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

*Volume four, number two
Winter 2001*



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International Geosphere Biosphere Programme

A Note from the Chair: Towards the New GAIM Programme

By John Schellnhuber

A powerful virus has recently infested the scientific community and already triggered a veritable pandemic. This virus causes the so-called “Integrative Policy-Relevant Research Disease” (vulgo: IPR Fever) with disquieting symptoms like excruciating synthesis urge, obsessive affection of natural scientists for social scientists (but not necessarily vice versa), insatiable desire for appreciation by decision makers, stake holders and the general public, and – above all – persistent thirst for deliberation hardly quenched by the crescendo of pertinent meetings across the globe.

The triumphant march of the IPR Fever can only be explained by the frailty of most contemporary scientific bodies – exhausted by decades, if not centuries, of disciplinary aspiration to erudition as an end in itself. As with many diseases, the fever aggressively attacks especially the junior and the very senior community members, while the middle-aged scientists often get away with an ephemeral indisposition. The virus is now raging in the ranks of IGBP researchers, predominantly at the international level as represented by the SC members and the main officers.

Yet alarming news keeps arriving also from the national IGBP communities, who seem to succumb to the disease one by one. The involvement of the GAIM Task Force in the outbreak and management of this crisis is subject to widespread rumours and far-fetched speculations. No definite proof has been presented so far, however, that the contagious germs originate from uncontrolled thought experiments carried out at the University of New Hampshire during the mid-1990s.

Let us turn serious now: IGBP is, in fact, facing a number of phase

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transitions towards trans-disciplinarity and strategic applicability. There is just no way to dodge challenges like the scientific assessment of carbon management options under the Kyoto Protocol, or comprehensive risk analysis concerning potential disruptions of large-scale bio-geophysical resp. biogeochemical components or processes by anthropogenic interference. It seems logical that the global sister programmes WCRP, IHDP, and DIVERSITAS will co-evolve in close interaction, and will ultimately merge with IGBP to form an international system of "Earth System & Sustainability Science (ESSS)".

What appears logical, however, does not need to be a possible, let alone a probable, development. Sectoral science has been so overwhelmingly successful in the past that even the most modest attempts of diagonalizing it arouse fierce opposition among the practitioners. And who can guarantee that the results of strategic research are not prescribed or misused by pressure groups and power cartels? Finally, which committee, group, network or procedure within the global change community will actually provide guidance and stewardship on this journey towards ESSS? It has become fashionable to trust in the "self-organization" of a complex system, but everyone responsible for a major research project is aware of the poor confidence level involved.

Without being presumptuous, one may conclude from a quick tour d'horizon that GAIM could act as an important condensation nucleus for the scientific phase transitions envisaged. Before the Task Force Spring Meeting 2000 in Hawaii, GAIM was basically an international carbon cycle initiative that demonstrated impressively, and exemplarily, how to cross-cut certain fibres of the IGBP texture. During that meeting, the contours of a "New GAIM" were drawn

with the broad brush of the "Waikiki Principles" (see Research GAIM, Winter 2000, p. 2). The three principles state that GAIM shall (i) act as a trans-project topics scout and feasibility assessor; (ii) support the construction, maintenance and application of a family of Earth System models of varying complexity, and (iii) advance the integration of global change wis-

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GAIM in the 21st Century

*By Dork Sahagian and
John Schellnhuber*

As we begin 2001 (an Earth Odyssey?), it is helpful to take stock of where we are and where we are going in GAIM and perhaps throughout IGBP and related international global change research communities. If the most recent decades of the 20th century were a period of building the foundations for understanding the disciplinary environment for the various processes that drive the Earth system, then the early part of the 21st century is likely to become a period of consolidation of diverse disciplinary studies into a few (or single) approaches to exploring the functioning of the system. (See "Note from Chair", p.1) IGBP as a whole is already beginning to evolve in that direction with the possible consolidations of distinct programs into the broader categories of land, atmosphere, and ocean along with a greater emphasis on their linkages.

In 2000, GAIM moved farther into its track of system-level research with the growth of the

EMIC initiative and the cementation of the "Flying Leap" experiment into a more focused C⁴MIP (Coupled Carbon Cycle Climate Model Intercomparison Project). At the same time, the three main "disciplinary" model and data intercomparison projects, OCMIP, TransCom, and EMDI have produced concrete results so that they are becoming well suited for integration into broader scale Earth System modelling activities.

At the recent GAIM Task Force Meeting in San Francisco, the past and present GAIM projects were reviewed in light of the renewed emphasis on Earth System Analysis. Anticipating some of the main issues that face GAIM, a set of GAIM Tasks was established for the next few years, as listed below. These will be complemented by additional projects formulated to address issues that emerge from the more specific questions being formulated this year.

- Development of a set of operational questions to be addressed by GAIM.
- TRACES (Trace Gas & Aerosol Changes in the Earth System)
- C⁴MIP (Coupled Carbon Cycle

- Climate Model Intercomparison Project)
- Earth System Atlas
 - Earth System Models Spectrum Interaction
 - Earth System Analysis Post-doc Network
 - Dynamical Large-scale Marine Biosphere Model
 - Land-atmosphere Interaction Initiative (GLASS-GAIM collaboration)
 - Conceptual exploration of total Earth System Assessment
 - Multiregional hot spots analysis
 - Global atmosphere methane synthesis
 - OCMIP; TransCom; EMDI-model and data intercomparison projects.

Development of a Set of Operational Questions to be Addressed by GAIM

At the recent GAIM Task Force meeting in San Francisco, it was decided that we should hold an email conference to formulate an updated set of questions for GAIM. The original questions posed in the 1997 GAIM PLAN have not yet been entirely answered, and may not even any longer be relevant, given recent developments at all levels. They may, in part, be useful as an overarching set of issues, but they were not created with specific research activities in mind. A more specific set of questions needs to be developed that can lend itself to the emerging structure of IGBP. This may both support and help steer the new IGBP structure. The projects that are developed to answer such questions should be tractable and able to be completed within a several year time frame. While these questions would be

developed for GAIM, they really should pertain to all of IGBP, and should therefore fit in well with the existing and/or planned IGBP structure.

TRACES

This project was initiated by GAIM as a “paleotrace gas challenge.” The ice core records tell us atmospheric composition over the last 400 ka, but the explanation for why the variations have occurred as they have will require an understanding of the mechanisms of interaction between the biogeochemical and biogeophysical interactions throughout the Earth system. TRACES involves a comprehensive view of ocean, land, and atmospheric processes (physical, biological and chemical) and their non-linear interactions.

C⁴MIP

The “Flying Leap Experiment” is now being referred to as the Coupled Carbon Cycle Climate Model Intercomparison Project (C⁴MIP). The models consider CO₂ from prescribed emissions and land cover. Minimum requirements for models for comparison include CO₂ emission specification, a set of initial conditions, and full coupling between radiation budget, biogeochemical cycles, and CO₂. At another level, models may also diagnose processes and include fully coupled carbon except that CO₂ is fixed at 280 ppm for climate. The highest level of experiment adds additional radiative forcings such as land use change, methane, etc. Off-line land and ocean carbon cycle models include prescribed atm CO₂ forced by control climate and tran-

sient climate to calculate carbon uptake by land and sea. Six to ten groups are involved and plan to meet in Amsterdam at the Open Science Conference in July, 2001. Hadley and IPSL have already completed a set of experiments. The two show the same emissions, but differ in sinks because of the terrestrial biosphere. Hadley includes dynamic vegetation while IPSL does not. GAIM can offer these results to the ecological community as a challenge to those who know the biosphere to prove or disprove these model results on the basis of observational or functional constraints.

Earth System Atlas

There has been considerable discussion since the SC-IGBP met in Cuernavaca last year, to construct an “Earth System Atlas” for the benefit of the research community as well as a mode for dissemination of our results to the general public. The “Atlas” would be a tool in helping to visualize how the Earth System is changing, and would document our analyses of the past, observations of the present, and forecasts for the future through scientific models, as well as introducing human dimensions. Uncertainties would be explicitly indicated because scenarios are often mistaken for predictions. The target audience would be scientists, policy makers, educational communities and the general public. The Atlas should be a useful tool for steering future research and understanding within the scientific and policy sectors as well as the general public. It would initially be created as a web-based information system, but could later

TransCom Update

By Scott Denning

TransCom is an intercomparison project for atmospheric CO₂ inversion calculations, currently in its third phase. Fifteen modeling groups have submitted “Level 1” output, which consists of annual mean global simulated concentration fields due to atmospheric transport acting on unit CO₂ emissions from each of 22 regions [Fig 1]. In addition, each model was

used to simulate spatial patterns associated with fossil fuel combustion, air-sea gas exchange, and seasonal net ecosystem production for a “balanced” terrestrial biosphere [Fig 2]. Each model’s results were then used to calculate annual mean CO₂ sources and sinks from each of the 22 regions to obtain a best fit to measured concentrations at each station shown in Fig 1.

Our results are broadly consistent with those reported for coarse spatial regions in the IPCC Third Assessment Report [Fig 3], with CO₂ release in the tropics, and uptake in the extratropics of both hemispheres. Although specific regional fluxes produce quite different simulated tracer fields among the 15 transport models, several features of the

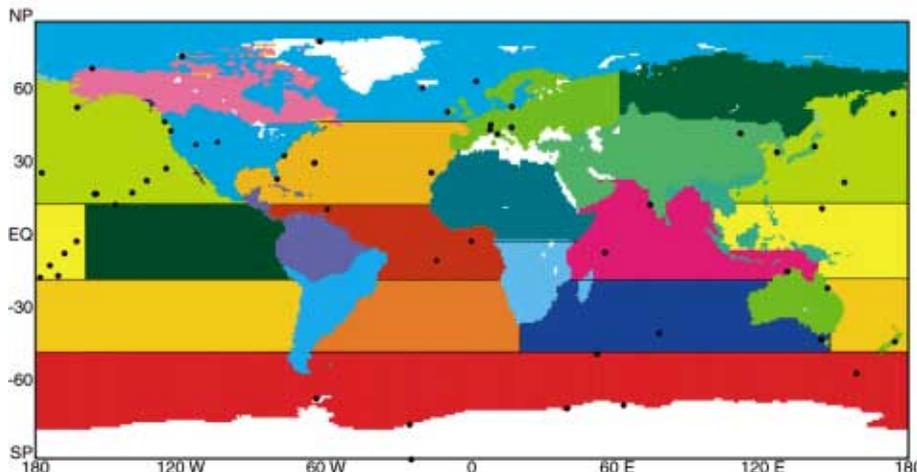
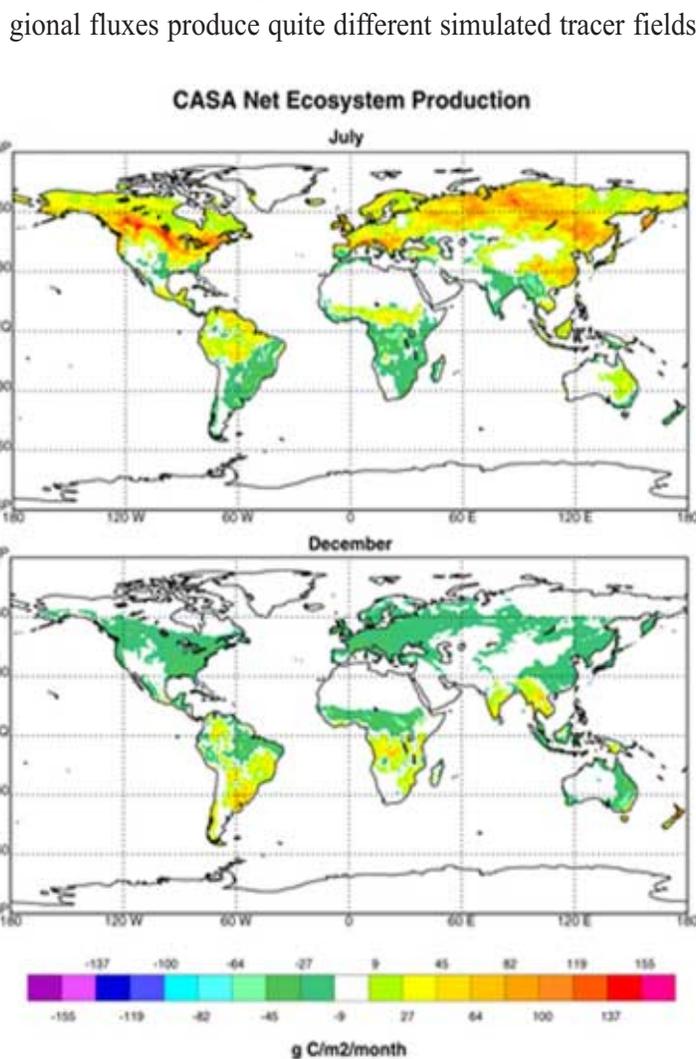


Figure 1: Regions used for TransCom 3 simulation. Black dots indicate stations used in the inverse calculations.



inverse results are quite consistent. In many regions, the differences in estimated flux among the models are smaller than our estimate of the uncertainty associated with a given model, suggesting that additional observations could add significant information to the inverse problem. In other regions, the between-model spread in inverse results is larger, particularly in the northern temperate regions. Most of these differences are related to the effect of the “balanced” seasonal terrestrial biosphere, which interacts with seasonal transport to influence the annual mean spatial pattern at the surface. Robust results across the suite of transport models include a reduction in the strength of the southern ocean sink relative to estimates made from air-sea gas exchange measurements, and a tendency for the terrestrial sink in the northern midlatitudes to be approximately evenly spread in longitude.

The participating modelers are busy running the “Level 2” experiment, in which spatial response functions are simulated for emissions for each region in each month. These will be used to invert for the monthly fluxes from each region, and will be the subject of our upcoming GAIM-sponsored workshop to be held March 19-23 in Melbourne, Australia.



Figure 2: Monthly fluxes from “balanced” terrestrial biosphere used in the TransCom 3, Level 1 simulations

EMDI News

By Kathy Hibbard

The next Ecosystem Model/Data Intercomparison will be held 18-21 April, 2001 and is jointly sponsored by GAIM and the National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, California. The first EMDI workshop included 12 bio-geochemical, satellite-driven, detailed process, and dynamic vegetation global model types. The EMDI II Participants will include all modeling groups from the first, except one (model is no longer supported) and has expanded to include 5 additional groups for a grand total of 16 global terrestrial ecosystem models. The participating modelers will utilize data sets that have been improved through outlier analysis and perform new

model runs for a set of approximately 4000 0.5° grid cells. Whereas the analysis in EMDI I was based on comparing ensemble values averaged from all 12 models strictly for total (above and belowground) NPP, EMDI II will compare model results with NPP data for individual models and also require models to supply above and belowground NPP estimates to assess how models allocate carbon in various biomes relative to the data. In addition, multi-year NPP estimates for a variety of sites to will be compared to interannual model estimates. In addition to the analysis of differences between models and data, EMDI will produce an enhanced multi-layered data collection, again that will ultimately be made available for additional use by the wider scientific com-

munity. The enhancements include associating climate, soils, NDVI, and vegetation characteristics with each of the NPP measurements, and performing an outlier analysis to address data quality concerns.

In addition to the comparisons, participants at the April workshop will refine the current draft of the paper describing the "ensemble" results from the first workshop. Future directions for EMDI will also be discussed. Current proposals include the inclusion of transient analyses to test models and data against data collected from tower flux sites. More information about EMDI can be found at the GAIM website: <http://gaim.sr.unh.edu/Structure/Intercomparison/EMDI/index.html>



OCMIP evaluation of deep ocean circulation

by James C. Orr

Ocean carbon transport and air-sea CO_2 fluxes are intricately linked to the rates and pathways of ocean circulation. Results from the current phase of the Ocean Carbon-Cycle Model Intercomparison Project (OCMIP-2) reveal that ten global ocean carbon-cycle models simulate about the same uptake of anthropogenic CO_2 for the modern period (1.9 Pg C yr^{-1} within $\pm 13\%$), but greater diversity for the future uptake (a range of $\pm 20\%$ about the mean in the year 2100 and $\pm 35\%$ in 2300). At present, most of the anthropogenic CO_2 in the ocean is confined between the surface and upper thermocline. In the future, a substantial fraction of

anthropogenic CO_2 will reach the deep ocean, where it will be necessary to establish skill in modeling deep ocean circulation.

To evaluate modeled circulation, OCMIP-2 made standard simulations with tracers of ocean circulation. A first effort focused on CFC-11 (Dutay et al., 2001; Orr and Dutay, 1999), a transient tracer that tracks waters that have been ventilated in recent decades. Another circulation tracer, natural radiocarbon, has been used during OCMIP to evaluate deep-ocean circulation. Natural ^{14}C is useful because it exhibits horizontal and vertical gradients in the deep ocean due to a combination of its decay rate (half-life of 5730 years) and the slow ventilation of deep ocean waters (100 to 1000

years). Thus natural ^{14}C offers time-dependent information, unlike tracers such as temperature and salinity (e.g., see Toggweiler et al., 1989). During OCMIP-2, we have compared simulated natural ^{14}C with that estimated by Broecker et al. (1995) from measurements taken during GEOSECS (Geochemical Ocean Sections Survey), the first global-scale oceanographic measurement campaign (during 1972-1978). Figure 1 shows the OCMIP-2 comparison along the Western Atlantic GEOSECS section. Clearly, it remains a challenge for models to match natural ^{14}C along this section. To do so, a model would have to obtain the right balance between the influx of young northern waters that fill the deep North Atlantic basin, and old southern waters

dom inside and outside the IGBP.

The Waikiki principles were adopted by the SC in the Cuernavaca Meeting a few weeks later (see IGBP Newsletter 41). This means, in particular, that the New GAIM is expected now to explore strategies that convert the IPR Fever into constructive and concrete actions. Discussions at the recent Task Force Meeting in San Francisco (see "GAIM in the 21st Century" on p. 2) has created a framework for these actions that will evolve into the New GAIM Programme over the next years. The programme should embrace four major items:

1. Identifying Key Questions

The GAIM Plan 1998 – 2002, formulated three or four years ago, was organized around “Fundamental Questions” that addressed past, present and future global changes in a rather sweeping way. During the San Francisco Meeting the Task Force carried through the exercise to revisit these questions and to assess their timeliness, adequacy and impact on the real spectrum of GAIM and IGBP activities, respectively. The conclusion was that the questions are somewhat obsolete, some ways dysfunctional, and only somehow related to ongoing research and intercomparison projects. As a consequence of this remarkably crisp statement, it was decided to conduct an email conference involving several internal Task Force members and the lead authors of the IGBP Earth System Overview volume. The goal is to come up with a well-crafted set of specific, operational key ques-

tions that reflect the present state of our knowledge/ignorance, and compel the scientific community to seek answers through well-designed research actions. If the enterprise succeeds, the resulting set will be more than just another collection of “Grand Challenges” – it will try to anticipate what Earth System Science shall be all about in the decade ahead.

2. Developing Powerful Tools

The advancement of appropriate methodologies and instruments for ESSS constituted one major focus of the Task Force discussions and may become, in fact, the most relevant service GAIM can render the global change community. The tools (or “macroscopes”) needed concern, in particular, (i) global observation, (ii) systems analysis, and (iii) simulation modelling. Regarding the first item, GAIM could help to design, e.g., global monitoring strategies that do not simply result in frantic data production due to the exploding remote-sensing opportunities. Regarding the second item, GAIM should join forces with potentials inside and outside the IGBP community in order to make the tool-kits of modern nonlinear dynamics & complexity theory available for ESSS (see P. Canadell’s recent contribution to Global Change Newsletter 43).

Regarding the third item, GAIM must take the lead in exploring all possible roads towards virtual reality of the environmental past, present and future. The Task Force started to deliberate and develop an “Earth System Modelling Matrix” that can be used,

i.e., as a production plan. The matrix embraces a spectrum of “models” in the wider sense – ranging from the Earth System Atlas over semi-quantitative approaches to genuine simulation machines of various degrees of complexity and sophistication (e.g. Frontier Project in Japan). The race for Earth Simulators that really deserve this name has to be complemented, however, by the construction of Regional Simulators that can be employed as assessment and management tools for “place-based” transitions to sustainability. Here we encounter one of the most advanced frontiers of the scientific enterprise at large: accounting for the crucial socioeconomic factors will require ingenious strategies based on, e.g., stochastic game theory, agent-based modelling and experimental decision dynamics generated from large representative samples of real “actors”.

3. Conducting Focused Campaigns

Dreaming, talking and planning are vital ingredients of the scientific stew, but ultimately a Task Force has to strike. GAIM boasts a record of seminal carbon cycle research actions including several highly successful intercomparison projects. The New GAIM seeks to become even more operational by subscribing to a short-list of well-defined campaigns to be led by well-selected Task Force members or affiliates. It is not possible – and probably not even desirable – to invent an optimized top-down structure for such a set of medium-term actions. The short-list generated in the San Francisco meeting is, in

fact, the result of an opportunity-oriented and curiosity-driven bottom-up process. There will be several biogeochemical intercomparison projects under the roof of GAIM also in the future, and there will be an initiative to synthesize the current wisdom about the dynamics of methane across the global atmosphere. There will be intensified efforts to reconstruct, interpret and model the strongly non-linear behaviour of trace gases, aerosols and dusts over the last 500,000 years. There will be a campaign to identify/summarize the switch & choke points, the critical threshold lines, and the operational hot spots in the planetary machinery; this can provide valuable guidelines for selection and performance of “big” region-focussed research like LBA. As a final example, there will be a concerted attempt to establish an international network of GAIM postdocs who are to address, i.e., the aspects of uncertainty and irregularity in ESSS.

4. Setting Integrative Agendas

There are two semi-orthogonal exits out of reductionistic research, namely horizontal integration (object-oriented avenue) and vertical integration (objective-oriented road). The first option is characterized by the ambition to grasp the nature, functioning, susceptibility, etc. of a given specimen as a whole – however clumsy or entangled it may be. The pertinent disciplines have to serve the common goal here, rather than to demonstrate their sovereignty. The Task Force pondered a number of opportunities for GAIM to advance horizontal integration processes within the ESS frame-

work: laying the foundations for a comprehensive “Dynamical Large-Scale Marine Biosphere Model” through dialogues between the proper IGBP communities (JGOFS, GLOBEC, LOICZ, GCTE) but also across the international programmes (involving, e.g., the ocean circulation and the biodiversity scientists); pursuing a land-atmosphere interaction initiative that brings together the specialists from GAIM and the WCRP-based GLASS group; exploring the eligible concepts for incorporating the “human dimensions” in quantitative assessment models of the total Earth System. All these processes are likely to amplify – beyond the cognitive progress to be achieved – the attractive forces between the different camps in the global change arena. Discussions have started already whether a joint agenda for GAIM and WGCM (the coupled modelling project within WCRP) could serve as a role model for the ultimate “grand unification”.

The second option to transcend traditional research schemes is characterized by the need for converting academic knowledge into operational wisdom for decision-makers and stakeholders. There is little doubt that anthropogenic interference with the planetary environment constitutes a management problem of entirely novel quality: how will we organize, for instance, an orderly retreat from the undefendable coastlines of the world? All the relevant societal layers that relate research to action have to cooperate on such a task. This requires, however, that the codes of honour within the

scientific community cease to dismiss policy relevance as an inferior-quality surrogate for originality. The IPCC process has done a lot to undermine prejudices of that kind, but its own future is shrouded in fog without a clear-cut concept for the aims and scope of the next assessments. Issues like equity and sustainability in times of climate change deserve strategic research efforts beyond the steps made so far. There needs to be a mobilization of “solution knowledge” concerning the other critical compartments of the Earth System like the degrading pedosphere? Should one strive to establish an IPSD (“Intergovernmental Panel on Soil Erosion and Desertification”), an IPBD (“Intergovernmental Panel on Biological Diversity”), etc.? How could these scientific panels cooperate to help matching the presently isolated environmental management regimes featured by distinct international conventions? The systems-level view seems to be the most appropriate instrument to tackle these questions, so it may be GAIM’s bounded duty to ventilate, at least, ideas about the possibly emerging structures. Here we are, of course, a very long way from home.

From all I have said, you may conclude that I am afflicted with an especially serious case of IPR Fever – let us not argue about this now. I did not warn you, though, that the virus is spread also by the written word. So if you have read this far, you may find out for yourself



'Flying Leap' becomes 'C⁴MIP'

By Peter Rayner

Although only now entering the stage of a formal GAIM project initial results from the Flying Leap are already arousing considerable interest. In particular the publication of the work by Cox et al. from the Hadley Centre, with an experiment almost exactly as envisaged in the early descriptions of the intercom-parison, marks a sharp raising of the profile of this kind of work.

On December 12 in Berkeley, a meeting was held between the coordinators of the Flying Leap (now including Peter Cox) and also including Curt Covey from PCMDI. PCMDI have agreed to offer hardware and logistical support for the experiment which will be known formally as the Coupled Carbon cycle Climate Model Intercomparison Project, thankfully abbreviated to C⁴MIP. At this meeting we agreed on the general form of the protocol for the experiments, guided by the experiences of the groups from the Hadley Centre and LSCE in France who have already performed the experiments. The cost of the simulation requires a relatively small number of simulations but with a correspondingly rich set of diagnostics. The first phase at least will focus on just two 250-year simulations, from 1850-2100. Both will use historical and projected emissions of carbon from fossil fuel (and land-use change). In one experiment this additional carbon will be visible only to the carbon-cycle models while in the other it will impact the climate as well. Thus we should

be able to quantify the size of climate change feedbacks on the carbon cycle. Note that the "on-line" nature of the experiment means that additional carbon fluxes which result from climate change may also affect the climate, i.e it is a full-feedback experiment. The magnitudes of all major carbon pools and fluxes will be archived in both experiments and, where possible, atmospheric CO₂ will be subject to atmospheric transport so that comparisons can be made with historical concentration datasets. The strong suggestion that participating models have submitted their components to other intercom-positions such as CMIP (to assess climate sensitivity) OCMIP (for the ocean carbon cycle) and the grand-slam experiment of the CCMLP (for the terrestrial carbon component) will ensure that the contributions to the feedback can be assessed.

At the meeting, Peter Cox and Pierre Friedlingstein gave presentations of their initial results, including some comparisons. The differences are indeed striking with the Hadley Centre model showing 250 ppmv extra CO₂ in the atmosphere as a result of the impact of climate change on the carbon cycle while the LSCE model shows 75 ppmv extra. It is noteworthy that this difference means that the uncertainty in the response of the carbon cycle to climate change is now comparable with differences between various emission scenarios. A striking difference between the two results was over Amazonia. Here the Hadley Centre simulation showed a large reduction in the wet tropical forest and a cor-

responding decrease in carbon storage. The LSCE model, without a dynamical land-cover change, showed smaller differences. However there were also larger-scale differences in soil carbon between the two models which contributed to the global difference. The ocean component in both models acted as a small negative feedback, absorbing some of the additional carbon released from land. Obviously, with such a rich set of interactions, fairly close analysis will be required to understand the differences. It is hoped that the availability of a few more model results might also give a picture of which parts of the climate response are robust.

A survey of global capability in this area suggested about six groups which can take part in such an experiment either now or soon. It is hoped to convene a larger meeting of these groups within the next 12 months. We are also exploring the chance of a smaller meeting attached to the IGBP Open Science Conference in Amsterdam in July .



FIELD TRIPS to LTER sites at the Spring AGU meeting !

At the Boston AGU meeting (May 29-June 2, 2001), a series of exciting oral and poster sessions will culminate with FIELD TRIPS to Harvard Forest and Plum Island Long Term Ecological Research sites (LTERs) on June 2. For details see <http://earth.agu.org> or contact the GAIM Office.

be converted to hard-copy if appropriate. Construction of the Atlas would be a major effort for IGBP.

Earth System Models Spectrum Interaction

There is a spectrum of Earth System models ranging from simple "daisy-world" models, through various levels of intermediate complexity models (EMICs), to full-form models (e.g. GCMs). Each have their strengths and weaknesses. There is a continuous spectrum in all dimensions, and EMICs generally occupy the middle ground in varying combinations. Models can be evaluated in two ways. The first check is internal to ensure mass balance, energy conservation, etc. The second is to test retrodictions against paleodata. By considering the full spectrum of models, insights from one level can be applied to other levels. For example, full form models (such as GCMs) could be used to calibrate EMICs that could then be applied to longer time scale system-level problems.

Earth System Analysis Post-Doc Network

The exploration of the Earth system as an integrated whole through model development and assessment will require considerable time and effort by the entire global change research community. The task is so broad that no single project can address the entire spectrum of interacting parts of the system. It has required entire institutions just to develop models of individual and isolated subsystems. We are now confronting the problems that reside at the

interfaces and at the system level that are not apparent when limiting ones attention to a single part of the system. Earth system analysis at this level will require coordinated effort and a team of dedicated scientists. The suggestion has been made to assemble such a network of 5-8 post-docs, each supervised by leading international scientists, and coordinated by the GAIM office. In the next year, the composition and specific tasks for this potential network will be specified. A number of issues are being considered, including: How should the post-docs fit into GAIM activities? Where should they work? How should they interact with each other? How will they be funded? What will be their products? As answers to these questions emerge, GAIM may begin to initiate such a program to more effectively reach its goals in Earth system analysis.

Dynamical Large-Scale Marine Biosphere Model

The importance of the marine biosphere has become clear in recent years because of its role in the carbon and other biogeochemical cycles in addition to direct biophysical influences such as ocean color. The exchange of carbon between ocean and atmosphere depends on the solubility pump and the biological pump. While the solubility pump is relatively simple to understand but is data-limited, the response of the biological pump to changing atmospheric CO₂ concentrations, water temperature, circulation, and nutrient loading needs to be much further explored before its role in the Earth system can be quantified. In addition, we can expect

adaptation and evolution of the marine biosphere in response to various aspects of global environmental change, but the nature, rates, and critical thresholds of such biospheric alterations have not yet been identified, much less understood quantitatively. Consequently, a comprehensive dynamical model needs to be developed for the marine biosphere that will represent the marine ecosystem in Earth system models. This will make it possible to not only predict specific responses of the marine ecosystem, but also to better assess the contribution of the oceans to the amplification, buffering, or simple transmission of changes occurring throughout other parts of the system.

Land-Atmosphere Interaction Initiative

Global Land Atmosphere System Study (GLASS) is an effort by GMPP/WGNE in collaboration with GEWEX and BAHC to improve surface schemes for the benefit of numerical weather predictions and climate models. One of the objectives of GLASS is to develop better land surface parameterization schemes. It will extend the previously developed PILPS schemes to the global system. The key issues are land surface schemes, and their coupling to Dynamic Global Vegetation Models (DGVMs). This coupling is the main potential area for interaction between GLASS and GAIM. New features include a carbon cycle and dynamic vegetation and horizontal complexity (hydrology, etc). GLASS represents a significant interaction between the carbon cycle community and the commu-

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ity that understands energy balance via land surface schemes.

Conceptual Exploration of Total Earth System Assessment

As the role of human society is further understood in the context of the Earth System, it is becoming clear that global models will not be fully complete until socio-economic factors are included in a robust manner. There are linkages between population, economics, policy, culture and technology. Human dimensions research is centered on an anthropocentric world view. However, it is difficult to make a linear coupling between ecosystem health and human welfare. In economists' calculations of ecosystem damage costs, for instance, figures are based not on abatement, but rather on adaptation. The basic kinds of knowledge being sought differ at a fundamental level between social and natural scientists. One difference is prediction vs. understanding of the mechanisms at work in a system. Social sciences are scenario-based, while natural science seeks to make predictions based on "first principles" and a set of observable initial conditions. It may be possible to develop a common understanding of basic attributes of the Earth System, provided we confront the methodological incongruities at the interface between natural and social sciences. GAIM can play an important role by providing: 1) A common core of research questions and conceptual tools; 2) Compatible epistemological positions and methodological strategies; 3) Ecocentric vs. anthropocentric views (ecosystem health

vs. human welfare); and 4) Notions of goals and thresholds. In so doing, GAIM and IGBP with its sister programmes will be in a stronger position to develop fully comprehensive prognostic Earth System models.

Multiregional Hot Spots Analysis

Certain regions can be viewed as 'hot spots' in the global context. A scheme to design a multi-regional assessment that would offer a global intellectual framework for looking from the top down could be beneficial. There are hot spots in ecosystems, atmospheric and ocean circulation, land use and land cover, population, social systems, and many aother parts of the Earth system. A discussion of such hot spots will begin at the Open Science Conference in July.

Global Atmosphere Methane Synthesis

The Global Atmospheric Methane Synthesis (GAMEs) project interfaces with other parts of GAIM mainly from the standpoint of some of the synthesis activities that will provide a sense of the evolution of methane in the atmosphere. Inverse modelling methods can be used to address sources and sinks, and GAIM contributes to this by considering all the processes together, and determining the uncertainties involved in methane as a tracer and perhaps a test of other model results. The paleo part of GAMEs intersects with the methane part of TRACES.

GAIM activities for the next few years with respect to Earth system analysis can be viewed in the context of the following "matrix" of

the Earth system, in which the level of model complexity is on the vertical "axis" and sequence of activities is on the horizontal. It has been said, half jokingly, that "the more you know, the more you know you don't know." Whereas we once thought we knew everything we needed to know to take full advantage of the natural resources available to us for the advancement of mankind, we are beginning to realize that as in all things, matters are not that simple. We now realize that human activity has a profound effect on the Earth system, with human perturbations in the form of emissions and land use becoming the fastest drivers of global change. However, we still do not know how to even qualify the effect of these or the response of the global system, much less how to quantify the amount and rates of changes in response to known anthropogenic perturbations.

One of the most important things GAIM learned in the 20th century is that it must be flexible and responsive to the changing needs of the global change research community. GAIM must be in a position to take advantage of and build on accomplishments and insights that emerge from a broad range of research communities. We are continuously faced with new challenges such as finding an explanation of the variability and finite amplitude envelope of climate and atmospheric composition over the last 400 thousand years. In the 21st century, these challenges can only grow, and their solutions will depend on a comprehensive approach to the Earth system and the dynamics that control its behavior.

EARTH SYSTEM ANALYSIS MATRIX

	Scoping, Targeting, Design	Construction, Implementation	Tuning, Harmonization	Numerical Optimization	Sensitivity & Uncertainty Analysis	Evaluation, Intercomparison	Application (Scenario & Case Studies, CB-Schemes, Policy Exercises)	Dissemination, Popularization
Earth System Atlas (ESAT)	Identification of Vital Organs & Processes in the Earth System	* Production of Syndromes Sub-Atlas, *Web-based input from CPs, WCRP, IHDP	Managing the Integration of Human Dimensions Information					*Web-based Atlas, *Hard copy full Atlas or sub-Atlases
System-Analytic Conceptions (ECONCs)	Lists of *Vital Organs & Processes, *Nonlinearities, *Synergisms, & Teleconnections	Wiring Diagrams, Flow Charts, Box Networks: Physiological Analogies	Adequate Representation of Anthroposphere		Graph-Theoretical, Bayesian, etc., Inspection	Input-Output Flow & Consistency Analysis	* Identification of Intervention Points, *Qualitative Projections	Demonstration & Visualization Software
Stylized Earth System Models (ESTYLs)	Selection of Priority Issues for Investigation	Building a Demonstration Eco-Anthroposphere Model	Parameterized/Semi-qual. Expert Representation of Human Dimensions	*Exploration of Potential Numerical Instabilities & Artefacts, *Object-oriented Operation	Full Investigations of Ignorance Dynamics and Bayesian Updating	Comparison with Existing Integrated-Assessment Models	Formal Sustainability Analysis (Paradigms, Guardrailing)	Creation of Earth Simulation Game
Inter-mediate Complexity Models (EMICs)	*Catalogue of Systems-Order Items, *Master Set of Questions		Strategy for Intermediate-Complexity Coverage of Anthroposphere	Investigation of Optimization Options	Illustrative Investigation of Ignorance Analysis (CLIMBER, e.g.)	*Model for Modelers, *Organization of EMICs Olympics?	Tentative Manual for Planetary Management	Dahlem Conference & Proceedings
Earth Simulator (ESIMs)	Complete List of Relevant Modules	Vision of Ultimate ESIM design?	Criteria for Full-Complexity Representation of Anthroposphere		Strategy for ESIM Uncertainty Analysis beyond Adjoint Modelling	Organization of Dialogue Between EMICs & ESIMs Communities		Advancement of Earth System Science Journal

that move northward near the bottom and at intermediate depths.

Four of the models (Princeton, LLNL, NCAR, CSIRO) reveal the classic problem first identified by Toggweiler et al. (1989). Their young northern deep waters penetrate no deeper than 3000 m, leaving room for very old southern bottom waters to move northward up to about 50°N. The other eight models manage to simulate younger deep Northern Atlantic bottom waters. However in six cases (AWI, IGCR, IPSL-GM, MIT, PIUB, SOC) their natural C-14 is too young throughout the section. In the two remaining models (IPSL-HOR, and MPIM) one generally finds about the right level C-14 along this section. In particular, both models simulate the southward moving tongue of younger North Atlantic Deep Water (NADW) confined by older waters moving in from the Southern Ocean, both above (AAIW) and below (AABW). Yet both of those models still have trouble matching observed gradients in natural C-14, particularly along the bottom, which could indicate inadequate northward penetration of AABW. The MIT model seems to offer the best performance in this regard.

OCMIP-2 has also evaluated the same models along six other basin-scale sections taken during GEOSECS. Generally, the RMS results support the visual qualitative analysis for each section. The comparison along sections along with comparison of global mean deep-water ¹⁴C set reasonable lim-

its for the mean age of deep waters and thus future uptake of anthropogenic CO₂. Further model evaluation with ¹⁴C is ongoing, with emphasis now being placed on more recent ¹⁴C measurements from the World Ocean Circulation Experiment (WOCE).

During the last few months, proposals have been submitted in the U.S. and in Europe for extending OCMIP into a third phase. If funded, U.S. groups would lead efforts to *i*) use recently available vast global data sets from JGOFS to make ocean inverse calculations and thereby improve estimates of air-sea CO₂ fluxes, and *ii*) implement a common, fully prognostic, marine biogeochemical model that would be used in a series of perturbation experiments focused on nutrient depletion scenarios. European groups, if funded, would lead complementary actions to study interannual-to-decadal variability of air-sea CO₂ fluxes. Discussions of future plans and the latest results from OCMIP-2 is planned for the next OCMIP workshop that will be held in Amsterdam in mid-July during the same week as the IGBP Open Science Conference. In conjunction with that conference, we are also organizing an ocean carbon cycle modeling poster cluster.

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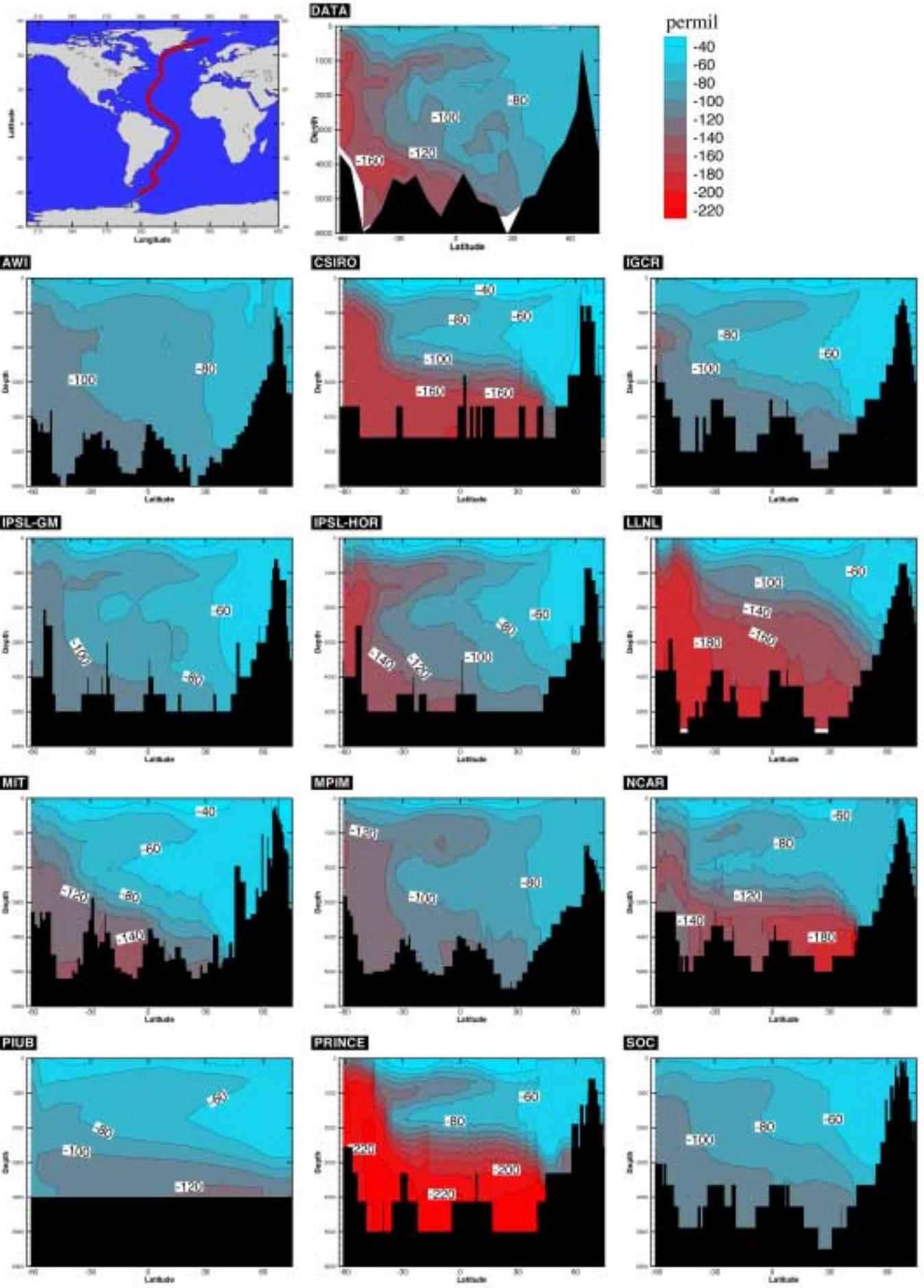
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Fig. 1: Section of natural $\Delta^{14}\text{C}$, the fractionation-corrected $^{14}\text{C}/^{12}\text{C}$ ratio (in permil) along the Western Atlantic GEOSECS cruise track as estimated from observations by [Broecker et al., 1995], and from eleven OCMIP-2 models. The IPSL model is included in two frames to show the sensitivity of changing the subgrid-scale parameterization in that model.



Earth System Models of Intermediate Complexity (EMICs)

By Martin Claussen & Dork Sahagian

At the IGBP (GAIM-BAHC-GCTE) workshop in Potsdam, Germany in June 1999, the state of the art of modelling the natural Earth system was reviewed. It became apparent that Earth system modelling has to rely on a spectrum of models in which models of intermediate complexity can play a central role. Depending on the nature of questions asked and the pertinent time scales, there are, on the one extreme, conceptual, more inductive models, and, on the other extreme, 3-D comprehensive models operating at the highest spatial and temporal resolution currently feasible. Models of intermediate complexity bridge the gap. The so-called Earth System Models of Intermediate Complexity (EMICs) describe most of the processes implicit in the comprehensive models, albeit in a more reduced, i.e., more parameterized form. They nevertheless simulate the interactions among several, or even all, components of the Earth system explicitly. On the other hand, EMICs are simple enough to allow for long-term simulations over several 10,000 years or a broad range of sensitivity experiments. Up to now, there is no concise definition of an EMIC. Perhaps, there can never be a specific definition because the border between EMICs and comprehensive models will change with time as computer capacity and our own understanding of the operation of the Earth system increase. Therefore, in a follow-up workshop in Nice, in April 2000, it was decided to publish a table of EMICs which are currently in operation. This table should reflect the broad spectrum of EMICs; moreover, it should provide an overview of what EMICs can do and where their limitations are. We hope that it will become apparent that EMICs are not designed to compete with comprehensive models, but to complement them. In many cases, EMICs can provide guidance for

a more detailed investigation using comprehensive models. The Table of EMICs is produced by the principal investigators, and they are responsible for the description of their models. The table will be updated regularly, and at http://www.pik-potsdam.de/data/emic/table_of_emics.pdf

In March 2001, as this newsletter was in press, another EMIC workshop was held in Nice. The structure and preliminary results of a set of EMIC sensitivity studies were presented. These include experiments with changing atmospheric CO₂ concentrations and experiments to explore the stability of the Atlantic thermohaline circulation. In this article, the models are only briefly described, but there are important similarities and differences that affect model performance. As additional models are developed and participate in the EMIC activity, this list will grow in number as well as breadth of model variety.

The Bern 2.5D Climate Model

This model is designed to study the role of the large-scale ocean thermohaline circulation in the Earth climate system of the past, present and future. We focus on the stability and dynamics of the thermohaline circulation and its interactions with the ocean carbon cycle on timescales of more than several decades and on spatial scales of more than a thousand kilometers. The simple parameterization of processes results in a computationally efficient climate model suitable for long-term integrations (up to millions of years) and large numbers of simulations not feasible with more complex models. This allows us to focus in detail on the mechanisms and processes of natural climate variability and on the potential anthropogenic climate change.

CLIMBER-2

The CLIMBER (for Climate and Biosphere) model is designed to explore the dynamic behavior of the natural Earth system, including the feedbacks between atmosphere, ocean, vegetation, ice sheets through energy, water, mo-

mentum, and carbon cycles. Besides palaeoclimate simulations, we focus on the resilience of the natural Earth system to natural and anthropogenic perturbations such as changes in solar luminosity, historical land cover change and anthropogenic greenhouse gas emissions. In its present version, CLIMBER-2.3 is applied to long-term, ensemble simulations over several millennia (for example to the mid-Holocene - late Holocene transition) and to the simulation of glacial-interglacial cycles. An extended documentation of the statistical dynamical model of the atmosphere is under preparation.

The ECBILT Climate Model

ECBilt denotes the atmospheric component of a coupled atmosphere/ocean/sea-ice model of intermediate complexity, which was primarily designed to study atmosphere-ocean dynamics in the mid-latitudes. A peculiarity of the atmospheric component is its use of the quasi-geostrophic approximation, with a correction for the ageostrophic terms. The inclusion of the ageostrophic terms results in an overall improvement of the model performance: the jet strength and the storm track are close to the observed state and the simulation of the Hadley circulation is qualitatively correct. The quasi-geostrophic approximation and the use of simplified representations of the diabatic-heating processes result in a computationally efficient climate model. Therefore, it is possible to consider climatic variability on timescales ranging from days to millennia. Focus of future work with ECBilt will be on paleo simulations as well as on ensemble scenario studies.

ECBILT-CLIO-VECODE

This model analyses processes which link ocean, sea ice, atmosphere, and vegetation at mid to high latitudes on time scales ranging from decades to thousands of years. Particular attention is paid to sea-ice processes and oceanic thermohaline circulation. To do so, the model has to include the more important processes at these latitudes (including synoptic atmospheric activity),

while being fast enough so that long runs (> 1000 yrs) and sensitivity studies can be easily performed. A first group of studies consists of analysing the variability of the system using constant forcing. This identifies the feedbacks inside the system which are important to maintain natural variability and increase understanding of these mechanisms. A second group of studies deals with the response of the system to changing conditions on various timescales (decadal to millennium). Attention is focused on how the feedbacks inside the system amplify or dampen the initial forcing as well as the impact of these perturbations on natural variability.

The IAP RAS Global Climate Model

This model is developed at the Oboukhov Institute of Atmospheric Physics of the Russian Academy of Sciences. It is designed to model large scale processes (with horizontal scales of several hundreds kilometers and time scale of few days). Efficient parameterizations of smaller scale processes allow one to perform long model runs. Currently the model has the horizontal resolution of 4.5° on latitude and 6° on longitude and time step 5 days.

The McGill Paleoclimate Model

The MPM is a new physically-based coupled atmosphere-ocean-sea ice-land surface-ice sheet model has been developed for long-term climate change studies. The MPM incorporates the seasonal cycle. Three ocean basins, the Antarctic Circumpolar Current region and the major continents are resolved. The model variables are sectorially averaged across the different ocean basins and continents. The major reason for developing the MPM is to investigate millennial and Milankovitch timescale climate variability during the Quaternary period. The model will be applied to other geological periods as well.

The MIT Integrated Global System Model

The MIT model simulates the global environmental changes that may arise as



a result of anthropogenic causes, the uncertainties associated with the projected changes, and the effect of proposed policies on such changes. The current model includes an economic model for analysis of greenhouse and aerosol precursor gas emissions and mitigation proposals, a coupled model of atmospheric chemistry and climate, and models of natural ecosystems. All of these models are global but with appropriate levels of regional detail. In the integrated model, the combined anthropogenic and natural emissions model outputs are driving forces for the coupled atmospheric chemistry and climate model. The climate model outputs drive a terrestrial ecosystems model predicting land vegetation changes, land CO₂ fluxes, and soil composition, which feed back to the coupled chemistry/climate, and natural emissions models. More details on the MIT program, the model, publications, and contact information are at <http://web.mit.edu/globalchange/www/>.

The MoBidiC Climate Model

The MoBidiC model is based on the LLN-2D sectorial model that has been used to study the importance of Milankovitch's astronomical theory and climate feedbacks on time scales from glacial-interglacial cycles to several millions of years. Process studies have been conducted on albedo feedback linked to sea ice, boreal forest extent, water vapour content, sea level and ice sheet isostatic rebound. The effect of CO₂ concentration variations on climate was also analysed. As the LLN-2D model was limited by considering the Northern Hemisphere only and by not including a representation for the ocean dynamics, a new model was designed from that basis for further studies. The MoBidiC model considers the whole Earth and includes a 3-basin, sectorially averaged dynamical ocean model. In addition, the global carbon cycle (ocean and continental biosphere) was recently embedded. The coupling with ocean dynamics and carbon cycle allows to simulate ocean related climate events at millennium time scale or even shorter

scales such as Heinrich events.

Toward a Planet Simulator:

PUMA - LSG

This model studies climate dynamics on decadal and millennial time-scales. The main task is to identify the driving mechanisms and potential thresholds responsible for climate transitions. Emphasis is placed on the multiple states of the system and the interaction of the dominant pattern of atmospheric variability with the ocean and land surface. In contrast to conventional time-slice experiments, the present approach is not restricted to equilibrium transitions and is capable to utilize all available data for validation. The model explicitly resolves the 3-D atmospheric and oceanic dynamics and is therefore conceptually different from statistical dynamical models. At this early stage of exploration for the coupled system, it is necessary to be able to carry out a large number of sensitivity experiments. The modular structure of the model enables the user to modify model configurations according to the application. This is particularly useful for paleoclimatic applications.

The UVic Earth System Climate Model

This model consists of a 3-D ocean general circulation model coupled to a thermodynamic/dynamic sea ice model, an energy-moisture balance atmospheric model with dynamical feedbacks, and a thermomechanical land ice model. A full 3-D OGCM is included in order to highlight horizontal ocean gyre transport and its control on the stability and variability of thermohaline circulation, an important factor in climate/paleoclimate change/variability on decadal and longer timescales. In order to keep the model computationally efficient, a reduced complexity atmosphere model is used. The model is available at <http://climate.uvic.ca/climate-lab/model.html>.



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Published by the GAIM Task Force Office
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Durham, NH 03824, USA

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The Global Analysis, Integration and Modelling Task Force (GAIM) is a component of the International Geosphere Biosphere Program (IGBP) of the International Council of Scientific Unions (ICSU). The GAIM Task Force Office is located in the Institute for the Study of Earth, Oceans, and Space, University of New Hampshire. Operating funds for the GAIM Office have been provided by NSF, NOAA and the DOE.

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