to explain the atmospheric dust loading at the LGM; changes in source areas have to be invoked. The role of dust as either an indicator of altered climate, or a primary driver of palaeoclimate, must still be determined.

V. TRACES Research Strategy

Activities needed in support of the objectives of TRACES fall into three broad categories. **Ecochemistry modelling** covers the further development of models to simulate the sources and sinks of trace gases and aerosols/aerosol precursors in the terrestrial and marine realms, in as mechanistic and integrated way as possible. **Palaeodata synthesis** refers to both ongoing terrestrial, marine and ice-core activities sponsored by PAGES, needed in order to test key aspects of palaeoenvironmental modelling, and further syntheses required specifically to test aspects of trace gas and aerosol balance (such as palaeowetlands and dust deposition). **Model/data comparison experiments** represent the core activities of TRACES: using novel combinations of global models to simulate past changes in the atmosphere and global palaeodata to evaluate the success of these experiments.

Ecochemistry modelling

Terrestrial climate/ecochemistry modelling. The aim is to develop more biogeochemically comprehensive models than today's DGVMs, including source and sink terms for key atmospheric trace constituents such as CH₄, CO, N₂O, NO_x and NMHCs and (where relevant) their isotopes; also for mineral aerosol (dust) and its mineralogy, which affects both the optical (radiative) and biogeochemical properties of dust. Such models will be designed to interface with atmospheric chemistry-transport models so that predictions of changed

surface sources and sinks can be translated into simulations of atmospheric composition.

One necessary component of such comprehensive models will be a model of continental hydrology (river flows and the extent of lakes and wetlands). Because of their key role as a net CH₄ source, wetlands (and their CH₄ balance) will have to be simulated explicitly and their biogeochemistry simulated independently of dryland ecosystems. Fully prognostic physical coupling of the atmosphere and oceans requires the simulation of freshwater fluxes into the ocean. A full understanding of long-term changes in the carbon cycle requires simulation of the land-sea fluxes associated with terrestrial leaching and weathering.

The modelling agenda would benefit from certain types of contemporary observation that are currently missing. For example, there is a dearth of information on CO₂ and CH₄ fluxes associated with tropical wetlands (an important part of the story for palaeo-CH₄). Ecosystem models that simultaneously predict fluxes of several trace gases (including C and N containing gases) would benefit from simultaneous measurements of these fluxes, which are generally not available.

Marine climate/ecochemistry modelling. The aim is to develop more biologically and biogeochemically explicit models than today's NPZD models. Such models will be designed to be embedded in OGCMs and AOGCMs. Sources of chemically important trace gases and aerosol precursors (N₂O, DMS) must be simulated as mechanistically as possible, allowing for the possible effects of changes in terrigenous nutrient inputs (e.g. Fe, Si) on marine ecosystem productivity and the N and S cycles. Prognostic distinctions need to be made among biogeochemically distinct marine functional groups of organisms (e.g. diatoms, coccoliths, radiolarians), and additional diagnostics (e.g. distributions of major taxa) provided to allow direct comparison with palaeo-assemblage data.

Attempts to simulate the low glacial atmospheric CO₂ concentrations have highlighted the importance of overall ocean diffusivity in determining the effectiveness of many conceivable mechanisms. In particular, some have claimed that the diffusivity of today's OGCMs is too high, so that the pCO₂ of the surface layer is insufficiently decoupled from that of the deep ocean. This physical ocean dynamics issue requires a solution before we can properly understand glacial-interglacial changes in atmospheric CO₂. Several aspects of this issue are being tackled by the GAIM project OCMIP, in collaboration with JGOFS and WOCE as key providers of relevant contemporary biogeochemical and physical measurements, respectively. The specifically trace-gas and aerosol aspects of the modelling will be central to SOLAS.

Palaeodata synthesis

Multiproxy palaeoenvironmental reconstruction of the last glacial maximum. Comprehensive reconstruction of climatic and biological conditions on land in the ocean for the last glacial maximum is required because "pre-industrial" and last glacial maximum are the two first priorities for modelling within TRACES. Such reconstruction is the goal of EPILOG, a fast-track activity under the PAGES-IMAGES project.

Palaeovegetation records in continuous time (last glacial maximum to present). Global synthesis of palaeovegetation data in continuous time is necessary to evaluate aspects of simulations of changes in terres-

trial carbon cycling and methanogenesis. Such synthesis has been carried out using a standard methodology by the BIOME 6000 project (GAIM-DIS-GCTE-PAGES). This methodology needs to be combined with automated procedures for extracting data from the new generation of regional pollen data bases.

Palaeowetland distribution and accumulation. Data on the past extent and accumulation rates of wetlands are widespread in the Quaternary science literature because wetlands are an important natural archive, e.g. for pollen. They are crucial for testing model results on the contribution of wetlands to the carbon cycle and CH₄, but they still must be compiled in an accessible format.

Dust accumulation rates in marine sediments, loess and ice. Required to test models of the distribution of mineral aerosol (especially as regards very high deposition rates observed for glacial periods), such data are being compiled by the INQUA-sponsored DIRTMAP project. Archived information should be extended to include grain size and mineralogical properties.

Ocean tracers from the last glacial maximum to present. Key tracers include sedimentary assemblages, ¹⁸O and ¹³C, alkenone temperatures, etc.; such data can provide multiple constraints on climate and carbon cycle model reconstructions. Global synthesis of such data is the aim of PAGES-IMAGES.

Targeted data collection: ice cores and marine and terrestrial sediments. Ice-core palaeorecords of atmospheric composition (PAGES project PICE) provide the ultimate rationale and challenge for TRACES. Improvement of the palaeoatmospheric record is still possible and desirable, especially with regard to isotopic composition of trace gases (e.g. δ¹³C in CH₄). There is a potential to obtain new dust records from archived marine cores.

Model/data comparison experiments

Time slice experiments for the global carbon cycle and global atmospheric chemistry. Such experiments would aim to find out what are the necessary components to describe observed changes in atmospheric composition, given the numerous supplementary constraints provided by spatially distributed palaeoenvironmental records. They could be performed by GCMs with additional coupled components, e.g. terrestrial and marine carbon cycling, entrainment and transport of dust, atmospheric chemistry and transport. Priority time slices would include pre-industrial, last glacial maximum, mid-Holocene (6000 yr BP) and early Holocene, building on work by the PMIP (PAGES-CLIVAR) project and the GAIM 6000 yr BP experiment.

Transient experiments with similar coupled components but focused on times of rapid change and transitions. Such experiments could be performed with GCMs (perturbation experiments focusing on times of apparent metastability, e.g. last glacial inception (115 000 yr BP) and Bølling-Allerød transition (14 500 yr BP), and with models of intermediate complexity (GAIM EMIC activity) which can be run continuously over longer periods. The aim is to find what ingredients are necessary to (a) cause abrupt climate changes in response to smooth forcing, (b) generate the associated changes in atmospheric composition seen in the ice-core record, and (c) to investigate the possibility of feedbacks between the biogeochemical and physical aspects of the climate system.



Earth-System Models of Intermediate Complexity

By Martin Claussen and Wolfgang Cramer

What do we know about models of the Earth system? This was the overarching issue addressed at the IGBP workshop (co-hosted by GAIM, BAHC, GCTE and PIK) in Potsdam on June 15-16. *Ad hoc*, it was proposed to define the Earth system as an envelope of the natural environment, i.e. the climate system or the ecosphere, and the anthroposphere. The climate system consists of the abiotic world, the geosphere, and the living world, the biosphere. Geosphere and biosphere are further divided into components such as the atmosphere, hydrosphere, etc., which interact via fluxes of momentum, energy, water, carbon, and other substances.

The workshop focused mostly on the natural dimension of the Earth system with the anthroposphere as a prescribed boundary condition (land use, CO₂ emissions), although an outline of Earth system analysis as well as some first steps towards (fully coupled) Earth system models were presented as well. Earth system modelling is motivated by our limited knowledge about the consequences of large-scale perturbations of the Earth system by human activities, such as fossil fuel combustion or the fragmentation of terrestrial vegetation cover. Earth system modelling should therefore answer questions such as: Will the Earth system behave resilient with respect to such disturbances, or could it be driven towards qualitatively new modes of operation? On the way to answering this, the problem of natural perturbations of the past are addressed, for example, the amplification of Milankovich forcing to glaciation episodes or the mechanisms behind the Dansgaard-Oeschger oscillations.

Participants agreed that models of the Earth system need to be “comprehensive” in the sense that they should include submodels of the abiotic world, the geosphere, and the living world, the biosphere. Moreover, Earth system models need to be global in scope, because the fluxes within the system are global (e.g. the hydrological cycle): changes in one region may well be caused by changes in a distant region. A currently open question is how much spatial (regional) resolution is required to appropriately capture processes with global significance. Clearly, Earth-system models need not capture all aspects of interaction between the spheres at the regional scale - this is the realm of regionally integrated models.

The workshop then discussed Earth-system models using a hierarchy of resolutions. Depending on the nature of questions asked and the pertinent time scales, there are, on the one extreme, zero-dimensional “tutorial” or “conceptual” models like those in the “Daisyworld” family. These provide a mathematical foundation for qualitative hypotheses. At the other extreme, three-dimensional comprehensive models, e.g. coupling atmospheric and oceanic circulation and dynamic vegetation with explicit geography and high spatio-temporal resolution, are under development by several groups. These are often based on coupled ocean-atmosphere GCMs

(general circulation models), but usually contain additional submodels for other system elements. A major limitation in the application of the latter models is their high computational costs (usually allowing ensemble calculations only at a very limited scale), whereas the former lack many important processes and feedback operating in the real world. In between the two extremes, Earth-System Models of Intermediate Complexity (EMICs) come into the game.

In the discussion it became apparent that a concise definition of EMICs is not yet feasible. The border between GCMs and EMICs will change with time and available computer capacity. As one of the participants put it: What you cannot do with a GCM, can be done with an EMIC. Or: If one re-



From Left to Right: Martin Claussen, Peter Liss, and John Schellnhuber at the EMIC Workshop in Potsdam

viewer of your paper states that your model is too simple, and the other, that it is too complex, than surely it is an EMIC. Perhaps, EMICs could be best characterized in the following way: They describe most of the processes implicit in GCMs, albeit in a more reduced, i.e. a more parameterized form. They nevertheless simulate the interactions among several components of the climate system including biogeochemical cycles explicitly. On the other hand, EMICs are simple enough to allow for long-term climate simulations over several 10.000 years or a broad range of sensitivity experiments over several millennia. Similar to GCMs, but in contrast to conceptual models, the degrees of freedom of an EMIC exceed the number of adjustable parameters by several orders of magnitude.

What can be learnt from GCMs – and then be implemented in EMICs? Certainly, parameterization of high-resolution processes, which are not resolved in an EMIC, but explicitly simulated in GCM can be derived from GCMs. This could work, for example, for parameterization of synoptic systems, while for processes which are sub-grid scale in GCMs, e.g. clouds, comparison is limited. In this respect, EMICs seem to work “as good or as bad” as GCMs.

A second issue raised in the workshop concerned validation of EMICs. Obviously, validation in its strict sense is not possible, because of the lack of controlled validation experiments – nature provides just one time series. On the other hand, models can be evaluated against various periods in Earth history, driven by changes in orbital parameters only. An interesting suggestion was made to aim at a prediction of palaeo trace gas concentrations, before new data are published, for example, from ice cores. In general, EMICs can be expected to become more widely accepted, if convincing predictions of palaeoclimates are made. At the workshop some first impressive examples were already given.

With respect to validation of EMICs, a special session of the workshop was devoted to palaeo data sources. A large number of well dated and synchronized sediment cores are available for the last 15.000 years. Similarly, high-quality reconstructions of vegetation of various sites have been made available, e.g., through the BIOME-6000 project. A serious problem, however, concerns the interpretation of site reconstructions. The spatial representativeness of point data or data from small regions is necessary before these can be used to validate large-scale models (GCMs or EMICs). Hence special efforts have to be made to aggregate data to larger spatial scales. Earlier best estimates obviously need to be revisited in the light of new reconstructions.

The discussion on EMICs gained at lot of momentum from the Potsdam workshop. Certainly, more questions were raised than answered. Hence there will be follow-up workshops at the AGU fall meeting in San Francisco, USA, this year and, for a more intense discussion on the physics of EMICs, at the next EGS meeting in Firenze, Italy.

GAIM PROGRAM ASSISTANT

IGBP/GAIM seeks an energetic and capable individual for the position of GAIM Program Assistant to assist the GAIM Executive Director, facilitate operation of the GAIM Office, and coordinate with the various other parts of IGBP.

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- Maintain detailed budgets of GAIM projects and activities and prepare reports to funding agencies
- Produce and disseminate GAIM Newsletter (Research GAIM)
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The ideal candidate will have some experience in international research programs, be comfortable with a range of software on various computers, including Mac, PC, and Unix. Excellent speaking and writing skills (English) are important. Salary is competitive and based on UNH salary scales. The full benefits package is included.