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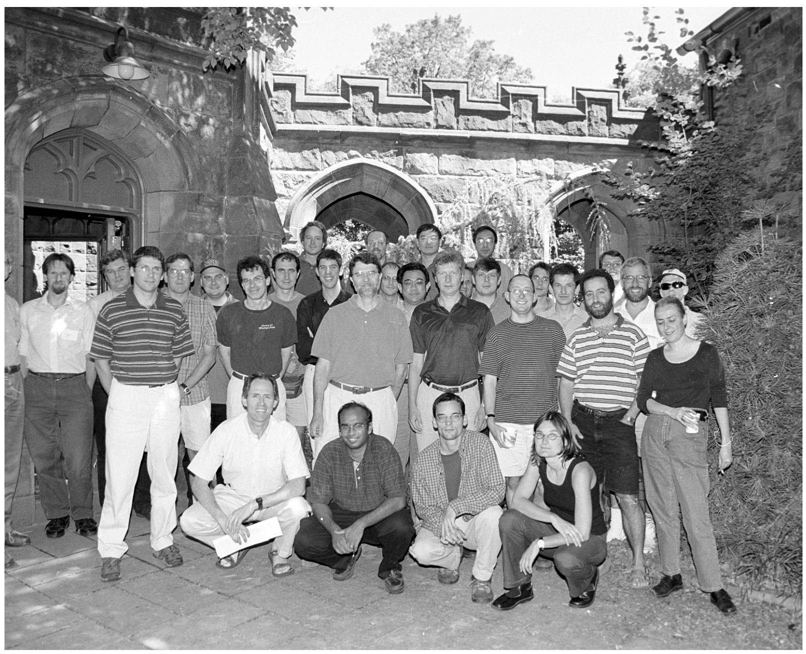
Predicting The Ocean's Response To Rising CO_2: The Ocean Carbon Cycle Model Intercomparison Project

by Raymond Najjar, Nicolas Gruber and James Orr

How much carbon dioxide (CO_2) will the atmosphere of the Earth contain in 50 or 100 years? Future generations will want to know. Atmospheric CO_2, a potent greenhouse gas, is rising rapidly, mainly as a result of human activities that include the combustion of fossil fuels and the conversion of forested lands into pasture or farmland.



Participants in OCMIP-2 workshop at Princeton University in July 2000.

R. Key, Princeton

A substantial fraction of the anthropogenic CO_2 that enters the atmosphere does not stay there; roughly 50% is taken up by the ocean and the terrestrial biosphere. We are not certain as yet how this uptake is partitioned between the land and the ocean or how much the total uptake will change with time. In order to predict future concentrations of CO_2 in the atmosphere, we need to develop a detailed understanding of the global carbon cycle and its responses to alterations in climate, both natural and anthropogenic.

Mathematical models of the ocean carbon cycle have been used to study the partitioning of carbon between the ocean and atmosphere since the late 1960s. Early efforts by C.D. Keeling of Scripps Institution of Oceanography, Bert Bolin of the University of Stockholm and Hans Oeschger of the University of Bern, among others, demonstrated that ocean uptake of CO_2 depends significantly on both the well-known chemical dissociation of CO_2 in seawater and the less well-known dynamics of ocean circulation.

Ocean circulation in these early models was crudely represented by flow among a few well-mixed reservoirs. With the development of global three-dimensional models of ocean circulation in the 1980s, much more detailed predictions of ocean uptake of CO_2 became possible.

By the early 1990s, a handful of modeling groups around the world were simulating the uptake of atmospheric CO_2 by the ocean. Unfortunately, their models produced widely varying estimates of the current and future uptake of anthropogenic CO_2 by the ocean, particularly on a regional basis.

With the goals of sorting out the causes of the differences among these models and accelerating the development of ocean biogeochemical models, the Global Analysis, Integration and Modeling (GAIM) initiative of the International Geosphere-Biosphere Programme (IGBP) launched the Ocean Carbon-cycle Model Intercomparison Project (OCMIP) in 1995. Funds were provided by the U.S. National Aeronautics and Space Administration (NASA) and the European Commission. Scientific teams at four institutions participated in the first phase of OCMIP: the Max Planck Institut für Meteorologie in Germany, Princeton University in the U.S., the Hadley Centre for Climate Prediction and Research in the United Kingdom, and the Institute Pierre Simone LaPlace (ISPL) in France.

During the first phase of OCMIP (OCMIP-1), participants ran modeling simulations for the natural marine carbon cycle, an "abiotic" marine carbon cycle, anthropogenic CO_2 and radiocarbon. The first two simulations were designed to quantify the relative roles of biological processes, represented by very simple models, and physical processes in the marine carbon cycle. Radiocarbon was included as a means of tracing the large-scale circulation and ventilation of the

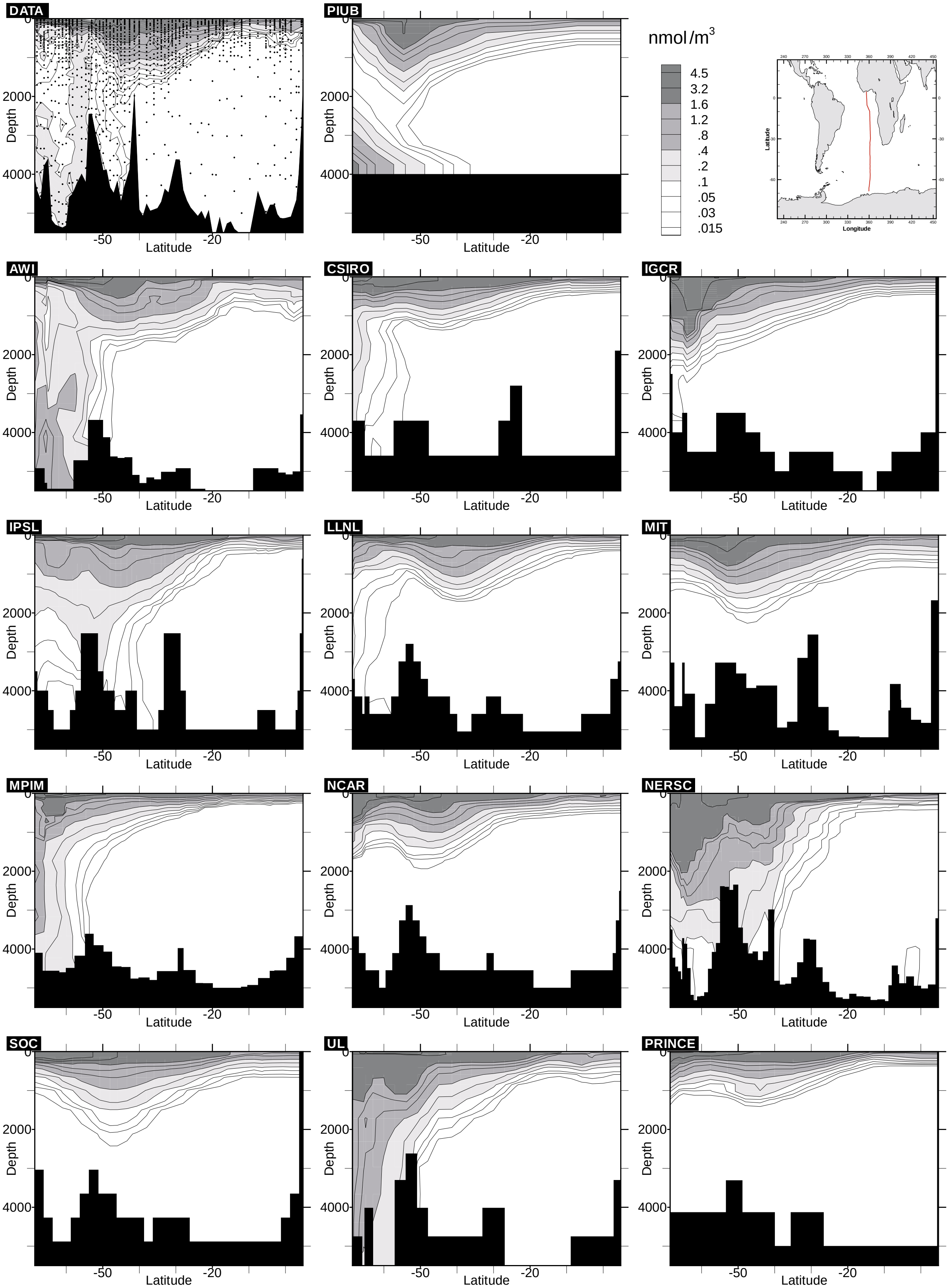


Figure 1: Comparison of chlorofluorocarbon-11 levels observed during an AJAX transect in the southern Atlantic Ocean in 1983 with results from model simulations conducted by investigators at 13 institutions participating in OCMIP-2. Values are in nanomoles per cubic meter.

ocean, processes known to influence the rate of CO_2 uptake.

One of the major findings of OCMIP-1 was that the Southern Ocean, because of its large size and strong vertical mixing, serves as a significant sink for anthropogenic CO_2 at present and is likely to increase in importance in the future. But the differences in uptake in the modeling simulations were large, almost a factor of two for this ocean region. Detailed discussions of the results of this study have been presented in two papers published in *Global Biogeochemical Cycles* during 2000, one by James Orr and colleagues and one by Jorge Sarmiento and colleagues.

The number and diversity of marine carbon cycle models grew steadily during the 1990s, providing an excellent opportunity for more comprehensive model evaluation, comparison and improvement. A second phase of OCMIP, launched in 1998, involved 13 modeling groups in nine countries (Table 1).

Funding for OCMIP-2 was provided by the European Union for the seven European groups, by NASA through the U.S. JGOFS Synthesis and Modeling Project for the four U.S. groups, and by the governments of Australia and Japan for their respective national groups. The number of ocean properties simulated grew to include chlorofluorocarbons (CFCs), which serve well as tracers of ocean ventilation on the decadal time scale, and a simple common biological model was added. Participants in OCMIP-2 included specialists in radiocarbon, inorganic carbon and CFC data. A rigorous protocol was set up for the simulations, which were run at the home institutions and delivered electronically to a central site at IPSL. In addition, a graphical analysis package was developed in order to facilitate the analysis of the model results.

As an example of OCMIP-2 results, we present in Figure 1 simulations of CFC-11 levels in the southern Atlantic Ocean by the 13 OCMIP-2 models, along with observations made during the AJAX expedition, conducted by Scripps Institution of Oceanography in the South Atlantic in 1983-84. The observations reveal several features of circulation in the Southern Ocean, such as the weak vertical exchange in the tropics and subtropics (0° to 30°S), the formation of Subantarctic Mode Water in the mid latitudes (40°S to 55°S) and the penetration of Antarctic Bottom Water at the southern end of the transect.

Although all of the OCMIP-2 simulations capture low-latitude structure in the distribution of CFC-11 accurately, ventilation in the higher latitudes varies from none to far too much. The modeling results support one of the basic findings of OCMIP-1: ocean models differ greatly in their simulation of Southern Ocean circulation. More detailed discussion of the CFC simulations is presented in an article by Jean-Claude Dutay of ISPL and colleagues that is currently in press in *Ocean Modeling*.

The large regional differences among model results shown in Figure 1 are reflected on the global scale; global CFC inventories vary by plus or minus 30% from the mean. On the other hand, simulations of the current global uptake of anthropogenic CO_2 show much greater similarity, with a range of plus or minus 14% from a mean of 1.9 petagrams of carbon per year (Pg C/yr) averaged over the 1980s. Simulations of future CO_2 levels, however, show much greater disagreement.

The differences between CFC and anthropogenic CO_2 levels in the ocean arise from differences in atmospheric history, solubility and chemical reactivity. It is clear that simulations and observations of CFCs and other tracers will have to be used creatively in order to describe or predict rates at which anthropogenic CO_2 is taken up.

Marine biological processes, which appear to play an important role in interactions between climate and the carbon cycle, are treated very simply in OCMIP-2 simulations. The uptake of nutrients in surface waters and subsequent export of organic matter is simulated by nudging modeled nu-

(Cont. on page 4)

OCMIP-2 Principal Investigators and Institutions

Coordination

James Orr, Institute Pierre Simone LaPlace, France
Raymond Najjar, Pennsylvania State University, U.S.

Modeling groups

- Reiner Schlitzer, Alfred Wegener Institute for Polar and Marine Research (AWI), Germany
- Richard Matear, Commonwealth Science and Industrial Research Organization (CSIRO), Australia
- Yasumoto Yamanaka, Institute for Global Change Research (IGCR), Japan
- James Orr, Institute Pierre Simone LaPlace (IPSL), France
- Kenneth Caldeira, Lawrence Livermore National Laboratories (LLNL), U.S.
- Mick Follows, Massachusetts Institute of Technology (MIT), U.S.
- Ernst Maier-Reimer, Max Planck Institut für Meteorologie (MPIM), Germany
- Scott Doney, National Center for Atmospheric Research (NCAR), U.S.
- Helge Drange, Nansen Environmental and Remote Sensing Center (NERSC), Norway
- Fortunat Joos, Physics Institute, University of Bern (PIUB), Switzerland
- Jorge Sarmiento, Princeton University (PRINCE), U.S.
- Ian Totterdell, Southampton Oceanography Centre (SOC), United Kingdom
- Jean-Michel Campin, A. Mouchet, University of Liege (UL), France

Data Specialists

- Robert Key, Princeton University, U.S.
- Christopher Sabine, John Bullister, Pacific Marine Environmental Laboratory, NOAA, U.S.
- Nicolas Gruber, University of California at Los Angeles, U.S.

U.S. JGOFS Synthesis And Modeling Project: Awards During 2000

The National Science Foundation awarded a third round of grants for participation in the U.S. JGOFS Synthesis and Modeling Project (SMP) during fiscal year 2000. The investigators, their institutional affiliations and their projects are:

• James Christian, NASA Goddard Space Flight Center, and Ricardo Letelier, Oregon State University: "Modeling Microbial Processes and Dissolved Organic Matter: A Case Study at the U.S. JGOFS Time-Series Station ALOHA."

• Wilford Gardner, Mary Jo Richardson and Alexey Mishonov, Texas A & M University: "Global Synthesis of POC Using Satellite Data Calibrated with Transmissometer and POC Data from JGOFS/WOCE."

• Eileen Hofmann and John Klinck, Old Dominion University, Walker Smith, Virginia Institute of Marine Science, and Barbara Prezelin, University of California at Santa Barbara: "Comparative Modeling and Data Analysis Studies for the Ross Sea and West Antarctic Peninsula Regions: A JGOFS Synthesis and Modeling Project."

• Susumu Honjo and Roger François, Woods Hole Oceanographic Institution: "Global Export and Recycling of Biogenic Material into the Ocean Interior: A Synthesis."

• George Jackson and Adrian Burd, Texas A & M University: "Understanding the Carbon Flows Between the Euphotic Zone and 1,000 Meters Depth."

• Richard Jahnke, Skidaway Institute of Oceanography: "Global Synthesis of Deep Ocean Carbon, Opal and Nutrient Fluxes and Sediment Accumulation."

• Michael Landry, University of Hawaii, Robert Armstrong, State University of New York at Stony Brook, John Steele, Woods Hole Oceanographic Institution: "Data-Based Models of Plankton Community Structure and Export Flux."

• David Nelson, Oregon State University, Mark Brzezinski, University of California at Santa Barbara, Paul Tréguer and Philippe Pondaven, Université de Bretagne Occidentale, Brest: "Silica Cycling and Control of New Production and Organic Carbon Export in the Southern Ocean and the Sargasso Sea: A JGOFS Synthesis."

• James Yoder, University of Rhode Island: "Large-Scale Spatial and Temporal Patterns Evident in the Chlorophyll *a* Imagery from the First Four Global Satellite Ocean Color Missions (CZCS, OCTS, POLDER and SeaWiFS)."❖

Ocean Carbon Cycle–from page 3

trient levels toward observations in the upper 75 meters of the water column. Only four models have reported results for this simulation, and their predictions for the global export of particulate and dissolved organic carbon from surface waters range from 5 to 18 Pg C/yr.

The diagnostic approach for modeling biological processes employed during OCMIP-2 is clearly not suited to the investigation of the interactions between climate-induced changes in ocean circulation and biological cycling. Fortunately, JGOFS and other ocean biogeochemistry programs have stimulated both interest in modeling biological processes that affect the marine carbon cycle and increased ability to do so. During the third phase of OCMIP, which we hope to begin this year, we will capitalize on these advances to increase the accuracy of our predictions of atmospheric CO_2 levels.

Among other changes, we plan to replace the nutrient nudging model used in OCMIP-2 with a common prognostic upper-ocean biogeochemistry model that describes the complexity of ecosystem processes in substantially more detail. This model, the exact structure of which is currently being determined, will allow us a better determination of the interactions between different ocean circulation models and ocean biogeochemical models and the ways in which these interactions affect upper ocean carbon fluxes.

OCMIP-3 investigators will also be able to capitalize on the availability of a large number of inorganic carbon observations gathered during the JGOFS-sponsored global survey of CO_2 in the ocean. We plan to perform a series of inverse calculations to estimate the magnitude and spatial distribution of air-sea CO_2 fluxes.

Finally, participants in OCMIP-3 plan to use the different ocean biogeochemical models in a suite of perturbation experiments, such as nutrient depletion scenarios, to investigate the sensitivity of these models to perturbations. These efforts are essential to our ultimate task, that of improving our prediction of future levels of CO_2 in the atmosphere.

More information about OCMIP is available via the home page of the project (**www.ipsl.jussieu.fr/OCMIP**). Those interested in participating in the next phase of OCMIP should contact James Orr (**orr@lsce.saclay.cea.fr**) or Nicolas Gruber (**ngruber@igpp.ucla.edu**).❖

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Deep-Sea Research II Volumes

Copies of a number of special issues of *Deep-Sea Research, Part II* on JGOFS programs are available from the U.S. JGOFS Planning Office as well. Issues and prices are:

Murray, J.W., guest editor. ***A U.S. JGOFS Process Study in the Equatorial Pacific.*** Volume 42, nos. 2-3. 1995. $30

Murray, J.W., guest editor. ***A U.S. JGOFS Process Study in the Equatorial Pacific, Part 2.*** Volume 43, nos. 4-6. 1996. $35

Karl, D.M. and A.F. Michaels, guest editors. ***Ocean Time-Series: Results from the Hawaii and Bermuda Research Programs.*** Volume 43, nos. 2-3. 1996. $40

Murray, J.W., R. Le Borgne and Y. Dandonneau, guest editors. ***A U.S. JGOFS Process Study in the Equatorial Pacific, Part 3.*** Volume 44, nos. 9-10. 1997. $40

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Smith, S.L., guest editor. ***The 1994-1996 Arabian Sea Expedition: Oceanic Response to Monsoonal Forcing, Part 2.*** Volume 46, nos. 8-9. 1999. $40

Smith, S.L., guest editor. ***The 1994-1996 Arabian Sea Expedition: Oceanic Response to Monsoonal Forcing, Part 3.*** Volume 47, nos. 7-8. 2000. $40.

Smith, Walker O., Jr., and Robert F. Anderson, guest editors. ***U.S. Southern Ocean JGOFS Program (AESOPS).*** Volume 47, nos. 15-16. 2000. $45.

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SCOR Executive Director Liz Gross Retires: A Salute From JGOFS

by Janet W. Campbell

When JGOFS emerged as an international program in 1987 under the auspices of the Scientific Committee on Oceanic Research (SCOR), one hand in particular rocked the cradle. SCOR executive director Elizabeth Gross served as the new program's administrator for its first few years, managing meetings, budgets, proposals, publications and liaison with other organizations from her office in Halifax, Canada. Liz and the SCOR office moved to Baltimore in the U.S. in 1992, and JGOFS established its own administrative offices, first in Kiel, Germany, and then in Bergen, Norway. But Liz always kept an eye on JGOFS.

Hearing that Liz was retiring from SCOR last fall, I asked several JGOFS friends to join me in recalling when they first met Liz, the adventures shared along the way and the role she played in JGOFS and other international programs. As one reads their comments, one sees that certain words - wisdom, grace, quiet efficiency, encyclopedic knowledge - come to the minds of all who know Liz.

Peter Brewer, a member of the original JGOFS Executive Committee, wrote: "It is with some disbelief that I write these words on the occasion of Liz Gross's stepping down as executive director of SCOR and contemplate the impact she has had on the creation and successful execution of JGOFS. Liz has made extraordinary contributions over many years. And she has done so with such skill, grace, style and courtesy that she has personified the remarkable mechanisms by which the international evolution of understanding of the biogeochemical cycles of the ocean has come about today.

M. Bowles

Elizabeth Gross

"I first observed this in 1986 when, at the WOCE (World Ocean Circulation Experiment) Core 1 meeting at the U.S. National Academy, a small group of us drafted a proposal to SCOR to secure their endorsement of a joint (J)GOFS-WOCE global survey of carbon dioxide in the oceans. That request was carried by hand to Tasmania the next day, dealt with positively, and a reply was received within the week. It was an extraordinary example of what was to come. Liz personally took on this challenge and began the process of both educating me on how to go about it and providing entrees to the deliberative bodies that guide international ocean science.

"An important meeting at ICSU (International Council of Scientific Unions) headquarters in Paris followed about six months later, where the 'internationalization' of the U.S. Global Ocean Flux Study (GOFS) program occurred as it metamorphosed into JGOFS. Liz led the way, securing the blessing of the ICSU staff, guiding us all through the labyrinth of committees, healing the inevitable rifts and misunderstandings and always keeping an eye out for strong, innovative, excellent science. Years later we have cruises accomplished, data secure, models run and satellites observing the ocean. Liz has played a formative role in all of this, and we thank her for it with true and deep appreciation.

"One of the great advantages one can have at complex international meetings is to sit where Liz can be observed. Her face involuntarily shows the ups and downs of an argument; a well-placed phrase can bring a grin of pleasure, and an ill-chosen theme, a frown of disapproval from which the wise take the signal to tack. I learned long ago to watch these invaluable signals as we navigated difficult international waters. We will miss that experience enormously."

Former JGOFS Scientific Steering Committee (SSC) chairman Michael Fasham wrote: "I first met Liz during the late eighties when JGOFS was being set up. The JGOFS community owes her a huge debt for her wisdom and quiet efficiency over the years. The thing that always impressed me at meetings was her encyclopedic knowledge of SCOR and other marine activities and the many times that her contributions helped resolve awkward problems.

"Her other skill is in organising evening restaurant trips and day tourist jaunts that help relieve the hard work of international meetings. I was also amazed at her ability to spend so much time in the air, and I am sure she will enjoy a slightly less frenetic life-style. We will all miss her."

Current JGOFS SSC chairman Hugh

Ducklow first met Liz in Halifax in 1983 when he was visiting Dalhousie University to give a seminar. “At that time I hadn’t even heard of SCOR,” he wrote, “just another meaningless acronym. By 1988 things had changed, and JGOFS had just come under SCOR sponsorship.

“I next met Liz at the first planning meeting for the JGOFS North Atlantic Bloom Experiment. I remember sitting and drinking pastis in a café on the Place Contrascarpe. I actually think of that every time I revisit that place.

“That began a long series of meetings with Liz around the world, mostly at JGOFS SSC meetings in the U.S., Europe and Asia. Recently the SSC met at the SCOR offices in Baltimore, and we had drinks at Liz and Grant’s row house near Johns Hopkins University. We owe Liz a lot and will miss her wisdom, her encyclopedic knowledge of the oceanographic world and her warm companionship. JGOFS wishes her well and hopes to see her again somewhere in the world.”

Venetia Stuart, executive scientist of the International Ocean Colour Coordinating Group (IOCCG), came to know Liz when SCOR took over as the umbrella organization for the IOCCG in mid 1998. She noted: “It immediately became apparent that the affairs of the IOCCG were being managed in a most efficient and professional manner.

“I can’t remember the first time I actually met Liz, but she always seemed to be there when you needed her, and she always had the right answer (diplomatically correct, of course). Best of all, she always had a refreshing sense of humour, even after spending 19 hours on a bus trying to get to a meeting in Halifax when the planes couldn’t land in the fog, only to find that we weren’t allowed to order lobster for supper. Her amazing ability to recommend the ‘absolute best’ place to stay, eat, drink, shop or sightsee in almost any city in the world intrigues us all, especially when she is more knowledgeable about restaurants in Cape Town (my hometown) than me!

“Needless to say, I was delighted to hear that she would be staying on at SCOR on a part-time basis to handle the financial affairs. We look forward to many more years of collaboration; hopefully she’ll have less work on her plate and more time to enjoy all the good things in life!”

Like Venetia, I met Liz when SCOR took over sponsorship of the IOCCG. It always seemed to me that Liz had the ideal job. She was at home anywhere in the world, having traveled to meetings in exotic places on practically every continent.

Liz was a calming influence, bringing quiet support, experience and management skills to meetings in Villefranche, Cape Town, Halifax, Noordwijk and Hobart. Wherever we were, she knew just what bargains to buy, the best restaurants, the secrets of negotiating with local officials and customs, not to mention customs officials! With the latest *Wall Street Journal*, she kept us informed of news-breaking stories back home. I’ll never forget the morning in January 1998 in Cape Town when Liz announced at breakfast, ‘It seems Clinton is really in trouble now!’ “

Her many friends in JGOFS send Liz their very best wishes as she ventures into retirement and the leisure she deserves so well. At last Liz and Grant will be able to do all that traveling they have been postponing. But if my guess is right, the Grosses will swear off traveling for a while in favor of summer gardening, sailing in the Chesapeake and winter nights by the fire with a brandy.❖

(Editor’s note: Janet Campbell is a research professor in the Institute for the Study of Earth, Oceans and Space at the University of New Hampshire and a former program manager for ocean biology and biogeochemistry at the U.S. National Aeronautics and Space Administration.)

IGBP Hosts Open Science Conference On Global Change

In collaboration with the World Climate Research Programme (WCRP) and the International Human Dimensions Programme (IHDP) on Global Environmental Change, the International Geosphere-Biosphere Programme (IGBP) is organizing an open science conference to be held July 10-13 in Amsterdam, The Netherlands. Goals of the conference, titled “Challenges of a Changing Earth,” are to present results from the last decade of global-change research and to elucidate the way forward.

The goal of the IGBP since its inception more than a decade ago has been to describe and understand the interacting physical, chemical and biological processes that regulate the Earth system, the unique environment that the planet provides for life, environmental changes that are occurring and the effects of human activities on natural systems. The conference will focus on synthesis of the knowledge that is emerging from the IGBP core projects such as JGOFS as well as on collaborations with the WCRP and IHDP.

The opening day of the conference will focus on four issues of major societal importance: air quality, the carbon cycle, water resources and food and land. Talks on these themes will be given by policymakers and representatives of companies and private foundations as well as by scientists.

The conference will be organized around a series of plenary, parallel and poster sessions, allowing the presentation of both major themes and the broad spectrum of individual research projects. JGOFS will be represented with a keynote talk titled “Ocean Biogeochemistry: A Sea of Change” by David M. Karl of the University of Hawaii, parallel oral sessions and poster presentations.

The JGOFS International Planning Office (IPO) notes several parallel

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Undersampled Ocean Systems: A Plea For An International Study Of Biogeochemical Cycles In The Southern Pacific Gyre And Its Boundaries

by Giovanni Daneri and Renato Quiñones

The central gyre of the southern Pacific Ocean is home to one of the most extensive ecosystems in the global ocean, yet one of the least studied. Although occasional cruises have been undertaken in the gyre, we have little knowledge for this huge region about the cycling of carbon and other biogenic elements that are crucial to modeling global climatic changes. The boundaries of the gyre have been somewhat better sampled as a result of regional research programs conducted in the western and eastern boundaries and past and ongoing research efforts in the equatorial Pacific and the Southern Ocean.

A special case can be made for the Humboldt Current System (HCS), one of the most productive continental margin systems of the world. The HCS produces more than one-sixth of the global fish catch, and primary production estimates as high as 19.9 grams of carbon per square meter per day have been reported for this region. This highly dynamic system possesses some special features, including an intense subsurface oxygen minimum that reaches the euphotic zone, extensive benthic mats of the nitrate-reducing bacteria *Thioploca*, and strong interannual variations associated with El Niño-Southern Oscillation (ENSO) cycles.

The HCS has been the focus of several major research programs, including the Coastal Upwelling Ecosystem Analysis (CUEA) program off Perú; the JGOFS-Chile program, supported by the Swedish Agency for Research Cooperation (SAREC) and the Chilean Comision Nacional de Ciencias y Tecnología (CONICYT); Sectorial Antofagasta, supported by the Chilean Fondo Nacional de Ciencia y Tecnología (FONDECYT, CONICYT), and the Fondo de Areas Prioritarias (FONDAP)-Humboldt Program, also supported by FONDECYT-Chile. But we are still far from reaching a synthesis stage that would allow us a better understanding of the biogeochemical cycles in the area.

The emerging question is whether it is possible to develop reliable estimates of global carbon fluxes at the planetary level when the Southern Pacific Gyre, one of the major marine ecosystems of the world, is still largely undersampled and poorly understood. In our opinion, this has been one of the important weaknesses of JGOFS.

Accordingly, it is time to start paying more attention to the southern Pacific Ocean. A multidisciplinary program in the Southern Pacific Gyre, similar to the one carried out in the Arabian Sea, is a necessary follow-up to the JGOFS field studies that have been completed. It should be dedicated to improving our understanding of the biogeochemical cycling of elements relevant to the global warming problem. In the eastern and western boundary regions, the situation could be improved by strengthening regional programs, while in the southern and northern parts of the gyre, our knowledge of the dynamics of the South Pacific would be greatly improved by the expansion of current equatorial Pacific and Southern Ocean programs into portions of the gyre.

As the FONDAP-Humboldt program off Chile and other important regional programs in the HCS wind up, and new international and national initiatives such as the proposed Surface Ocean-Upper Atmosphere Study (SOLAS) or Ocean Carbon Transport, Exchanges and Transformations (OCTET) come forward, we can not restrain ourselves from making a strong plea to the international oceanographic community to include the South Pacific Ocean fully among the geographical regions where significant biogeochemical research efforts should be undertaken.❖

(Editor's note: Giovanni Daneri is at the Centro de Ciencias y Ecología Aplicada of the Universidad del Mar, Valparaíso, Chile. Renato Quiñones is in the Departamento de Oceanografía of the Universidad de Concepción, Concepción, Chile. Daneri is a member of the executive committee of the Eastern Pacific Consortium for Research on Global Change in Coastal and Oceanic Region, and Quiñones is a member of the JGOFS Scientific Steering Committee.)

JGOFS Synthesis Volume Published

The Changing Ocean Carbon Cycle: A Midterm Synthesis of the Joint Global Ocean Flux Study is now available from Cambridge University Press. The volume, edited by Roger B. Hanson, Hugh W. Ducklow and John G. Field, contains a set of articles based upon plenary presentations at the JGOFS scientific symposium held at Villefranche-sur-mer, France, in May 1995. It presents a synthesis of the multidisciplinary research in ocean biogeochemistry conducted during the first half of the decade-long JGOFS field programme.

The book provides a recent overview of the role of ocean processes in Earth system science and their wider implications for climate change. It can be ordered online at **http://uk.cambridge.org/earthsciences/** or from Cambridge University Press, Edinburgh Building, Shaftesbury Road, Cambridge, UK, CB2 2RU. Price is £37.95.

North Pacific Symposium Assesses Synthesis Of Ocean CO_2 Data

by Richard A. Feely and Yukihiro Nojiri

More than 60 scientists and administrators traveled to Tsukuba, Japan, last October to attend a two-day symposium on the synthesis of carbon dioxide (CO_2) data from the North Pacific. Co-sponsored by the North Pacific Marine Science Organization (PICES) and the Core Research for Evolutional Science and Technology of the Japan Science and Technology Corporation (JST), the symposium was held at the Tsukuba Center for Institutes. The National Institute for Environmental Studies (NIES) served as host.

Co-convenors of the meeting were Andrew Dickson of Scripps Institution of Oceanography, U.S., Richard Feely of the U.S. NOAA Pacific Marine Environmental Laboratory, Koh Harada of the National Institute for Resources and Environment of Japan and Yukihiro Nojiri of NIES. The scientific symposium was held in conjunction with the PICES ninth annual meeting in Hakodate and joint meetings of the PICES working group on CO_2 in the North Pacific and the JGOFS North Pacific Task Team (NPTT) in Tsukuba.

The North Pacific Ocean takes up a significant amount of CO_2 from the atmosphere and thus plays an important role in the regulation of long-term climate change on the Earth. The purposes of the symposium were to review the ongoing synthesis of CO_2 data from various ocean regions and to plan for the integration of data from the North Pacific.

The first day of the symposium was devoted to the synthesis of basin-scale observations and time-series measurements. Richard Feely opened the session with an update on the ongoing synthesis of Pacific Ocean data from the JGOFS global survey of CO_2 in the ocean, conducted in collaboration with the World Ocean Circulation Experiment (WOCE). He also reported on the progress of an international effort to develop a unified, internally consistent data set of inorganic carbon parameters for the Pacific.

Feely showed how he and his colleagues used results from certified seawater samples and deep samples from stations where cruise tracks crossed each other to propose adjustments for each of the inorganic carbon parameters measured on each cruise in the Pacific. The revised data set shows remarkable coherency among cruises, even though a number of different scientific teams were involved in making the measurements.

Christopher Sabine of the University of Washington Joint Institute for Study of the Atmosphere and Oceans and Nicolas Metzl of the Institute Pierre Simone LaPlace, France, gave similar talks on the synthesis of the JGOFS global survey data from the Indian and Southern oceans. Sabine discussed his work on comparing observations and model estimates of anthropogenic CO_2 inventories in the Indian Ocean, and Metzl reported on temporal and spatial variability in CO_2 fluxes in the Indian Ocean sector of the Southern Ocean.

John Dore of the University of Hawaii, Keiri Imai of JST/Hokkaido University, and Yukihiro Nojiri reviewed results from measurements at the Hawaii Ocean Time-series (HOT) and the Kyodo North Pacific Ocean Time Series (KNOT) stations in the North Pacific. Based on seasonal amplitudes of nutrients and dissolved inorganic carbon, the northwestern Pacific KNOT data indicate significantly larger variations in primary production and new production than other regions of the North Pacific.

On the second day of the symposium, the focus was on data synthesis and integration. Kitack Lee of the U.S. NOAA Atlantic Oceanographic and Meteorological Laboratory gave a presentation on global interannual variability in air-sea fluxes of CO_2. His analysis is based on regionally and seasonally varying relationships between the partial pressure of CO_2 (pCO_2) in surface waters and seawater temperature and on interannual anomalies in sea-surface temperature and winds. The results indicate much smaller interannual variability in CO_2 fluxes, on the order of plus or minus O.4 petagrams of carbon per year, than is predicted by atmospheric inversion models or ocean biogeochemical models.

Paulette Murphy of the U.S. National Oceanographic Data Center presented her studies of sampling strategies for pCO_2 distributions and CO_2 fluxes based on data collected aboard merchant ship *Skaugran*. One result from the MS *Skaugran* data is that nine or 10 samplings a year are required to provide an adequate representation of pCO_2 distributions in the subarctic North Pacific.

Masao Ishii of the Meteorological Research Institute in Tsukuba presented an estimate of net community production (38 millimoles per square meter per day), based on dissolved inorganic carbon and pH measurements in the central and western equatorial Pacific. Ludger Mintrop of the University of Bremen, Germany, summarized efforts to synthesize CO_2 survey data from the North and South Atlantic under the Carbon Dioxide in the North Atlantic Ocean (CARINA) project.

The symposium also included presentations on data management and database technology as well as improvements in ocean CO_2 measurements. The joint PICES working group and JGOFS NPTT sessions that followed featured reviews of the results of the second PICES intercomparison for measurements of alkalinity in the ocean and other carbonate parameters as well as discussions of plans for North Pacific CO_2 data synthesis.❖

EisenEx: International Team Conducts Iron Experiment In Southern Ocean

by Victor Smetacek

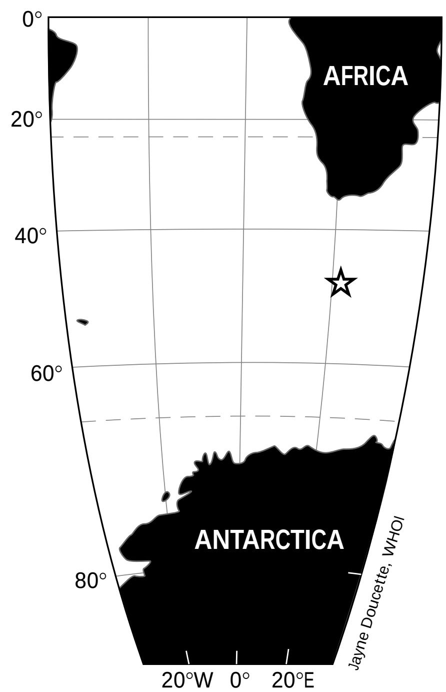
Research vessel *Polarstern* left Cape Town, South Africa, on Oct. 25, bound for the Southern Ocean with an international and multidisciplinary science party of 58 and crew of 44 aboard. Darkness descended before we left; the twinkling lights of the city were our last glimpse of land for the next five and a half weeks. Our goal was to conduct an iron fertilization experiment (EisenEx), designed to test the hypothesis that iron, transported in airborne dust from the continents and deposited on the ocean, enhanced productivity during glacial periods and contributed to the lower concentrations of carbon dioxide (CO_2) in the atmosphere that characterized these colder periods in the Earth's history.

Funding for EisenEx was provided primarily by the German Ministry of Research and Technology with additional support from the European Union, The Netherlands and the United Kingdom. The scientists aboard represented 15 countries and several major subdisciplines of physics, chemistry and biology.

Ice-core data show that changes in global temperature are closely linked to atmospheric CO_2 concentrations. Because the oceans contain far more CO_2 than the atmosphere, the balance of carbon at the ocean surface has a critical effect on atmospheric concentrations. This balance is influenced by phytoplankton, the single-celled algae that grow in the surface, sunlit layer. By taking up and converting dissolved CO_2 into biomass, the algae create a deficit in the surface layer that is compensated by CO_2 drawdown from the atmosphere.

Phytoplankton growth is dependent on light supply and the availability of dissolved nutrients, of which nitrate is the most important. However in three vast regions of the ocean, the equatorial and subarctic Pacific and the entire Southern Ocean, phytoplankton production is low, despite favourable light conditions and high nitrate concentrations. A solution to this enigma is emerging from studies over the past decade. Iron appears to be the major limiting nutrient in these regions.

The most convincing evidence has come from three experiments during recent years in which phytoplankton production was significantly enhanced by the addition of iron in solution to patches of ocean. The Southern Ocean Iron Release Experiment (SOIREE), carried out in waters south of Australia, resulted in a phytoplankton bloom of over a 100 square kilometers (km) in size.



Location of EisenEx fertilisation experiment.

Because of a shortage of shiptime, the fate of the SOIREE bloom could not be ascertained during the experiment. This is crucial for the CO_2 budget. If the biomass is broken down in the surface layer by bacteria and zooplankton, no net removal of CO_2 occurs. If the organic matter sinks out of the surface layer, however, the equivalent amount of CO_2 is removed from the atmosphere for tens to hundreds of years.

The goal of the EisenEx team was to simulate a "dusting" episode in the Southern Ocean by fertilising a patch of ocean with iron sulphate solution and studying the response of the plankton. The first task was to select an appropriate site with low iron concentrations and a stable water mass that maintained its integrity over the course of the experiment.

Most of the Southern Ocean consists of a broad eastward-flowing ring of water, the Antarctic Circumpolar Current (ACC), that encircles Antarctica. The Antarctic Polar Front (APF) divides the ACC into the northern Polar Frontal Zone (PFZ) and the southern Antarctic Zone. The northern border of the PFZ tends to subduct under the neighbouring subantarctic zone.

Because the plankton of the ACC are iron-limited in their growth, huge amounts of dissolved nitrate and phosphate are entrained unused into the deep ocean. Were enough iron available, the algae would grow faster, take up more nutrients and fix more carbon, which would either sink out as a rain of particles or be carried down to the deep sea with the subducting PFZ water.

Fronts are the fast lanes of the ACC; current speeds in between them are slower. In satellite images the fronts appear as broad, meandering "rivers" from which eddies spin off and mix slowly into the surrounding waters. The centre of a spinning eddy is kept from mixing for a relatively long period. We hoped to carry out our experiment in the eye of an eddy.

The first week of the cruise was spent in gaining an overview of the position of Southern Ocean fronts by towing a ScanFish, an undulating instrument package that records temperature, salinity and chlorophyll fluorescence in the upper 250 metres, for 750 km on our way south along the 20°E meridian. The transect commenced at the Subantarctic Front at 45°S, covered the PFZ, crossed the

APF and ended in the Antarctic Zone at 52°S. Temperatures were lower, diatom stocks larger and silicate concentrations, used by diatoms to construct their shells, higher across a stretch of water around 48°S.

This band of water was part of a water mass originating from the APF that had drifted 400 km northward. It exhibited similar current speeds as the water around it but in the opposite direction - towards the west. Where the currents shifted directions, speeds were at their lowest. Further support came from altimeter images. This was the core of an eddy.

We spent the second week of the cruise carrying out a fine-scale hydrographical survey of the region. The pre-conditions were good: very low iron concentrations throughout and a sparse but species-rich plankton community combined with fairly shallow mixed layers. Measurements of the photosynthetic performance of individual cells showed that the algae were growing at only 30% of their potential rates. A cause for concern was the large numbers of copepods (millimetre-sized zooplankton) in the area. Their grazing pressure could nip the bloom in the bud.

Fertilisation began on Nov. 7 at approximately 48°S, 21°E. The team aboard RV *Polarstern* changed from nomadic hunters to sessile agriculturists tending a watery garden, waiting for it to burst into bloom. The physical oceanography group located, tracked and pinned down the eye of the eddy with a drifting buoy. The ship's navigators spent all of the night "ploughing" ever-widening circles around a buoy drifting with the currents while we released 4 tonnes of iron sulphate dissolved in 30 cubic metres of acidified sea water through a hose around a spiral about 70 km in length and 7 km in diameter.

In iron enrichment experiments, the iron added to the patch vanishes within a few days. Thus an inert tracer, sulphur hexafluoride (SF_6), is added to the enriched water to identify the patch. Because SF_6 is volatile and escapes into the atmosphere, we released the iron and tracer mixture at a depth of 15 metres in the wake of the ship's propeller.


U. Bathmann, AWI

R/V *Polarstern* weathers rough seas in Southern Ocean.

We found the first signs of a response in the phytoplankton two days after fertilisation, a day or two earlier than we had anticipated. With a fast repetition rate fluorometer, which measures the photosynthetic efficiency of algal cells, we observed that the algae in the patch had increased their efficiency, hence growth rate, significantly. Despite the favourable light climate for the phytoplankton during the first half of the cruise, chlorophyll levels throughout the region stayed more or less constant. Within the patch, they more than doubled over the first five days. The bloom had begun.

The first severe storm of the cruise hit us on Nov. 12, five days after fertilisation. We welcomed it because it mixed the water column, but we were apprehensive that we might lose the patch. After the storm, we carried out a few long transects to measure SF_6 concentrations and were much relieved when we found strong signals to the west of the buoy. The patch had stayed in the eddy's eye and was now moving west after making a semicircle.

After carrying out a series of long stations within and outside the patch, we decided to add another few tonnes of iron in its centre. Although iron concentrations were still high, they had dropped in the week since the first fertilisation. Another complete spiral was fertilised on Nov. 16. By Nov. 18, the highest chlorophyll levels within the patch had increased to bloom proportions, with values roughly four times those found in the surrounding waters.

Preliminary results suggested that although the iron-enriched plankton were growing at least twice as fast as those in the surrounding water, the accumulation of biomass was kept in check by the poor light conditions associated with intermittent stormy weather in combination with heavy grazing pressure exerted by the various organisms, ranging from protozoa to crustacean zooplankton, that feed on phytoplankton. The latter migrate vertically during dawn and dusk and feed in the surface layer during the night.

Since our patch was being diluted on its way around the eye of the eddy and iron concentrations were very low throughout, we refertilised its centre, where SF_6 concentrations were highest, on Nov. 22. The tracer was only added during the first fertilisation. Results from mapping transects showed close correlation between chlorophyll and SF_6 concentrations in an elongated coherent patch at least 15 km long and 10 km across, demonstrating beyond doubt that our bloom was a result of iron fertilisation.

As predicted by the physical oceanographers, the eddy stood its ground in the current for more than three weeks. Our bloom circled its centre about two times, steadily increasing in size as it mixed with the surround-

(Cont. on page 14)

Mapping Out Future Directions In Ocean Biogeochemical Research

by Susannah Eliott and Wendy Broadgate

Progress in ocean biogeochemistry over the last two decades and priorities for future research were topics of discussion at an international workshop held last September under the auspices of the Scientific Committee on Oceanic Research (SCOR) and the International Geosphere-Biosphere Programme (IGBP).

Some 41 scientists from 15 countries met at Plymouth Marine Laboratory in the United Kingdom to work towards developing a framework for future research in ocean biogeochemistry. Co-chairmen of the workshop were John Field of the University of Cape Town, South Africa, and Patrick Buat-Ménard of the Université de Bordeaux, France.

Participants in the workshop represented a wide variety of international ocean research programmes of the 1980s and 1990s, including such IGBP core projects as JGOFS, Global Ocean Ecosystems Dynamics (GLOBEC), Land-Ocean Interactions in the Coastal Zone (LOICZ) and Past Global Changes (PAGES). Also attending were representatives of World Climate Research Programme (WCRP) studies such as the World Ocean Circulation Experiment (WOCE) and the Climate Variability and Predictability Programme (CLIVAR). The planners of a proposed international research initiative, the Surface Ocean-Lower Atmosphere Study (SOLAS), were represented as well.

JGOFS has done much to improve scientific understanding of ocean biogeochemical cycles, and GLOBEC is contributing considerably to knowledge about the functioning of marine ecosystems. LOICZ has many well-established research projects studying continental margins. SOLAS proposes to advance our knowledge of ocean-atmosphere interactions. An overarching structure that complements the goals of existing programs and ensures that any gaps are filled is the aim of the new framework that is under development.

The workshop began with "big picture" questions about current research and the gaps in our knowledge. What do we know now, and what more do we need to know? What scientific information will societies need from us in order to preserve the health of the oceans and live on the planet in a sustainable fashion?

Four major issues were defined with specific questions and research objectives:

1. **Ecosystem structure, function and feedbacks:** Marine ecosystems take up carbon dioxide (CO_2) from the atmosphere through the functioning of the "biological pump." Microorganisms also release substances from the ocean that are active in the atmosphere. Changes in the input of materials from the atmosphere, such as nitrate, silicate, iron and CO_2, could significantly alter the structure and functioning of marine ecosystems. How might these processes and subsequent feedbacks be altered by human activities in the future?

2. **Carbon storage:** A large body of data has accumulated over recent decades that improves our understanding of the distribution and intensity of ocean sinks for anthropogenic CO_2. We need to build on this foundation in order to predict how the oceans will respond to increasing levels of CO_2 in the atmosphere in the future.

3. **Continental margins:** Coastal waters make up roughly 5% of the global ocean but account for about 50% of global primary production and 60% of fish harvests. To what extent do variations in chemical elements such as carbon, nitrogen, phosphorus, silicon and iron, sediments and transport of water in the coastal margins influence global change?

4. **Fisheries:** Although synchronous changes in fish populations around the world can be seen on decadal time scales, the processes underlying these changes are not well understood. How do natural cycles interact with anthropogenic factors? What impact will fisheries have on marine ecosystems in the long term?

A planning committee is currently being established to expand the draft report from the Plymouth workshop into a comprehensive framework for research.❖

(Editor's note: Susannah Eliott serves as science communicator at the IGBP Secretariat in Stockholm. Wendy Broadgate is deputy director for natural sciences for IBGP.)

IGBP (Cont. from page 8)

sessions that will be of particular interest to JGOFS participants. They include sessions on the global carbon cycle, El Niño-Southern Oscillation (ENSO) cycles and past and future climate variability, coupled earth system modelling, the oceans and climate change, and non-linear responses and surprises in global change.

The IPO is issuing a call for poster clusters with themes that demonstrate the relevance of ocean biogeochemical research to broad earth system concerns. Suggestions for themes, organizers, titles, and authors may be sent to JGOFS executive scientist Roger Hanson (**Roger.Hanson@jgofs.uib.no**).

The JGOFS Scientific Steering Committee will take advantage of the opportunity afforded by the conference to hold its 16th meeting at the Dutch Academy of Sciences July 7-8. The chairmen of national JGOFS committees or their representatives are welcome to attend. More information is available from Roger Hanson.

The conference will take place at the Amsterdam RAI. All abstracts should be submitted before March 31 to the Conference Secretariat, Congrex Holland (**http://www.congrex.nl/igbp/abstracts/**).

(Cont. on page 14)

EisenEx: (Cont. from page 12)

ing water.

Because we were scheduled to leave the eddy at midday on Nov. 29, we carried out the final grid with short CTD stations the day before and the last two major stations inside and outside the patch after that. The grid revealed that fertilised water now covered an area of 500 square km, which extended over the entire eye of the eddy.

The highest chlorophyll concentration we measured was 2.84 milligrams of chlorophyll per cubic metre (mg Chl/m^3) with a standing stock of more than 200 milligrams per square metre, which is a large algal biomass by any standard. Yet these values are a very rough measure of the total biomass built up by iron fertilisation because they have to be corrected for dilution with surrounding water.

A correct estimate of the carbon actually taken up as a result of iron fertilisation will require a calculation of the total area covered by the bloom, estimated by means of the SF_6 and another tracer, Helium 3, that was added to the water. The final estimate will be conservative, because we had to leave the eddy as the bloom was beginning to "take off."

Our budgets will incorporate a number of measurements carried out during EisenEx, including CO_2 deficits and nitrate, phosphate and silicate concentrations, as well as increases in biomass of bacteria, zooplankton and their waste products. In the water with the highest chlorophyll concentrations, nitrate and phosphate declined by only 10%, whereas silicate decreased by 30%.

The lowest concentration of CO_2 that we found was equivalent to an uptake of about 7 grams of carbon per square meter (gC/m^2). If all the nitrate were converted into algal biomass, the equivalent chlorophyll concentration would be around 50 mg Chl/m^3, and the total amount of CO_2 converted to organic carbon in a water column 60 metres deep would be over 80 gC/m^2. These figures suggest the enormous potential of these waters for building up biomass and removing CO_2 from the atmosphere.

It was not clear at first which of the many groups of phytoplankton represented in the eddy were primarily responsible for the increase in chlorophyll within the patch. Plankton diversity was unusually high because the eddy had spun off from the APF in the south and carried with it large diatoms and presumably also the colonial flagellate *Phaeocystis*, which are typical of the Antarctic Zone. Lighter surface water encroaching from the north carried species typical of the subantarctic: dinoflagellates, coccolithophorids and minute cyanobacteria that were mixed into the surface layer with the southern plankton.

The smallest cells in our patch belonged to the cyanobacteria, which are about 1 micron in diameter, and the largest was a rod-shaped diatom that is more than 2 millimetres long. Growth rates, ecological preferences and life cycles of these species differ widely. Since the fate of the carbon fixed by the fertilised community depends largely on which size class and group accumulates most biomass, it is essential to follow changes in community composition closely.

Initially it looked as though cells in the intermediate size class, between 10 and 20 microns, had increased in number the most, but during the third week of the experiment an as-yet unidentified species of the cosmopolitan diatom genus *Pseudonitzschia* clearly attained dominant status. Many other algal species contributed to our bloom, but in smaller numbers. Careful counting in the laboratory will disclose the respective contributions of various species to the fertilised biomass during the course of its growth.

Preliminary results indicate that bacterial growth was also strongly stimulated by iron addition, but the extent to which the protozoa and zooplankton responded to the increase in food supply still needs to be analysed.

We could not be sure about the fate of our bloom while we were at sea. A sensitive technique using natural radioactive tracers to estimate the rate at which particulate material sinks from the surface layer to the deep ocean indicated that there was little difference in loss rates between water inside the patch and outside. We expected that to change over time. We hoped to use satellite imagery to monitor the eventual disposition of our bloom, but heavy cloud cover has so far revealed only glimpses of it.

Although the cruise was too short to assess the eventual magnitude and fate of the bloom we created, EisenEx was a great success. We showed that plankton growth in the PFZ is limited by iron availability and that addition of this element can lead to a quadrupling of biomass within a period of three weeks, despite heavy grazing and poor light conditions characteristic of the austral spring. We were well cared for by a remarkably patient crew, whose good humor and willingness to help at any hour contributed greatly to the success of our venture.

(Editor's note: Victor Smetacek, a scientist at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany, served as chief scientist on the EisenEx cruise.)

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The abstract form and guidelines are published at this web site. The early registration deadline is April 30.

More information on the programme, speakers, fund-raising or guests is available from IGBP conference coordinator Rowena Foster (**Rowena.Foster@dwe.csiro.au**) or IGBP executive director Will Steffen (**will@igbp.kva.se**). Questions concerning registration, abstract submission, accommodation and local matters should be addressed to conference manager Annemiek van Iersel (**annemiek@congrex.nl**).

Information about all aspects of Challenges of a Changing Earth is available at the conference web site (**http://www.sciconf.igbp.kva.se**).

New Assistant Executive Officer Sought For JGOFS

Assistant executive officer Beatriz Baliño will be leaving the JGOFS International Project Office (IPO) in Bergen, Norway, next month to take a new position as programme coordinator for a newly established centre on climate research, also in Bergen. During her years with JGOFS, she has had primary responsibility for the JGOFS home page, publications and data management matters.

Baliño joined the IPO in the summer of 1996, the year that she completed her doctorate in biological oceanography at the University of Bergen. She grew up in Montevideo, Uruguay, where she received her undergraduate degree in biological oceanography.

The staff of the IPO assists the JGOFS Scientific Steering Committee with the management of scientific activities, fund-raising and the organization of conferences and meetings. The office serves as a channel for communication among JGOFS committees and investigators in more than 20 countries as well as with other international global change programs.

Data management is expected to be the most important responsibility of the assistant executive officer over the next three years. The new officer will work closely with the JGOFS Data Management Task Team and will be responsible for the research cruise inventory, the production of data documentation and the maintenance and development of the JGOFS home page (**http://ads.smr.uib.no/jgofs/jgofs.htm**). The position, supported by the University of Bergen, will run through 31 December, 2003.

More information is available from JGOFS executive officer Roger B. Hanson (**Roger.Hanson@JGOFS.uib.no**).

Getting Access To JGOFS Data and Information From Other Countries

The JGOFS International Project Office provides on-line information at **http://ads.smr.uib.no/jgofs/pgtt.htm#DM** about JGOFS programs and data sets in many of the countries that have participated in the study. Listed below are the data managers, their phone numbers and email addresses and World Wide Web home pages, where appropriate, for national JGOFS programs that make data available to interested users via a central contact.

Australia
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Canada-JGOFS web site: **http://www.meds-sdmm.dfo-mpo.gc.ca/jgofs/**

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JGOFS-France web site: **http://www.obs-vlfr.fr/jgofs/html/index_eng.html**

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27 Feb.-1 March: U.S. JGOFS Scientific Steering Committee meeting, Santa Barbara, California. Contact: Ken Buesseler, U.S. JGOFS Planning Office, Woods Hole Oceanographic Institution, Woods Hole, MA (**kbuesseler@whoi.edu**).

27-29 June: JGOFS-WOCE CO_2 Transport Workshop, Southampton Oceanography Centre, Southampton, UK. Contact: Douglas Wallace, Institut für Meereskunde, Kiel, Germany (**dwallace@ifm.uni-kiel.de**).

7-8 July: JGOFS Scientific Steering Committee Meeting, Amsterdam, The Netherlands. Contact: Roger Hanson, JGOFS International Project Office, Universitet Bergen, Norway (**Roger.Hanson@jgofs.uib.no**).

10-13 July: IGBP Open Science Conference, "Challenges of a Changing Earth," Amsterdam, The Netherlands. Contact: CONGREX HOLLAND BV, Amsterdam, The Netherlands (**igbp@congrex.nl**).

16-20 July: U.S. JGOFS Synthesis and Modeling Project workshop, Woods Hole Oceanographic Institution, Woods Hole. Contact: Scott Doney or Joanie Kleypas, National Center for Atmospheric Research, Boulder, CO (**kleypas@ncar.ucar.edu**).

Getting Access to U.S. JGOFS Data and Information

Information on the U.S. JGOFS program and access to all U.S. JGOFS data can be obtained through the U.S. JGOFS Home Page on the World Wide Web:

http://usjgofs.whoi.edu/

Inquiries may be addressed to the U.S. JGOFS data management office via electronic mail to **dmomail@dataone.whoi.edu** or by phone to David Schneider (508-289-2873).
Data from U.S. JGOFS process study cruises are available through the U.S. JGOFS data management system at the Web site above.
Data from the U.S. JGOFS time-series programs are also available via the World Wide Web at the following sites:
HOT **http://hahana.soest.hawaii.edu/hot/hot-dogs/interface.html**
BATS **http://www.bbsr.edu/ctd**
Data from the Survey of Carbon Dioxide in the Oceans are available from the Carbon Dioxide Information Analysis Center at
http://cdiac.esd.ornl.gov/oceans/home.html

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