

4.0 OCEAN CARBON AND OTHER ACTIVITIES

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4.1 Advisory Panel on Ocean CO₂ (joint with IOC)

Terms of Reference:

General Terms of Reference

- i. Advise SCOR/JGOFS, GOOS, LOICZ, and OOPC on observations, data management and modeling needed for studies of the global carbon cycle.
- ii. Provide an international forum for initiatives to promote high-quality observations needed to understand the ocean component of the global carbon cycle.

Specific Terms of Reference

- i. To identify gaps and weak links in the present carbon cycle observation system that compromise the ability to understand and predict global change
- ii. To identify opportunities that can be used to further develop such an observing system (e.g., collaboration with other global observing systems)
- iii. To aid the synthesis of JGOFS and IGBP results with respect to marine CO₂ observations, data management and modeling by:
 - a. Initiating and facilitating the assembly of necessary data bases
 - b. Interacting with ocean modelers to identify the weaknesses and encourage appropriate uses of ocean carbon cycle data
 - c. Encouraging and facilitating the collaborative analysis of CO₂ data with other carbon cycle and supporting data sets.
- iv. To maintain a watching brief to advise IOC and SCOR on CO₂ sequestration in the ocean
- v. To advise GOOS and OOPC on technology development needed to improve future capacity for carbon cycle monitoring
- vi. To advise GOOS and OOPC on the observational strategies needed to assess, model, and predict global ocean CO₂ fluxes

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Andrew Dickson	USA	Corinne Le Quéré	GERMANY
Roger Francey	AUSTRALIA	Yukihiro Nojiri	JAPAN
Michele Frankignoulle	BELGIUM	Andrew Watson	UK

IOC Liaison: Maria Hood

Executive Committee Reporter: John Field



PROGRESS REPORT, JUNE 2003

Publications:

IOC-SCOR Ocean CO₂ Advisory Panel, First Session Report, September 2000. Available on Web site or in hard-copy from the IOC documentation center.

A Global Ocean Carbon Observation System: A Background Report, GOOS Technical Report 118, 2002. Available on Web site or in hard-copy form the IOC documentation center.

IOC-SCOR Ocean CO₂ Advisory Panel, Second Session Report, February 2002. Available on Web site.

Ocean Carbon Sequestration: A Watching Brief, 2002. Available on the Web site.

Ocean Carbon Observations from Ships of Opportunity and Repeat Hydrographic Sections: Results from the first workshop of the International Ocean Carbon Coordination Project. January 2003. IOCCP document 03/1, available on CD-ROM or via Web site.

Sabine, C.L. and M. Hood, New levels of international cooperation among ocean carbon scientists, *EOS Trans. AGU*, June 10, 2003.

Please visit our Web sites for more information: <http://ioc.unesco.org/iocweb/co2panel> and <http://www.ioccp.org>

The SCOR-IOC Advisory Panel on Ocean CO₂

Human activities have profoundly altered the Earth's global carbon cycle. These alterations are linked to globally rising temperatures, increases in severe weather events, and an ever-shifting and currently unpredictable pattern of droughts, floods, famine, and disease. The study of the Earth's carbon cycle and climate is no longer strictly an academic exercise, but rather one that demands political consideration at an international level. The CO₂ Panel serves as a liaison between the scientific community, which must be engaged to develop observation

networks and unbiased syntheses of our scientific knowledge, and the policy-makers who must use this information for the wise stewardship of the global environment. The IOC is the sub-task manager for the UNCED Agenda 21, Chapter 17, Programme Area E, “Addressing critical uncertainties for the management of the marine environment and climate change”. In this programme area, section 17.102 on management-related activities states: *“Recognizing the important role that oceans and all seas play in attenuating potential climate change, IOC and other relevant competent United Nations bodies, with the support of countries having the resources and expertise, should carry out analysis, assessments and systematic observation of the role of oceans as a carbon sink.”*

Project Briefs:

The International Ocean Carbon Coordination Project (IOCCP)

A proper understanding of the global carbon cycle is critical both for understanding the environmental history of our planet and its human inhabitants, and for predicting and guiding their joint future. The challenge to the scientific community is to monitor (quantify), understand (attribute) and predict the evolution of the carbon cycle in the context of the whole Earth system, including its feedbacks with human components. Three international global environmental change research programmes—IGBP, IHDP, and WCRP—have come together to bring such a coordinated program into reality, in the form of the Global Carbon Project (GCP). Recognizing the need for coordination of carbon observations and research in the atmosphere, land, and oceans, the GCP has sought partnerships with existing international groups to serve as GCP affiliate offices and to develop joint pilot projects for coordination within and between domains. The CO₂ Panel and the GCP have initiated a collaborative project to (i) develop a compilation and synthesis of ocean carbon activities and plans, (ii) work with international research programs to fully integrate carbon studies into planning activities, (iii) standardize methods, qc/qa procedures, data formats, and use of certified reference materials, and (iv) support regional synthesis groups and create regional databases. The Letter of Agreement between SCOR, IOC, and the GCP is given in Annex I.

The CO₂ Panel, working with GCP representatives, developed the first workshop of the International Ocean Carbon Coordination Project, which was held at the IOC-UNESCO Headquarters in Paris, France on 13-15 January 2003. Support for this workshop was provided through US National Science Foundation Award No. OCE-0245278 to SCOR. This meeting brought together 56 participants from 17 countries to discuss activities and plans for carbon measurements from ships of opportunity and the repeat hydrographic sections of CLIVAR. Dr. Chris Sabine, NOAA/PMEL, serving as the scientific focal point for the GCP, and the CO₂ Panel technical officer Maria Hood have written an article about the IOCCP for the American Geophysical Union publication EOS, which appeared in the June 10 2003 issue (see reprint following this report).

The workshop summary and specific action items are given in Annex II and the full report of the workshop is available on CD-ROM from the IOC project office or on-line at www.ioccp.org. The IOCCP is planning a 2nd workshop for October 2003, focusing on data

formats for carbon measurements from ships of opportunity. This workshop is being led by CO₂ Panel Members Yukihiro Nojiri and Andrew Dickson.

A Broader Focus for the CO₂ Panel

Because the IOCCP pilot project will now encompass most of the observation coordination activities previously carried out by the Panel, there is a need to review the activities of the Panel and to broaden its focus to address new issues and activities. The IOCCP will focus on observation coordination of ongoing and planned programs, and deal with related issues such as data formats and coordination among data centers and regional projects. There is still a need, however, to encourage and facilitate the development of historical databases of CO₂, to advise on and advocate for technology development, and to develop best practices guides and training courses for measurement programs. As listed in the current Terms of Reference, the CO₂ Panel will continue to focus on ocean carbon sequestration science and will begin to address ocean carbon modeling issues.

Over the last decade, it has become clear that the ocean's carbon cycle cannot be understood or predicted through quantification of the CO₂ cycle alone. To fulfill the mandate of the Panel to provide advice on the observations and research needed to understand and quantify the ocean's role in the global carbon cycle, the Panel's Terms of Reference need to be broadened to include all aspects of ocean carbon and key nutrients. The Panel Chair, Panel Technical Officer, and SCOR Executive Officer are developing new draft Terms of Reference that would meet these needs, with the understanding that the composition of the Panel will need to change to include the necessary expertise. In 2004, in conjunction with the international symposium "The Oceans in a High-CO₂ World" (see below), the new Panel will meet to highlight new activities and work plans.

The IGOS Partners Integrated Global Carbon Observation (IGCO) Theme

The IGOS-P IGCO strategy was endorsed by the IGOS Partners at their June 2003 meeting. The strategy is in final stages of preparation and is available in draft form on the IGOS-P Web site at: www.igospartners.org. This document has been developed to present an integrated strategy for satellite and in-situ based observations of the global carbon cycle, including land, atmospheric, and oceanic components. The CO₂ Panel took the lead in developing the contributions for the ocean observations through the publication of "A Global Ocean Carbon Observation System: a Background Report" (April 2002, GOOS Technical Document 118 / IOC Information Document 1173). The IGOS Partners IGCO Theme Team, including several Panel members, will form an implementation team to document progress against the stated priorities, and to use this information to advocate for international commitments to meet the objectives. The IGCO is working very closely with the Global Carbon Project to combine research priorities with observation priorities to create a coordinated and integrated strategy for the study of the global carbon cycle.

Carbon and Tracers in CLIVAR

In 2002, the Panel was asked to serve as the focal point for ocean carbon observations being made on the repeat hydrographic sections of CLIVAR. In response to a proposal developed through the IOCCP, the CLIVAR Scientific Steering Group agreed at its May 2003 meeting to

include carbon experts on each of the Basin Panel steering groups to better coordinate carbon and tracer measurements within the larger hydrographic program. The IOCCP will provide some amount of financial support for experts to attend the meetings when necessary. The IOCCP project officer (same as the CO₂ Panel technical officer) has been working directly with the CLIVAR International Project Office to coordinate Web site development between the hydrographic program and carbon measurements to create a seamless and complementary information system for the repeat hydrographic sections.

Carbon and the JCOMM Ship of Opportunity Program (SOOP)

The WMO-IOC Joint Commission on Oceanography and Marine Meteorology (JCOMM) asked the CO₂ Panel to be the focal point for carbon and biogeochemical measurements made from ships of opportunity. During the first workshop of the IOCCP, the group discussed possible collaborations with JCOMM, which is encouraging the carbon community to adopt an operational approach to observations, including real-time release of data and international planning of lines measuring carbon and other variables. The group decided to establish a cooperative system of data centers handling carbon SOOP data, and through the IOCCP, to begin developing yearly regional datasets from carbon SOOP programs. It was also noted that the salinity data from the carbon SOOP programs are often of higher quality than the salinity data from the JCOMM SOOP program, and the group offered this data to the JCOMM SOOP program user community, albeit on a yearly basis only. At the present time, the group does not feel that it was desirable to move to a more operational system for carbon data, since there is still scientific interest in the results from each single program (rather than only through collective efforts as for temperature and salinity) and also because there is no identified user group for real-time carbon measurements. Regional and global flux estimates will be made annually from the available data, and researchers wishing to make seasonal estimates may use the data available in the participating data centers.

Coordination with the Partnership for Observations of the Global Ocean (POGO)

POGO has requested that the IOCCP / CO₂ Panel present the ocean carbon observation activities and coordination project to the next POGO steering committee meeting (November 2003), with a view to working together to develop a similar coordination effort for biological variables. It was noted that the priorities outlined in the global ocean carbon observation system report and those listed in a POGO-sponsored report on biological variable priorities have significant overlap, and that the infrastructure for these observations is almost identical.

Coordination with the Ocean Time-Series Project (the Global Eulerian Observatories (GEO) project)

The IOCCP/CO₂ Panel technical officer attended the 3rd Science Team meeting of the GEO project in April 2003 to discuss collaborations and ensure compatibility between coordination projects. Carbon measurements from time-series stations made as part of national, regional, or international projects will be coordinated through the GEO project as a demonstration of the benefits of a global coordinated network of sustained, fixed-point ocean observations. The IOCCP will link to the information system of the GEO project for ocean carbon data from fixed-point observations, and will encourage other measurement platforms (underway measurements, etc.) to adopt similar data management procedures and formats (e.g., netCDF

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file format with agreed definitions on ftp servers, with a central group such as the CORIOLIS project creating a data catalog and pointer to sites). The data management group advising the GEO project (CORIOLIS/IFREMER – France) has been contacted and has provided information to the underway carbon measurement group that will be meeting in October 2003. This is the same group managing the Argo float data.

Reference Materials/Methods Handbooks

Developing compiled data sets from a global network of observations made using a variety of techniques and platforms requires the development and use of standards and certified reference materials (CRMs). Panel Member Andrew Dickson has been working with the Kansai Environmental Engineering Center (KEEC) in Japan to develop a new CRM programme. At the request of KEEC, Dr. Dickson is currently revising the U.S. Department of Energy manual for preparation of standards to simplify the English to facilitate translation. The first draft of this best practices guide will be available in October 2003, and the CO₂ Panel will financially support its publication and distribution. Upon completion of the manual, it will be translated into other languages as requested, and the IOCCP / CO₂ Panel will plan the first of a series of training courses for ocean carbon measurements using the handbook as a guide (late 2004/early 2005).

Intercalibration Exercises

Panel Member Yukihiko Nojiri hosted an intercalibration workshop for pCO₂ sensors used on underway measurement systems in March 2003, which was endorsed as a CO₂ Panel activity. In contrast with DIC and alkalinity measurements, it is difficult to prepare standard seawater for underway pCO₂ measurements. Intercomparison exercises are crucial to ensure the accuracy of pCO₂ observations. Previous pCO₂ intercomparison experiments (1994 at the Scripps Institution of Oceanography and 1998 on board *R/V Meteor*) were useful, but the experimental set-up was not completely ideal in either case. This intercalibration workshop used an indoor seawater pool under controlled laboratory conditions, which allowed very precise comparisons of the equilibrators and gas measurement systems. The results of the intercomparison workshop will be published as a Numerical Data Package (NDP) of the Carbon Dioxide Information Analysis Center (CDIAC - the World Data Center for carbon data) as was done for the previous intercomparison experiments.

In October 2003, Dr. Nojiri will host a follow-up workshop to discuss the results of the intercomparison exercise, and the IOCCP will support an additional two- to three-day workshop on data formats for underway CO₂ measurements. There are at present approximately 22 underway ocean carbon measurement programs operating, with no coordination through any international research program. There are as yet no agreed data formats and no means of combining the results of individual programs. This workshop will draw on the results of the intercomparison exercises, the soon-to-be-published methods handbook, and discussions with data managers to create a cooperative network for ocean carbon observations from ships of opportunity that is capable of providing the data necessary to produce regional annual air-sea flux maps.

Regional Groups

PICES Working Group 17 on *Biogeochemical data integration and synthesis* is developing a North Pacific database for ocean CO₂ and related parameters, and a written guide of best practices for oceanic CO₂ measurements and data reporting. The CO₂ Panel has been asked by PICES to endorse and co-sponsor this working group, whose two co-chairs are Panel Members. The CO₂ Panel will co-sponsor a special session at the 2004 Ocean Sciences meeting jointly with PICES on this activity, and the IOCCP has endorsed a North Pacific data workshop to be held in 2004.

The funding for the Carbon in the Atlantic (CARINA) program, sponsored by German JGOFS, ended in June 2003, and the CO₂ Panel and IOCCP are working with the CARINA steering committee to find ways and means for continuing the work of this group. The CO₂ Panel / IOCCP technical officer will work directly with the steering committee chair to continue the annual workshop and database collection activities until a more permanent arrangement can be found.

The IOCCP has discussed the need to develop similar regional groups for the Indian Ocean and the Southern Ocean. These will be discussed at the next CO₂ Panel meeting and may be done in conjunction with the existing CLIVAR Basin Panels.

Ocean Carbon Sequestration Science

The Panel has developed a Watching Brief on ocean carbon sequestration, which provides information for the general public on the scientific and policy issues surrounding ocean carbon sequestration. It is available on the Panel Web site.

SCOR and IOC, in close collaboration with the Panel, are planning an international science symposium called "The Oceans in a High-CO₂ World" to be held in 2004 (tentatively in Lisbon, Portugal), with the goal of synthesizing the current understanding and outstanding scientific questions regarding the biogeochemical consequences of the natural invasion of atmospheric CO₂ into the surface ocean and of the chemical and biological consequences of proposed ocean carbon sequestration methods. The Steering Committee, headed by Dr. Ralph Cicerone (UC-Irvine), met in February 2003 in Irvine, California, and the draft agenda developed at that meeting will be distributed at the SCOR Executive Committee Meeting. The results of this conference will be presented as a special issue of a peer-reviewed scientific journal (e.g., the *Journal of Geophysical Research – Oceans*).

IOC and SCOR are working closely with the IPCC on their Special Report on Carbon Capture and Storage. This special report is scheduled to be published in early 2005, and the results of the symposium published in the *Journal of Geophysical Research* will be used by the Special Report authors to assess our state of understanding of ocean carbon sequestration techniques, efficiencies, and concerns. The CO₂ Panel technical officer attended a meeting with the Special Report support unit to discuss the planning / scheduling for our respective meetings and publications. Three members of the symposium steering committee are also authors of the IPCC Special Report.

Annex I

Letter of Agreement
(signed by all 3 partners, June 2003)

Between

The Intergovernmental Oceanographic Commission of UNESCO (herein called IOC) the Headquarters of which are situated in Paris, France

The Scientific Committee on Oceanic Research (herein called SCOR) the Headquarters of which are situated in Baltimore, Maryland, USA

The IGBP-IHDP-WCRP Global Carbon Project (herein called the GCP) the Headquarters of which are situated in Canberra, Australia

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The Intergovernmental Oceanographic Commission (IOC), the Scientific Committee on Oceanic Research (SCOR), and the Global Carbon Project (GCP), recognizing the mutual benefit arising from increased collaboration, undertake to strengthen their cooperation on activities related to coordination of regional and national ocean carbon studies. For their part, the IOC and SCOR will coordinate these activities through their jointly sponsored advisory group, the SCOR-IOC Advisory Panel on Ocean CO₂ (herein called the CO₂ Panel).

Rationale

There is an immediate need to coordinate the large number of national and regional ocean carbon programmes and activities currently being planned, such as the re-occupation of WOCE hydrographic sections, new pCO₂ systems for a network of surface observations on ships of opportunity, and a time-series network pilot project. The SCOR-IOC CO₂ Panel, established with its current Terms of References in 2000, provides an international, program-independent mechanism for cross-cutting issues of data standards and formats, inter-comparison studies, modeling, measurement techniques and technology development, and observation network development needed to improve our understanding of the ocean's role in the global carbon cycle. It pursues this work through the development of technical background documents, workshops, special working groups, and conferences.

To facilitate the coordination of national, regional, and international ocean carbon activities, the GCP and CO₂ Panel will work together to: (i) develop and maintain a Web-based information clearinghouse on ocean carbon activities, building upon existing Web information, (ii) develop periodic, focused workshops to gather information on the latest observation and research plans and to identify programs that have possible conflicts or potential for better collaboration, and (iii), at the request of individual research or observation projects, provide other services to facilitate coordination of programmes and data products.

Role of Partners

Under the terms of the Agreement, the collaboration will operate under joint participation as follows:

The Intergovernmental Oceanographic Commission of UNESCO will provide the part-time services of the Technical Officer of the CO₂ Panel to serve as the Technical Officer and Secretariat for the collaboration. Duties will involve (i) periodic Web updates and maintenance, (ii) workshop development in collaboration with one or more designated focal points of the GCP and CO₂ Panel as appropriate, and (iii) writing, compiling, and editing publications stemming from workshop and collaboration activities as necessary.

The Scientific Committee on Oceanic Research will serve as the principle financial administrator of the collaboration. External financial support for workshops and other collaboration activities will be directed to SCOR, unless otherwise required for GCP-contributed or acquired funds. SCOR will review the collaboration annually through its scientific and financial oversight of the CO₂ Panel and may suggest tasks for the partnership.

The IGBP-IHDP-WCRP Global Carbon Project will identify one or more focal points to serve on the planning committee of each workshop developed through the collaboration. This person will be expected to play a leading role in development of workshop objectives and agendas, and identification of participants. The GCP focal point for each workshop will be the principle partner responsible for identifying and acquiring external funds to support the work of the collaboration through contacts and proposal writing.

<p>Patricio Bernal Executive Secretary IOC Assistant to the Director- General, UNESCO</p>	<p>Edward R. Urban, Jr. Executive Director, Scientific Committee on Oceanic Research</p>	<p>Josep Canadell Executive Officer, IGBP-IHDP-WCRP Global Carbon Project</p>
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Annex II

International Ocean Carbon Coordination Project Workshop Summary

Objectives for the International Ocean Carbon Coordination Project (A Joint Pilot Project of the SCOR-IOC Advisory Panel on Ocean CO₂ and the Global Carbon Project)

1. Develop a compilation and synthesis of large-scale ocean carbon observation activities and plans.
2. Promote the full integration of large-scale carbon studies into the planning activities of international research programs (e.g., CLIVAR, OCEANS, SOLAS)
3. Identify and coordinate regional-scale science groups (e.g., PICES WG17, CARINA) to critically examine the scientific balance, quality and completeness of these programs with reference to global-scale research needs. Promote the establishment of other regional groups as needed.
4. Organize international groups to promote acceptance of:
 - Standardized measurement techniques (e.g., through the publication of a best practices handbook).
 - Improved accessibility to international carbon data sets (e.g., promoting more uniform data handling/reporting, encourage submission of data to one of three regional data centers within 2 years or less of data collection, investigate data citation issues)
 - Internationally recognized QA/QC procedures (e.g., promoting the use of CRMs, helping to organize training workshops and inter-laboratory comparison exercises)

Specific Action Items from this Workshop:

The IOCCP should develop a Web site to disseminate information on national plans for large-scale carbon observations and progress on objectives listed above. **Action 1:** Hood, Sabine, Wallace, Canadell, Foster, and Hill to develop site through IOC and GCP in collaboration with CLIVAR.

The IOCCP should serve as a focal point for communication between the carbon community and CLIVAR to identify key areas of common interest and promote a stronger collaboration in developing a measurement strategy for carbon and tracers on repeat hydrographic sections. **Action 2:** Hood, Tilbrook, Sabine, and Feely to develop a statement to the CLIVAR community about the need for tracer measurements on specific repeat sections, promote the appointment of carbon representatives to the CLIVAR regional panels, and establish a closer dialogue with CLIVAR planning of repeat section work in each basin.

The IOCCP should establish formal links with PICES WG17 and CARINA to encourage these regional programs to evaluate the scientific balance, quality and completeness of the large-scale carbon programs with reference to global-scale research needs and facilitate the organization of training workshops and inter-laboratory comparisons to improve data quality.

Action 3: Hood, Sabine, Dickson, Mintrop to establish mechanism for IOCCP to provide global coordination to regional groups.

The IOCCP should facilitate closer links (possibly through interdisciplinary workshops) between the ocean and atmospheric carbon observation communities and the modelling community. **Action 4:** Hood, Canadell, Feely, Gnanadesikan, and Heinze to document on-going ocean carbon modelling projects and groups, and begin a dialogue with appropriate key scientists to outline the needs for a workshop.

The IOCCP should promote the public release of large-scale carbon data sets within 2 years of cruise completion and encourage submission of international repeat hydrographic section data with carbon measurements to CDIAC and to GHDO. **Action 5:** Kozyr, Swift, and Hill to provide a plan for coordinated data submission of carbon and tracer data on CLIVAR repeat hydrographic sections.

The IOCCP should facilitate the revision and expansion of the DOE CO₂ Methods Handbook (lead by A. Dickson) and promote it as a manual of best practices to be followed by those participating in the large-scale carbon observation network. **Action 6:** Hood and Dickson to develop a plan to finalize the revision, possible translation into other languages, and to promote and distribute the handbook.

The IOCCP should work with appropriate organizations and scientific groups to develop a policy for the proper citation of large-scale data sets. **Action 7:** Hood, Sabine, Feely, and Wallace to encourage data centers to clearly indicate appropriate reference/acknowledgement for data being downloaded and to contact the American Geophysical Union, the European Geophysical Union, and other appropriate groups to initiate discussions on policies for acknowledging the use of large-scale data sets in peer-reviewed articles.

The IOCCP should coordinate and promote the compilation and public release of historical pCO₂ data sets. **Action 8:** Dickson, Kozyr, and Heinze to develop a brief position paper outlining this high priority for the community and a plan for coordination between on-going efforts at CDIAC, WDC-MARE / ORFOIS, and other programs.

The IOCCP should address the problem of excessive delays in obtaining permission from governments to make pCO₂ measurements on ships of opportunity in territorial waters. **Action 9:** Hood, Manabe, Tilbrook, Zika, Feely, and Nojiri to document particular problems faced with the current system and work with the IOC-WMO JCOMM Ship Observations Team to find the best way forward.

The IOCCP should support and promote certified reference material programs, including the development of appropriate standard gases for ocean carbon work. **Action 10:** Hood, Dickson, and Nojiri to work with the atmospheric community (Roger Francey) to develop a round-robin intercomparison test for ocean carbon gases.

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Priorities for Future Workshops:

1. pCO₂ inter-laboratory comparison study - March 10-14, 2003, Japan (Nojiri through PICES WG17)
2. Data exchange and formats - workshop should be held in close collaboration with data centers and analysis projects; suggested end 2003 / early 2004 (Nojiri).
3. Ocean carbon modelling and new observation system planning (Gnanadesikan).
4. Ensure increased representation of the ocean community in the International CO₂ Conference, and encourage the ocean community to participate in this integrated workshop. (Wallace to contact Tans).
5. Publish the Methods Handbook and then hold a training workshop with the manual to train new / young scientists.

Web site Features:

The central means of communication between the IOCCP between sessions / workshops will be the IOCCP Web site. The participants suggested that the site include

1. Information about current and on-going repeat sections, underway measurement programs, and time-series stations, including interactive maps and tables of information.
2. Information/recommendations for coordination of activities, upcoming workshops or meetings, position statements on best practices for large-scale ocean carbon observations
3. Information about current ocean carbon modelling and relevant atmospheric projects and groups
4. Contact lists/email lists for international colleagues
5. A news bulletin, with notices and abstracts of news items sent to the community via email with links back to full articles on the Web site.

Resources and Project Feasibility Issues:

Meeting participants noted that, given the number of different organizations to be contacted, coordinated with, and linked to, an international coordination project must have one central focal point. It was remarked that the roles for this coordination project outlined here are not new – they have been discussed for 20 years or more. Participants stressed that the reason these coordination activities have never been accomplished is because there has never been a central focal point or sufficient secretariat support to adequately establish such a program. Participants also stressed that because there is interest and pressure to develop an ocean carbon observing capability and research strategy for ocean carbon assessment and projection, the ocean carbon community must have its own international coordination program rather than trying to coordinate its activities via individual scientists participating in interdisciplinary programs.

Participants strongly urged the IOC, SCOR, and the GCP to undertake seriously this initiative to develop an international ocean carbon coordination project, taking into account previous failures at similar attempts, and further urged that these sponsor organizations recognize and support the critical need for adequate secretariat support for such an endeavour. The Participants noted with appreciation the value of the close association with the IOC, particularly in matters of developing and gaining international acceptance of standards, the development of international data exchange agreements, and issues of conducting marine scientific research in territorial waters.

4.2 SCOR/IOC Symposium on the Ocean in a High-CO₂ World

Committee Charge:

The planning committee will determine the scope of the symposium, plan the agenda, develop the list of invited participants, and handle any publications that result from the symposium.

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IOC Liaison: Maria Hood

Executive Committee Reporter: Bob Duce

The Ocean in a High-CO₂ World:
Anthropogenic CO₂ and Carbon Sequestration

Program

Day 1

9:00-9:30 Welcomes
Local Host
Patricio Bernal (IOC)
Robert Duce (SCOR)
Ralph Cicerone (Committee)

A. Overviews (25 min. presentation + 5 min. discussion)

- 9:30-10:00 1. What human activities drive atmospheric CO₂ increases? –
- 10:00-10:30 2. Details of the three selected projections of atmospheric CO₂ levels (from pre-industrial levels to 2100) –
- 10:30-11:00 3. Physical/climate drivers of the ocean in the future (circulation, temperature, light, stratification, pH) –
- 11:00-11:30 Break

B. Effects of CO₂ enrichment on ocean chemistry (pH, alkalinity, DOC/DOM, carbonate dissolution, paleo)

- 11:30-12:00 1. The natural carbonate cycle and its effects on atmospheric and oceanic CO₂ -
- 12:00-12:30 2. Paleo perspective on ocean pH and carbon cycle–
- 12:30-14:00 Lunch

Discussion of sequestration strategies to give context for following presentations

- 14:00-14:30 3. Fertilization Overview –
- 14:30-15:00 4. Direct Injection Overview – **Peter Brewer (USA) - confirmed**
- 15:00-16:00 Break-Out Session #1 – Identification of Research and Observation Priorities and Approaches – Formulate and circulate a list of questions in advance to stimulate discussion

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16:00-18:00 Poster Session with Refreshments

Day 2

C. Short and long-term effects of CO₂ enrichment and surface fertilization on organisms and ecosystems

Speakers: Speculate on ecosystem changes, biodiversity, productivity, approaches to study for fertilization and direct injection

- 9:00-9:20 1. Effects of CO₂ on marine animals: Time scales, processes, and limits of adaptation – **Hans-Otto Pörtner (Germany) - confirmed**
- 9:20-9:40 2. Chemical and biological effects on phytoplankton in a high-CO₂ world -
- 9:40-10:00 3. Chemical and biological effects on corals in a high-CO₂ world -
- 10:00-10:20 4. Chemical and biological effects on benthic organisms and communities in a high-CO₂ world –
- 10:20-10:40 5. Chemical and biological effects on mesopelagic organisms and communities in a high-CO₂ world –
- 10:40-11:00 6. Chemical and biological effects on fishes in a high-CO₂ world –
- 11:00-11:30 Break
- 11:30-11:50 7. Ecosystem-level effects of deep-ocean CO₂ enrichment: What we know from natural high-CO₂ environments –
- 11:50-12:10 8. Ecosystem-level effects of surface fertilization, including food-web structure and nutrient dynamics –
- 12:10-12:30 Question and Answer Period
- 12:30-2:00 Lunch

D. Effects and effectiveness of carbon sequestration techniques

Observational/Experimental Results

- 14:00-14:30 Summary of iron-enrichment experiments -
- 14:30-15:00 Physics and chemistry of deep-ocean CO₂ release - **Peter Haugan (Norway) - confirmed**

15:00-15:30 Biological effects of deep-ocean CO₂ release –

Modelling Results

15:30-15:50 Biogeochemical modeling with an ecological model for the upper ocean.–

15:50-16:10 Modelling of dispersion from direct injection in the water column –

16:10-16:40 Break

16:40-17:00 Role of iron fertilization in glacial-interglacials –

17:00-17:20 Global Modelling -

17:20-17:40 Global Modelling/OCMIP – **Jim Orr (France) and Ken Caldeira (USA) - confirmed**

17:40-18:00 Question and Answer Period

Day 3

9:00-11:00 Break-out Session #2

11:00-11:30 Break

11:30-12:30 Break-out Session #2 (continued)

12:30-14:00 Lunch

14:00-16:00 Reports from Break-out Groups and General Discussion

16:00-16:30 Break

16:30-17:30 Closing – Summary, point to the future, unanticipated consequences

16:30-16:50 Summary of implications of the high-CO₂ world for ocean chemistry and how the research community could respond -

16:50-17:10 Summary of Implications of the High-CO₂ World for Ocean Biology and how the research community could respond -

17:10-17:30 **Ralph Cicerone**, Planning Committee Chair – **confirmed**

Status of Symposium Planning

Place and Dates—After consideration of several potential locations, we decided to convene the symposium in ____ on _____.

Publication Venue--Given the information that we collected, we have decided to place the special issue in the *Journal of Geophysical Research--Oceans*. This journal appears to have the best combination of reputation, cost, and flexibility. *Limnology and Oceanography* is more expensive and it only publishes one special issue per year (and they have already scheduled for the next two years). *Global Biogeochemical Cycles* does special sections of a few papers, but not special issues. We were contacted by someone from *Oceanography* magazine, who inquired about us buying a special issue. This is a not a good option for our special issue, but we may want to submit the summary of recommendations about research priorities to *Oceanography*. We should also try to have some kind of meeting report in *EOS*.

Funding--NSF has agreed to provide an additional \$35,000 and the Norwegian Research Council agreed to extend our grant through 2004. A request has been included in the list on **p. 5-3** for some funds to support travel of scientists from developing countries. We are pretty close to having the funding completed, but will still approach a few more potential sponsors, to make sure we can keep the registration fees reasonable and have a contingency for unforeseen circumstances.

Research Priorities—Ed Urban has discussed with the committee responsible for both the Surface Ocean - Lower Atmosphere Study (SOLAS) and the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER, formerly OCEANS) the idea of convening a research planning meeting following the symposium to pick up the research priorities from the symposium to weave them into SOLAS and IMBER. (Both projects contain elements related to pH effects and other aspects of the ocean carbon cycle relevant to the symposium.) Both projects are interested in pursuing the idea of the follow-on meeting, since the right kind of people will be attending the symposium and might be convinced to stay a few extra days. The agenda will be forwarded to SOLAS and IMBER when we have the speakers in place.

Policy Issues Related to Ocean Carbon Sequestration

We received a letter from John Cullen about the need for policy action related to plans for commercial-scale iron fertilization. Robert Duce brought this issue to the attention of Robert Patricio Bernal, the Executive Secretary of the Intergovernmental Oceanographic Commission, since SCOR's mandate does not include policy development. The letter from John Cullen, to Patricio Bernal from Robert Duce, and the response from Patricio Bernal, are included below.

Letter from John Cullen to Ed Urban

4-20

Letter from John Cullen to Ed Urban, page 2

Letter from Robert Duce to Patricio Bernal, page 1

4-22

Letter from Bob Duce to Patricio Bernal, page 2

Letter from Patricio Bernal to Bob Duce

4.3 Other Activities

4.3.1 SCOR/IOC Activity on Extending Ecosystem Models to the Basin Scale

The Intergovernmental Oceanographic Commission (IOC) requested that SCOR and IOC bring together a group of scientists who have been active in ecosystem modeling (particularly in the North Atlantic region), to write a paper to describe the status of ecosystem models and how they could be extended to the basin scale (see following).

Writing Group Proposal: Extending Ecosystem Models to the Basin Scale

Background

We propose to write a paper, coupled to a short report, for publication in the science literature (Science or Nature) on the topic of developing basin and global scale models of marine ecosystems. This work will involve integration of ideas that are percolating in the community and require the integration of research from several different research programs including GLOBEC, JGOFS and WOCE. Our goal is to tackle the problem from a broad, interdisciplinary perspective and not from a program perspective although this initiative is driven from GLOBEC's Focus 3 working group on modelling and predictive capabilities. The resulting paper will stimulate thinking about an important problem in marine science and also offer a guide to the development of large-scale, trophically integrated ecosystem models. The fundamental biological problem is how to resolve the mass-balance representation of production with the life-history developments that are important at higher trophic levels. Integrating detailed biological models with large-scale physical models begs fundamental scientific questions of model resolution and fidelity to key processes.

This problem is at the forefront of marine science and while there have been some attempts at basin-scale, ecosystem models, there remain many fundamental issues to resolve. Many of the required components for the development of basin-scale ecosystem models now exist but uncertainty remains about how to put the pieces together. A review of this problem would be timely and would be extremely useful to the marine science community.

We propose to organize a writing team to work on this problem. We will hold two meetings in 2003, with a core group leading the organization and writing, and invited scientists who will contribute their ideas towards specific aspects of the problem. We will organize a video or teleconference in advance of the first meeting to plan the project and assign writing and preparation tasks. All attendees at the meetings will be expected to contribute. If necessary, we will supplement the expertise of the core group with scientists at each of the two meetings to ensure that we have broad coverage of the issues and ideas. This approach will also help to keep the group size at each meeting to a number less than seven, to ensure productivity and also to minimize costs.

Summaries and key materials and results will be organised in advance of the first meeting whose primary goal will be to generate a first draft report. This report will then be revised following the meeting so that can be sent out to colleagues for review sometime in the summer. These

comments will be integrated into the report at the fall meeting.

Terms of Reference

- To review and discuss approaches for the development of models that include population structure and dynamics and how to integrate such models into basin-scale circulation models.
- To review the necessary assumptions underlying the model architecture and consider different possible approaches for ensuring that the model is suitably designed for the basin-scale ecosystem problem.
- To review and consider different numerical approaches, different possible trophic architectures and different possible population dynamics models. Integration across trophic levels, and fidelity to life history, will be key issues.
- To review key work in the scientific literature on ecosystem modelling from four very different oceanographic regimes: the North Atlantic, the North Pacific, the Southern Ocean and the equatorial Pacific. Key species will differ between these basins as will the connections to higher and lower trophic levels.

Product

We will produce a scientific review paper for submission to *Science* or *Nature* by the fall of 2003, and a brief report for the sponsors. The completed paper will be submitted for publication following the fall meeting. A longer report could possibly be published in the GLOBEC Report Series or GLOBEC Newsletter.

People

The core group leading this writing team will be:

- (1) Dr. Brad de Young, Physics and Physical Oceanography, Memorial University, St. John's, Newfoundland
- (2) Dr. Mike Heath, Fisheries Research Service, Marine Laboratory, Aberdeen, UK
- (3) Dr. Michio Kishi, Graduate School of Fisheries, Hokkaido University, Hokkaido, Japan
- (4) Dr. Eugene Murphy, British Antarctic Survey, Cambridge, UK
- (5) Dr. Dennis McGillicuddy, Woods Hole Oceanographic Institution, USA

These scientists will be supplemented at the spring and fall meeting by 2-3 scientists from the following group. It is not yet known if all these scientists will be available. We will select from this group to ensure that our expertise is appropriately balanced.

- (1) Dr. P. Monfray, LSCE, Gif-sur-Yvette, France
- (2) Dr. E. Hofmann, Old Dominion University, USA
- (3) Dr. F. Werner, University of North Carolina, USA
- (4) Dr. Fei Chai, University of Maine, USA
- (5) Dr. B. Megrey, National Marine Fishery Service, USA

Our goal will be to stretch the travel budget so that 7 scientists will be able to attend each of the two meetings.

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Budget

1. Teleconference - Initial phone conference to organize the first meeting and to assign tasks. Total time two hours with six people, the core group plus Manuel Barange to aid in the logistics. \$500

2. Spring meeting - We propose to hold the meeting in England to minimize the travel costs (the GLOBEC IPO will contribute towards the travel costs for Murphy and Heath – this is not certain, it depends on state of the IPO budget). Travel costs are requested for five (\$10,000 total) plus on-site costs of \$2000 for a total cost of \$12,000

3. Fall meeting - The second meeting will be much the same as the first. It may be that we will need to invite one additional scientist to cover expertise that is missing from our group. Travel costs are requested for five (\$10,000 total) additional plus on-site costs of \$2000 for a total cost of \$12,000

4. Publication costs - There may be some costs associated with the scientific publication and the final report. We estimate these costs as \$2,000

We estimate the total costs as \$26,500. We already have a commitment from PICES for a contribution of \$3,000, and a contribution from GLOBEC IPO of about \$1,600 (depends on GLOBEC budget status) and so **we are requesting \$21,900.**

4.3.2 The Global Iron Cycle

As described in the International Geosphere-Biosphere Programme (IGBP) report (see p. 7-22), a new set of fast-track initiatives was approved by IGBP at their meeting in Punta Arenas, Chile in January 2003. The idea for a fast-track initiative on the global iron cycle was developed primarily by Robert Duce and Peter Liss at the IGBP meeting. The following proposal was submitted to ICSU by IGBP, with SCOR as a supporting applicant, and was funded. IGBP has given the responsibility for planning coordination and logistical arrangements to IGBP's Global Analysis, Integration, and Modeling (GAIM) office. The SCOR Secretariat will be involved in the continued planning. SCOR committed \$5,000 in funding for travel of developing country scientists as our proposed financial contribution to the activity (see request list on p. 5-3).



INTERNATIONAL COUNCIL FOR SCIENCE (ICSU)

GRANTS PROGRAMME FOR 2004

REQUEST FORM FOR FINANCIAL ASSISTANCE (CATEGORY 2 GRANT APPLICATION)

Deadline for submission 1 March 2003

Lead applicants' may submit up to two applications under Category 2 Grants
(US\$ 50,000 and below).

Lead Applicant (Organization): International Geosphere-Biosphere Programme

Contact name & Designation: Will Steffen, Executive Director

Email address: will@igbp.kva.se

Supporting Applicant(s) (Organization(s)): Scientific Committee on Oceanic Research

Contact name & Designation: Ed Urban, Executive Director

Email address: scor@jhu.edu

Title of activity: Global Iron Connections: Review of Scientific Knowledge of the Global Iron Cycle

In addition to the application form, please provide a detailed proposal (4-6 pages maximum) for the activity including an estimated budget indicating the breakdown of grant requested and nature of activity (meeting/training course etc).

Please identify the category in which the main objective of proposed activity best fits:

a. Science and technology for sustainable development	X
b. Capacity building in science education	
c. Science / Policy Interface	
d. Dissemination of scientific information	
e. Emerging science and technology – creation of new knowledge	
f. Others	

Priority themes: This proposal best fits in the ICSU theme of “Science and technology for sustainable development” because it will assemble existing information to identify gaps in our knowledge of the global iron cycle and make recommendations for research and modelling activities needed to fill these gaps. The activity also fits within the “Dissemination of scientific information” theme because of the planned production of a peer-reviewed article that will reach a wide scientific audience.

Principal beneficiaries of the activity: By bringing together terrestrial, atmospheric, and aquatic scientists who do not normally work together, the proposed activity will benefit the worldwide community of scientists working on the iron cycle (as well as scientists in related disciplines, since iron is a major factor controlling terrestrial and aquatic productivity). The activity would contribute to the implementation of the IGBP/SCOR/WCRP/CACGP Surface Ocean – Lower Atmosphere Study (SOLAS), the International Global Atmospheric Chemistry (IGAC) II project, the new IGBP Land Project, and the IGBP/SCOR Ocean Biogeochemistry and Ecosystems Analysis project. Better knowledge of the iron cycle could allow improvement of global climate models and understanding of the global cycles of carbon and other elements that are affected by the iron cycle, which would help policymakers and benefit society.

Location and proposed schedule of the activity: The location of the activity will be determined by the project group based on the locations of individuals expected to participate in the activity. It is expected that the activity will be completed in 2004, with a review paper submitted by the end of the year. The activity will be one of the first of IGBP’s “fast-track” projects, designed to gather and disseminate policy-relevant scientific information quickly.

The workshop may be held in a developing country to enhance the participation of developing country scientists.

Collaboration with other international organizations: The applicant organizations will invite participation by other key organizations to ensure that this activity and those of related organizations can derive the maximum benefit from the proposed activity. Specifically, the applicant organizations sponsor several research activities whose participants will be invited to participate in the workshop.

Outline of the Proposed Activity

ICSU Priority Themes

This proposal best fits in the ICSU theme of “Science and technology for sustainable development” because it will assemble existing information to identify gaps in our knowledge of the global iron cycle and make recommendations of research and modelling activities needed to fill these gaps. The activity also fits within the “Dissemination of scientific information” theme because of the planned production of a peer-reviewed article in publication that will reach a wide scientific audience.

The proposed activity would be the first of its kind to bring the international scientific community together for an interdisciplinary discussion of the global iron cycle. This approach has been very important in stimulating new research and new understanding for the global cycles of other elements, such as carbon. The activity has great potential to lead to the creation of a landmark article in the scientific literature that could have a significant positive impact on creating new international linkages among individual scientists, research projects, and international science organizations to conduct new scientific research.

The Scientific Issue

The role of iron in the Earth system has risen to prominence in the past decade following the demonstration that addition of this element to certain areas of the ocean can lead to dramatic increases in marine productivity. This effect of iron has substantial implications not only for our understanding of how ocean biogeochemistry operates now and has done in the past, but also how it may change in the future. Alteration in marine production has the potential to affect the amount of carbon dioxide transferring between the atmosphere and the ocean, the flux of carbon into the deep ocean and sediments, and the production of a range of gases important in atmospheric chemistry and climate. The importance of iron in nitrogen fixation in the ocean also has been recognized recently. In addition, there is commercial interest in and scientific concern over the proposal to fertilise the ocean with iron as a way to ameliorate increasing atmospheric carbon dioxide levels that will result from fossil fuel burning. (SCOR and the Intergovernmental Oceanographic Commission are planning a symposium on the ocean in a CO₂-enriched world for early 2004. This symposium will include presentations related to fertilization of the surface ocean with iron.)

Fluvial sources of iron to the ocean have limited impact due to rapid and efficient removal of iron near the river/ocean interface. Hence, the major input of iron to the ocean is believed to be via atmospheric transport of dust and spoil from land. Dust comes predominantly from the arid and semi-arid areas, probably in a highly episodic process in dust storms. The terrestrial and atmospheric controls on dust storm activity are very poorly known. The incidence and nature of dust storms will change as climate changes and with societal response to climate change, and the dust in the atmosphere will itself influence climate. Atmospheric transport of dust storms now can be modelled and tracked with satellites. While improvements in this area are needed, we already can contemplate field experiments guided by such information. (Duce, 1995; Andreae, 1996; Ridgwell, 2002).¹ Atmospheric deposition of dust is, however, much less well understood.

¹ Duce, R.A. 1995. Sources, distributions and fluxes of mineral aerosols and their relation to climate in. Pp. 43-72 in *Aerosol Forcing of Climate*, R.J. Charlson and J. Heintzenberg (eds.). John Wiley, New York.:

We now know that marine (and possibly some terrestrial) ecosystems depend on dust supply for nutrients, particularly iron, but possibly also other elements. However, quantification of the response of marine ecosystems to highly episodic atmospheric deposition events of a key nutrient with a short surface ocean residence time is not currently possible, although major advances in various relevant technologies make it possible to anticipate considerable progress in this area in the near future (Turner and Hunter, 2001).²

Research on the global iron cycle has received a substantial boost in recent years because of its scientific and societal importance. However, the work has generally been conducted in rather distinct scientific disciplines. For example, research is pursued in virtually all of the programme elements of IGBP. This research ranges from studies of the production of dust (source of the iron) at land surfaces (Land-Use and Land-Cover Change [LUCC] and the new Land Project), how it is released into the atmosphere and transformed and transported therein (Integrated Land Ecosystem – Atmosphere Processes Study [ILEAPS] and IGAC), its deposition onto the ocean surface and effect on surface ocean biogeochemistry and nitrogen fixation (SOLAS), the importance of changes in ocean productivity on air-sea exchange of carbon dioxide and other trace gases (SOLAS), and, finally, the long-term sequestration of carbon in the deep ocean and sediments (Ocean Biogeochemistry and Ecosystems Analysis project, the Past Global Changes [PAGES] project, and the Global Carbon Project). There is a clear need to bring these disparate research efforts together into a global framework, and ICSU and the applicant organizations are the appropriate sponsors of such an activity that combines all aspects of the global iron cycle. Thus, we now recognize the key role of dust and iron transport, and scientific tools to study its transport and effects are becoming available. This initiative is particularly timely in providing the opportunity to catalyse and focus scientific research across disciplinary boundaries to consider the role of iron in Earth system science.

Budget

The total budget for the activity will be US\$55,000. This includes the cost for 12 group members and 12 others to participate in the workshop, and for the group members to draft the review article. A subset of the group (about 4 individuals) will hold a two-day meeting later in the year to finalize the article. The proposed budget is shown below.

Income

ICSU	US\$40,000
IGBP	US\$10,000, plus staff support
SCOR	US\$5,000, plus staff support
Total Income	US\$55,000

Ridgwell, A. 2002. Dust in the earth system: the biogeochemical linking of land, air and sea. *Phil trans Roy Soc A* 360:2905-2924; Andreae, M.O. 1996. Raising dust in the greenhouse. *Nature* 380:389.

² Turner, D.R., and K.A. Hunter (eds.). 2001. *The Biogeochemistry of Iron in Seawater*. IUPAC Series on Analytical and Physical Chemistry of Environmental Systems. Volume 7. John Wiley & Sons, Ltd., New York.

Expenses

Travel and per diem for group members to attend workshop and writing meeting	US\$23,000
Travel and per diem for developing country and women scientists to attend workshop	US\$23,000
Travel and per diem for meeting to finalize the article	US\$ 7,000
Meeting room, AV equipment, supplies	US\$ 2,000
Total Expenses	US\$55,000

Work Plan for the Activity

A group of about 12 members will be assembled to plan and conduct a small workshop on the global iron cycle, and to prepare a review paper for the peer-reviewed literature on the global iron cycle. This group will include experts in the following areas: desertification/climate change, dust generation/fluxes, atmospheric reactions, palaeo records (sedimentary and ice core), atmospheric transport and its potential change, deposition fluxes, ocean iron chemistry, biological uptake and utilization (ocean and land), nutrients/primary production/nutrient dynamics, nitrogen fixation and iron, iron-induced production of greenhouse gases (e.g., dimethyl sulphide), remote sensing, modelling, and integration and synthesis. IGBP and SCOR staff will work with the group and its chair to implement the activity, in consultation with WCRP staff.

Group members will be asked to prepare a short summary (2 or 3 pages) on the topic of their expertise, emphasising the major scientific questions and uncertainties in their topic area in relation to the global iron cycle. These summaries will be distributed before the workshop. The workshop will begin with presentations by the group members on all aspects of the global iron cycle.

Much of the research on iron chemistry has been conducted by scientists in developed countries, because of the expense of such research and the need for large ships and aircraft to conduct the research. Yet, many of the key areas for the global iron cycle are located adjacent to developing nations. For example, most of the iron-bearing dust that is carried through the atmosphere and deposited to the ocean originates from the desert areas of China and northern Africa. Most of the areas of the ocean that are most depleted of iron are in equatorial mid-ocean areas and the Southern Ocean. Some developing country scientists, women scientists, and young scientists are already involved in research relevant to the global iron cycle and part of the ICSU funds will be used to involve a significant number of such scientists in the writing team and the workshop. Scientists from the new IGBP Land Project, ILEAPS, SOLAS, IGAC II, and the Ocean Biogeochemistry and Ecosystems Analysis project also will be invited to the workshop. The workshop location will be selected based on consideration of the locations of the participants and ensuring participation by scientists from a range of developing countries.

Following the workshop, group members will spend an additional one or two days to develop the draft of the review article. A smaller meeting will be held in mid-year to finalize the publication, with a goal of submitting a final draft within one to two months after the workshop.

Expected outcomes of the activity

This activity will have three planned outcomes:

1. A major paper on the global iron cycle that emphasizes impacts of the mobilization of iron on critical global-scale biogeochemical and ecosystem processes and their susceptibility to change, reviewing the state of the science and identifying research and modelling needs. The goal would be to have the paper published in a major international scientific journal, such as *Science* or *Nature*, to reach a broad multidisciplinary audience. ICSU support would, of course, be acknowledged explicitly in the paper.
2. Input for the SOLAS, IGAC II, ILEAPS, the new IGBP Land Project, and Ocean Biogeochemistry and Ecosystems Analysis projects, as they continue their research planning and implementation.
3. Background information and input for an activity led by the Global Analysis, Integration, and Modelling (GAIM) project. GAIM could define modelling experiments and targets based on the review and, one to two years later, would analyse the new model results and plan a publication. The proposed activity would prepare for the GAIM project by including one or more presentations on modelling in the workshop, focusing on what modellers need to know to include the correct equations and parameterisations in their models.

Specific reasons for this application

A grant from ICSU would help IGBP, SCOR, and WCRP combine their expertise and would bring visibility to these organizations, as well as to ICSU. It would further establish the reputation of all four organizations as a source of balanced, authoritative scientific information useful for research managers and policymakers. Funding for cross-disciplinary activities such as the one proposed herein is difficult to obtain from traditional sources.

Potential follow-on activities

Imperfect models exist for all parts of the iron cycle. The proposed activity should produce well-defined research questions that modellers could address, which should help to (a) catalyse rapid improvements in the relevant models and their degree of coupling, and (b) advance the underlying science. The type of modelling-relevant questions that could be addressed in the proposed activity include

- Which chemical interactions between aeolian iron and other atmospheric constituents have significance for atmospheric composition?
- How much of the glacial-interglacial variation in atmospheric CO₂ concentration can be explained by changes in aeolian iron input to the ocean?
- Can we develop plausible scenarios for future changes in the iron cycle due to climate change and other human activities? What would be the implications of these scenarios for ocean biogeochemistry, atmospheric composition, and climate?

Modelling alone will not provide definitive answers, but it could sort out more-likely from less-likely speculations, and provide a preliminary quantification that might suggest key additional observations or experiments.