IGBP/SCOR Open Science Meeting on *Ocean Biogeochemistry and Ecosystems Analysis*

With the completion of the Joint Global Ocean Flux Study (JGOFS) in 2003, there will be a gap in major international marine research relating to ocean biogeochemistry and lower trophic levels and their roles in mediating or exacerbating global change. This has been recognized by the International Geosphere-Biosphere Program (IGBP) and the Scientific Committee on Oceanic Research (SCOR), who have jointly supported planning over the past two years for a major program to fill this gap. This planning has culminated in a draft framework for future research on biological and chemical aspects of global change in the ocean (http://www.igbp.kva.se/obe/) and an Open Science Meeting to build the scientific foundations for a new international OCEANS (**Oc**ean Biogeochemistry and **E**cosystem **An**alysi**s**) program, which was held January 7-10, 2003, at the UNESCO Headquarters in Paris, France.

The meeting was very successful, and brought together almost 400 participants from around the world for 1.5 days of presentations, over 200 posters, and 2.5 days of discussions in plenary and in 10 working groups. Three broad research issues were identified by the project Transition Team (co-chaired by Julie Hall, New Zealand, and Patrick Monfray, France) in the meeting background documents:

1. *What controls the time-varying biogeochemical state of the ocean system and how will it respond to global change?* This question focuses on research involving the physical forcing of biogeochemical cycles at time scales longer than the interannual, the transfer and transport of materials between surface waters and the mesopelagic layer beneath, coupling between water column and sediment nutrient cycling, processes at the sediment-water interface and interactions with benthic biota and the dynamics of "hot spots" (*e.g.*, upwelling and deep mixing zones) and their sensitivity to global change.

2. *How will marine food webs respond to, and force, global change?* Key challenges include integrated analysis of marine food webs, from viruses to fish, and the sensitivity of individual components to change; comparison of open-ocean and continental margin food webs and an analysis of their sensitivities to changes in forcing; the relationship between diversity, stability and structure of food webs, and biogeochemical function; and the drivers of non-linear processes that generate "regime shifts" in food webs and foodweb structure and function.

3. *How does carbon accumulation in the ocean, as well as the release of carbon dioxide and methane, respond to global change?* Several gaps exist in understanding the carbon cycle and feedback mechanisms. These include cycling in the ocean interior and in high-flux regions, and the sensitivity of this cycling to changes in external forcing; the transformation and transport of terrigenous carbon in the marine environment; and carbon cycling in the continental margins. Other important research issues relate to attempts to sequester atmospheric carbon dioxide in the ocean and processes related to the deposition and release of methane clathrates in continental margin sediments.

The ten Working Group topics were identified as:

- Trace elements in ecological and biogeochemical processes
- Physical forcing of biogeochemical cycling and marine food webs
- Climatic modulation of organic matter fluxes
- Direct effects of anthropogenic CO_2 on biogeochemical cycles and ecosystems
- Integrating food web dynamics from end to end
- Continental margins
- The mesopelagic layer
- Biogeochemical hotspots, choke points, triggers, switches and non-linear responses
- Feedbacks to the Earth System
- Coupled models of biogeochemical cycles and ecosystems

After the Open Science Meeting, the Transition Team met to begin drafting a Science Plan for this new program. The developing draft is expected to be presented at the 3rd IGBP Congress (Banff, Canada), in June 2003, and put onto the IGBP and SCOR web sites for comments shortly thereafter. Since this new program is likely to involve considerable interaction with GLOBEC and PICES, we would like to give here a brief discussion of the Paris meeting and a sense of the major findings of the various Working Groups.

Each Working Group was asked to identify (a limited number of) key themes, key scientific questions, strategies and approaches, and impediments for their topic. The following represents a summary of the key themes as presented at the meeting (the proceedings are expected to be available later in 2003):

1. *Trace elements in ecological and biogeochemical processes* (Keith Hunter, Chairman; Peter Statham, Rapporteur)

a) Interactions between trace elements and biota, for example:
   - What elements are needed by biota, and how are they assimilated, and recycled?
   - How do trace elements influence species composition and community structure?

b) The role of trace elements in major global biogeochemical cycles, for example:
   - Are trace elements drivers or "passengers" in biogeochemical cycles?
   - How do these processes change with climate?

c) Sources, sinks, and transformations of trace elements, for example:
   - What will be the impact of global change on the relative importance and variability of sources and sinks of trace elements in the ocean?
   - What is the importance of colloids in trace elements cycles?

d) Proxies, for example:
   - Can existing trace elements be used to improve understanding of global biogeochemical cycles, and can new proxies using these elements be developed?

2. *Physical forcing of biogeochemical cycling and food webs* (Michael Follows, Chairman; Evgeny Pakhomov, Rapporteur)

a) What are the mechanisms underlying the observed ecological and biogeochemical responses to climatic changes? For example:
   - What are the underlying interactions between climate, ecology, and biogeochemistry?
   - What are the paleo-proxies for ecological change?

b) How does the physical variability associated with large scale or global climate regimes modulate the chemical composition of the oceans and air-sea gas fluxes? For example:
   - How are biogeochemical cycles controlled by food webs?
   - What is the role of mid- and high-latitude oceans on interannual variability in the air-sea flux of CO_2?

c) Ocean margin – open ocean interface, for example:
   - What is the role of mean flow and mesoscale features in the exchange of nutrients and organisms between shelf and open oceans?
   - What is the role of atmospheric dust and sedimentary sources of nutrients to marginal seas?
   - How significant are ecosystem disturbances by gelatinous zooplankton?

d) What is the role of mesoscale and submesoscale (frontal) features in controlling large-scale ecological and biogeochemical distributions and fluxes? For example:
   - What is the local impact of mesoscale and submesoscale motions on ecology (*e.g.* nutrient supply and community composition)?
   - How do eddy transfers modulate the mean overturning circulation and vertical exchanges in the southern ocean?
   - How might these influences change with climate change?

e) Scale interactions of the climate and biogeochemical systems: what do we need to get right? For example:
   - How do elements of climate variability project onto the variability of elements of marine ecosystems?
   - Which elements of physical and biological variability impact most on ecosystems and biogeochemistry?

3. *Climatic modulation of organic matter fluxes.* (Andreas Oschlies, Chairman; Osvaldo Ulloa, Rapporteur)

a) What are the mechanisms and controls of organic matter fluxes? For example:
   - What controls the partitioning between inorganic and organic pools in space and time?
   - What are the relative contributions from sinking of particulate organic material, passive transport of dissolved and particulate organic material, and active transport by vertically migrating zooplankton?
   - What factors control organic matter burial and release from the sediments?

b) Which climate variations are important, how, and where? For example:
   - What are the regional patterns and modes of variability in organic matter fluxes and their relationship to atmospheric and oceanic variability?
   - What ecosystem properties are most sensitive to climate change (*i.e.* which might be early warning indicators)?

c) How does climate variability affect food-web dynamics and its interaction with organic matter fluxes? For example:
   - What is the relation between functional groups/key species and organic matter fluxes?
   - What is the impact of internal food web variability on organic matter fluxes?

4. *Direct effects of anthropogenic CO_2 on biogeochemical cycles and ecosystems* (Jim Orr, Chairman; Carol Robinson, Rapporteur)

a) Direct effects of anthropogenic CO_2 on ecosystems, for example:
   - Which are the pH sensitive organisms and metabolisms in the ocean?
   - Can organisms adapt to changes in pH and CO_2 and what can be learned from the past about their survival?

b) Biogeochemical consequences, for example:
   - How will changes in community structure and growth rates affect export, re-mineralization, particle fluxes and sediment processes?
   - How will changes in community structure modify the potential for CO_2 uptake?

c) Assessment (past, present, future), for example:
   - What are the distributions of uptake, transport and storage of anthropogenic CO_2 and how will these change?

- What are the possible consequences of purposeful injection of CO_2 in the ocean?

d) Mechanistic understanding, for example:
   - What processes control calcification and carbonate dissolution?
   - Which oceanic areas are most vulnerable (or suitable) to deliberate CO_2 sequestration?

5. *Integrating food web dynamics from end to end* (Mike St. John, Chairman; Angelica Pena, Rapporteur)

a) Quantify the ocean's role, as mediated by the biota, in determining elemental fluxes between global compartments, for example:
   - What are the key species/functions/processes, and how are they controlled in space and time?
   - What is the importance of the continental shelf to global and regional biogeochemical cycles?

b) Determine the nature of changes in ecosystem state and develop techniques to monitor and predict them, for example:
   - How do climate cycles and elemental cycles select for life cycles?
   - What is the role of biodiversity for function and adaptability of the systems?
   - How do large and small perturbations of an ecosystem by human activities affect food webs, their emergent properties, and the time-scale of return to the previous or a new ecosystem state?

c) What is the role of adaptation for global change and what are the effects on ecosystem dynamics? For example:
   - How do communities respond to environmental changes, in terms of genetic "options", phenotypic variability, species replacements?
   - How important are biodiversity and the persistence of rare species for future surprises in an ecosystem?

d) How does the nature of empirical and modeling aggregation influence our ability to understand and predict the dynamics of an ecosystem and elemental fluxes? For example:
   - What is the impact of "arbitrary" definitions of taxonomic level and functional groupings?
   - How much complexity in foodweb models is required?

6. *Continental margins* (Kon-Kee Liu, Chairman; Laura David, Rapporteur)

a) How do continental margins interact with land, ocean interior, and atmosphere? For example:
   - What are the key processes that lead to important functions, and how might these be modified by global changes?

b) What is the distribution and magnitude of sources and sinks of carbon and nutrients in continental margins? For example:
   - Where are the hot spots for sources and sinks?

c) What are the unique characteristics of continental margin ecosystems and how do they respond to global changes? For example:
   - How do continental margins control the food webs?
   - How is the pelagic realm coupled to the benthic realm?

d) How do we model continental margins by including critical forcings and characterizing their relative importance in the past, present, and future?

7. *The mesopelagic layer* (George Jackson, Chairman; Temel Oguz, Rapporteur)

a) Characterization and development of a predictive capability for the fluxes and material transformations in the mesopelagic. For example:
   - What are the fluxes through the mesopelagic in space and time?
   - What are the main processes involved in transformations?
   - How will these respond to global changes?

b) Characterization and development of predictive capability for the mesopelagic ecosystem structure, dynamics, and function. For example:
   - What are the structures and variability of these ecosystems, and how are they controlled?
   - How do ecosystems control the fluxes of materials through the mesopelagic?

c) Characterization and development of predictive capability for the interactions and feedbacks between mesopelagic and boundary systems. For example:
   - How does the mesopleagic respond to material fluxes from above, from below, and from the sides (*e.g.* continental margins)?

8. *Biogeochemical hotspots, choke points, triggers, switches, nonlinear responses* (Christopher Sabine, Chairman; Catharine Goyet, Rapporteur)

a) Understand hot spots and choke points, for example:
   - What regions and biogeochemical processes are most sensitive to climate change, and therefore need special study?
   - Do these locations need to be protected (conserved) or treated differently because of the potential consequences of their responses to global changes?

b) Understand the controls, triggers and switches on biogeochemical cycling and ecosystem structure, for example:
   - What controls oceanic productivity, and species composition of blooms?
   - What allows the decoupling of growth and grazing?
   - How do regime shifts in climate trigger shifts in ecosystem structure?

c) Identify natural and human-induced reversible and irreversible changes on time scales relevant to climate change, for example:

- ➢ What are the non-linear controls on the trophic levels and can changes in trophic structure be reversed?
- ➢ What affects the timing and duration of seasonal cycles of productivity and biogeochemical cycles?

d) Identify thresholds, for example:

- ➢ What biogeochemical and physical shifts might result from methane release?
- ➢ What are the true threshold processes versus non-linear effects, and how do we study them?

9. *Feedbacks to the earth system* (Graham Shimmield, Chairman; Tony Michaels, Rapporteur)

a) The carbon cycle and climate, for example:

- ➢ What are the mechanisms that control the portioning of CO_2 between the ocean and the atmosphere?

b) Other "radiatively-important" gases, for example:

- ➢ What are the sign, magnitude, and controls on the feedbacks of these gasses to the atmosphere and climate system, *e.g.* DMS fluxes, methane clathrates in sediments, methane and N_2O in anoxic waters and sediments, etc.

c) Biology and physical structure, for example:

- ➢ To what extent does heating of the surface ocean changes as a result of the profile and dynamics of phytoplankton, and how does this affect the local climate?

d) Human activities, for example:

- ➢ Do feedbacks involving human activities affect the ocean and how do they impact society's options for sustainability?

10. *Coupled models of biogeochemical cycles and ecosystems* (Shubha Sathyendranath, Chairman; Richard Lampitt, Rapporteur)

a) What triggers sporadic biological events in the ocean that are relevant to biogeochemical cycles?

b) What controls the distribution of species today, and how will it be modified by global changes?

c) What sustains the present ecosystem, and how does it respond to perturbations?

At the conclusion of the meeting, Dr. Patrick Holligan summed up what he felt were the main themes arising from the conference, such as

- ▪ Ecosystem dynamics and biogeochemical cycles
- ▪ Physical and chemical feedbacks on the earth system
- ▪ Boundary conditions, between ocean provinces, ocean margins, and the interior
- ▪ Time series data

He suggested what he felt was the "big question" for the new program: *How do ocean ecosystems respond to, and force, global change in terms of their biophysical and biogeochemical properties and their capacity to sequester biogenic material?*

The challenge is now to the program Transition Team and the sponsors, in consultation with the scientific community, to refine these discussions to develop the new 10 year program on ocean biogeochemistry.

Ian Perry and *Roger Harris*