Discussion Document for the IGBP/SCOR

OCEANS: Ocean Biogeochemistry and Ecosystems Analysis

Open Science Conference, Paris, France, January 7-10, 2003

For full programme and registration details, visit www.igbp.kva.se/obe/

The Transition Team developing the OCEANS project outline below some ideas to seed discussion at the Open Science Conference.

We invite your participation in the conference, which is designed to gather community input to develop a new ten-year international research project, OCEANS. The development of OCEANS, to date, is a result of two years of planning by IGBP and SCOR scientists through the "Ocean Futures" process. A Draft Framework document (available at http://www.igbp.kva.se/obe/background.html) and this discussion document (prepared by the current IGBP/SCOR OCEANS Transition Team, Appendix 1) are background materials to stimulate discussion at the Open Science Conference.

Your feedback on this discussion document and the development of OCEANS is welcomed, particularly if you are unable to attend the meeting. Please email your comments to scor@dmv.com. If you have comments on specific working groups, please refer to the working group number.

Introduction

The primary goal of OCEANS is to understand the sensitivity of the ocean to global change within the context of the broader Earth System, focusing on biogeochemical cycles*, marine food webs and their interactions. The overarching questions to seed discussion are:

- *How does global change, represented by changes in natural climatic modalities and anthropogenic forcings, impact marine biogeochemical cycles and ecosystem dynamics?*
- *How do these impacts mechanistically alter the relationship between elemental cycling and ecosystem dynamics?*
- *What are the feedback mechanisms to the Earth System from these changes?*

OCEANS will seek a comprehensive understanding of the impacts of climate and anthropogenic forcings on food web dynamics (i.e., structure, function, diversity, and stability) and elemental cycling (i.e., biogeochemical pathways, transfers, and cycling), including the impacts of underlying physical dynamics of the ocean. It will also strive for mechanistic and predictive understanding of how these linked systems respond to global change, resulting from natural climate modes (e.g., the El Niño-Southern Oscillation [ENSO] and the North Atlantic Oscillation [NAO]) and anthropogenic perturbations, and then feed back to climate, ocean physics, and marine resources (Fig. 1).

Some areas of the ocean are likely to be particularly sensitive to long-term changes and will be subject to intensive studies. These "hot spots" often occur in critical domains such as regions of upwelling and deep mixing, continental margins, high-latitude areas, the sediment-water interface, the mesopelagic layer and intermediate waters.

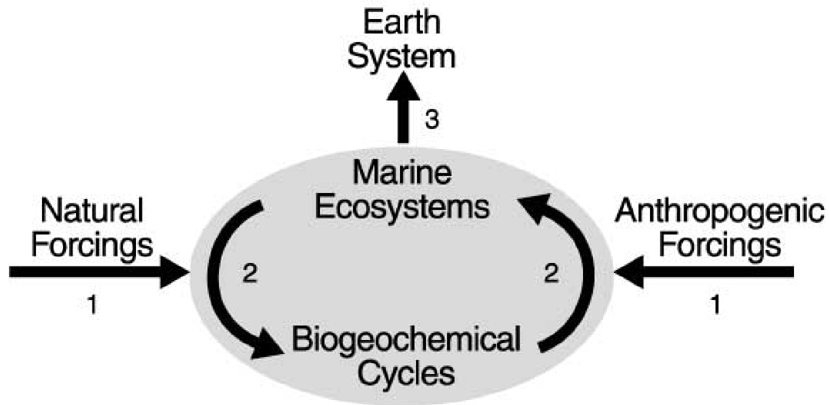

Figure 1: The scientific questions of OCEANS focus on the impacts of natural climatic and anthropogenic forcings on biogeochemical cycles and marine ecosystems (arrows 1), with particular focus on how these forcings alter the relationships between elemental cycles and ecosystems (arrows 2) and how these responses feed back to the Earth System (arrow 3).

Science Background for the Working Group Discussions

The following are the topics for the Working Group discussions at the Open Science Conference. Two successive sets of working groups will be conducted: The first set (Set A) will deal primarily with process issues while the second set (Set B) will tackle domains and cross-cutting issues.

Set A

1. Trace elements in ecological and biogeochemical processes
2. Physical forcing of biogeochemical cycling and marine food webs
3. Climatic modulation of organic matter fluxes
4. Direct effects of anthropogenic CO_2 on biogeochemical cycles and ecosystems
5. Integrating food web dynamics from end to end

Set B

6. Continental margins
7. The mesopelagic layer
8. Biogeochemical hotspots, choke points, triggers, switches and non-linear responses
9. Feedbacks to the Earth System
10. Coupled models of biogeochemical cycles and ecosystems

The text below is an introduction to ideas to be explored during the Working Groups. Discussion should be seeded by, but not limited to, these topics.

1. Trace elements in ecological and biogeochemical processes

It is clear that the oceanic distribution of macro-nutrients such as nitrate, phosphate, and silicate provide critical controls to biological growth and related geochemical processes. The extent to which the distribution of macro-nutrients and biological activity depend on the availability of trace elements and over what spatial and temporal scale this control manifests itself is far less clear. Iron has received a great deal of attention as a controlling element in certain ecosystems but links between other trace elements (e.g., Zn, Co, Cu, Mn) and ecological and geochemical cycles are likely to be at least as complex and important. The source function for, and oceanic lifetime of, newly identified biogenic ligands that specifically complex these trace elements will provide control for their chemical speciation and biological uptake dynamics at the community level. The degree to which multiple trace element processes serve to stabilize and/or change oceanic ecosystems could provide insight into ecosystem response to global change. There is a need to identify and evaluate the complex trace element interactions between ecological and geochemical cycles and their relationship to changing oceanic conditions.

2. Physical forcing of biogeochemical cycling and marine food webs

The variability of large-scale climate phenomena (such as ENSO, NAO, PDO, ACW, AO) affects the ocean by altering the physical forcing on seasonal to inter-decadal time scales, resulting in changes in ocean circulation and water mass properties. Such phenomena include changes in the thermohaline circulation due to heat and radiation fluxes; freshwater input from precipitation, melting ice and river flows; and variation in regional current systems and upwelling intensities due to changes in wind fields. On the meso- to small-scale, such changes have the potential to alter eddy and gyre activities, vertical stratification and frontal structures. Such changes in physical conditions exert, in diverse ways, a “bottom-up” control on biogeochemical cycles and ecosystem dynamics.

Changes in stratification, thermohaline circulation, and horizontal transport directly alter the distribution of carbon and nutrients in the upper ocean. Flux of anthropogenic carbon dioxide into and out of the ocean, as well as its transport and storage in the ocean, is directly affected by such physical variability. Physical variability impacts nutrient fluxes into the euphotic layer and thus sustenance of primary production and food webs. Changes in ocean stability and temperature may also impact functions of the photosynthetic and chemosynthetic food webs. At all trophic levels, changes in habitat, species composition, and individual growth and behavior, may occur due to changes in the physical environment at different space and time scales.

Understanding the responses of biogeochemical cycling and food web dynamics to large-scale climate phenomena is a prerequisite for modelling and predicting global change. In fact, at province scales, climate phenomena exhibit the same range of variability in temperature, mixed-layer depth, sea-ice extent or horizontal transport that is predicted for the oceans impacted by global change.

3. Climatic modulation of organic matter fluxes

The distribution and transformations of the major elements through organic matter (particularly organic carbon, nitrogen and phosphorus; both in dissolved and particulate form) are largely controlled by physical and biological characteristics and processes within ecosystems. For example, the physical dynamics of ocean and atmospheric systems control the inputs of nutrients to the euphotic zone, and the strength and timing of the inputs probably dictates community composition. Shifts in community composition (biodiversity), in turn, change the flux of the major elements (e.g., new vs. regenerated production; vertical vs. horizontal export; remineralisation length scales and composition of sinking particulate organic matter; lifetime spectra and composition of dissolved organic matter), but the mechanisms and processes are not well characterized. A critical prerequisite for predicting the contribution of the ocean to global biogeochemical cycles in a changing world is knowledge of the amount, nature, controlling factors and fate of net community production in the upper ocean (0-1000m), including both photic and mesopelagic layers, and subsequent transport to the deep ocean.

Insights into the controls of organic matter fluxes, and how these controls may create new food webs and biogeochemical conditions in the future, can be evaluated using present-day climate phenomena or shifts. Climatic conditions favoring stratification, for example, may shift the balance in sources of new nitrogen from vertically mixed nitrate (and phosphate) to fixed atmospheric nitrogen. Such shifts will be felt in the magnitude, form and fate of organic matter constituting the biological pump, and will resonate throughout the ecosystem over short and long time scales. A priority activity is an evaluation of the major uncertainties and mechanisms, particularly in terms of controls by physical dynamics and associated community structures (biodiversity), in processing of the major elements through organic matter in the upper ocean. Can the present, recognized shifts in ocean climate, and associated impacts on marine ecosystems, be effectively evaluated in order to predict changes in the organic matter fluxes of the future?

4. Direct effects of anthropogenic CO_2 on biogeochemical cycles and ecosystems

Anthropogenically driven atmospheric changes in CO_2 translate directly to global changes in dissolved CO_2 in the surface ocean. Subsequent changes in inorganic carbon chemistry (pH, pCO_2, alkalinity) have the potential to directly alter carbon cycles and could propagate through marine ecosystems. Small changes in carbonate chemistry have the potential to alter ecosystems and consequently the potential for oceanic CO_2 sequestration through changes in calcification and organic carbon partitioning. It is currently unclear as to exactly how these changes will affect carbon cycles through related chemical and biological processes and particularly through altered partitioning between the surface and deep ocean. Identification of the time scale for alterations in biogenic carbonate formation and preservation rates of marine sedimentary carbonates could be critical for understanding future global carbon cycles. Quantifying the specific feedbacks and cycling between atmospheric changes in CO_2, alkalinity, biogenic carbonate formation, vertical partitioning of inorganic and organic carbon, and sedimentary carbon preservation are required to progress to effectual models of CO_2 in the Earth System.

5. Integrating food web dynamics from end to end

Food webs can be represented in many different ways, for example, as thousands of individual species feeding on, competing with, and preying on, each other; as far fewer functional groups having similar ecological roles in the system; or as particles of different sizes, arranged in a size spectrum in which larger organisms feed on those smaller than themselves. The "functional group" approach most closely links the structure of food webs with their biogeochemical activity involving the flows of energy and materials through the system from viruses to fish. Traditionally, microbial food webs have been considered the component most closely associated with recycling of inorganic elements such as nitrogen, phosphorus, iron, sulphur and silicon. We need to better quantify the role of grazers on recycling rates through excretion, and predation on bacteria. Similar questions should also be asked in the deep ocean, where we have little understanding of the structure and function of chemolithoautotrophic food webs or the relation of these food webs to biogeochemical cycles. For example, changes in thermohaline circulation and deep-ocean temperatures may impact the functions of the chemosynthetic food web and this may alter coupling of biogeochemical cycles between deep water and the upper ocean.

How changes in biodiversity (or species richness and evenness) translate into changes in ecosystem dynamics in the ocean is important at all trophic levels, from viruses to fish. Marine biodiversity itself is only partially known and new species and even new biochemical pathways are constantly being discovered using traditional and molecular biological methods. The relationship between biodiversity and ecosystem functioning is largely unknown. There is observational and theoretical evidence that changes at the top of marine food webs can induce switches in equilibrium states at lower trophic levels; however, there is little understanding of the impact of these shifts on food web function. Such top-down effects can lead to "regime shifts" in which the system sustains a different community of organisms. Such an alternate state can be stable and may need a strong perturbation to shift it back to its previous, or another, state. Historically, these switches appear to occur on decadal to centennial time scales but, under strong forcing, could become more frequent

6. Continental margins

Increased organic and nutrient loading from the land and changes in biogeochemical cycling have led to eutrophication and oxygen-depleted conditions in some margins, altering transformations of carbon, nitrogen, sulphur, phosphorus, iron and other trace elements. Changes in such processes are likely to decouple nutrient cycles, impacting food web structure and benthic communities, and ultimately the sustainable use of coastal zones. Continental margins are characterised by a close coupling between the water column and the sediment, which strongly influences such processes as nutrient upwelling, cross-isopycnal mixing, denitrification and trace element inputs. Processes at the sediment-water interface significantly influence ocean biogeochemical cycles and the coupling of these cycles. Investigating the remineralisation of nutrients and trace elements within this boundary layer is critical to understanding their fate and transport, both in the deep sea and the continental margin. Changes in sediment fluxes also alter the quantity, quality, and distribution of biogenic habitat and communities that have major influences on chemical and energy fluxes within coastal regions. Past human activities have left sediments contaminated with organic compounds and heavy metals, which will continue to impact benthic nutrient and metal cycling long after inputs have ceased. Groundwater and its related chemical inputs have been identified to be important to coastal zone fluxes; however, the magnitude of these fluxes and the time scales in which they modulate in response to human and climate perturbations remain poorly quantified. The impact of this change on coastal benthic ecosystems is unclear and may vary from location to location.

7. The mesopelagic layer

The mesopelagic layer, located between the base of photic layer and 1000m depth, plays an important role in ocean biogeochemistry but it has been under-studied in the past. Remineralisation of organic compounds and inorganic shell (calcareous or siliceous) within the mesopelagic layer plays a critical role in controlling primary production by recycling the elements. Globally, the residence time of carbon in phytoplankton is only a few weeks, whereas the turnover of carbon and nutrients via export, remineralisation and water mixing in the mesopelagic layer occurs on seasonal to decadal time scales. Climatically driven changes in surface water hydrology will affect intermediate water sources and their chemistry and nutrient content on decadal to centennial scales. Therefore, on a global scale, the vertical and horizontal redistribution and return of these nutrients to the euphotic zone control the biological state and processing in the upper ocean on these time scales.

Remineralisation processes are difficult to observe and quantify, especially in the mesopelagic layer, and remain poorly characterised throughout the entire water column. Yet, the depth dependence of nutrient remineralisation and the factors that control it for various nutrients are important features of biogeochemical cycles. The relation of remineralisation depths, to the vertical scales of stratification, circulation, and isopycnal ventilation determines the various time scales of nutrient sequestration and recycling to the surface ocean. The character of the material, organic and inorganic, transported to the mesopelagic layer, which reflects the ecological structure in the upper ocean, also influences the remineralisation rate. Input from the continental slopes to the mesopelagic layer are still poorly quantified processes and the return pathway of nutrients from the mesopelagic layer to the euphotic zone are not well understood.

Microbial activity is a major component of remineralisation processes. Although past research has focused on bulk biological processes, it is important to determine roles of specific species, functional groups and specific gene expressions for remineralisation processes. Recent advances in molecular biology include new techniques to identify species and functional groups in the ecosystem. Such approaches, however, are just beginning to be applied. The mesopelagic layer has a high biodiversity of zooplankton and nekton, organisms that are important for fractioning, repackaging, and decomposing organic materials. Information about the structure, biodiversity, function and stability of the ecosystem in the mesopelagic layer are essential to understand remineralisation processes and the role of the mesopelagic layer in ocean biogeochemistry.

8. Biogeochemical hotspots, choke points, triggers, switches and non-linear responses

Global change manifests itself in different ways in complex systems such as the ocean. These changes are dominated by non-linear processes such as complex time-delayed feedback loops, emergent phenomena and chaotic behaviour. It has become understood that some parts of the Earth System have thresholds, beyond which abrupt non-reversible changes occur, and can result in cascading effects through other parts of the system. For example, if indeed the North Atlantic thermohaline circulation is a highly non-linear system, relatively small changes in climate or salinity could switch the deep water formation into 'off' mode, with significance consequences for Atlantic ecosystems, ocean circulation and the climate system. There are a number of other potentially critical points (hot spots) in the Earth System, where major thresholds, bottlenecks and switch elements exist. Perturbations to the system may trigger abrupt changes, either repeating conditions that have existed in the past, or even causing shifts to new modes of operation. Regime shifts occur when there are positive interactions through which the system changes beyond a threshold and does not return to its former state, even if the forcing function does. Examples include changes in nutrient control in the North Pacific from nitrogen to phosphorus as typified by the dominance of one species of *Trichodesmium* sp., and the rapid changes in fish species in the North Pacific in 1977 and 1989.

The most sensitive regions or hot spots often occur in continental margins, especially those experiencing upwelling or receiving large river runoff, and areas of deep convection/deep water formation. For example, the intense oxygen-minimum zones extending offshore from the coastal upwelling centres provide conditions under which large biogeochemical ecosystem switches and regime shifts can occur in response to modest environmental changes. Transition between oxic and anoxic conditions can occur rapidly, affecting several processes that control nutrient and carbon cycles, such as denitrification, phosphorus burial, and iron remobilisation.

The significance of the high latitude areas in the context of the global change arises from their role as choke points in ocean biogeochemistry. Intense vertical mixing in conjunction with partial nitrate utilisation that characterise these zones make high latitude areas important sites of air-sea CO_2 exchange. Future changes in physics and biology are likely to affect this exchange significantly by altering the functioning of both the solubility and biological pumps.

Switches can also occur in the open ocean, for example, via the indirect effects such as warming, stratification, pH and sea ice retreat or by direct effects such a fishing pressure. These impacts need to be evaluated for various scenarios of global change. We need to answer the questions: what are the critical elements and processes in the ocean? Which of these can actually be transformed by human action? It is imperative that we identify and focus our research and observations in the regions and on the processes most vulnerable to changes or which can moderate or accelerate global changes through negative and positive feedbacks, respectively. Obtaining long time-series data and data from observing systems will be crucial to addressing these questions as will comprehensive mining of datasets acquired in the last century.

9. Feedbacks to the Earth System

This session will explore the role of the ocean in Earth System functioning. Whether the ocean is understood as a regulator or trigger for the state of the Earth System depends on the quantification and understanding of the connections and interfaces linking land, ocean and atmosphere. Discussion will focus on how biogeochemical cycles and ecosystems - and the natural climatic and anthropogenic impacts on them - can force and feedback to global change. Specific topics may include feedback to climate systems from ocean-atmosphere radiation balance; impacts of ocean biogeochemical cycles on climate systems; microbial processes as forcings for global change; feedbacks between large-scale atmospheric dynamics and ocean radiative fields; effects of ocean ventilation on global CO_2 cycling; impacts of organic carbon storage in marine sediments; and feedbacks to society

For example, biogeochemical consequences of the projected increase in atmospheric CO_2 concentration - approaching 750 uatm by 2100 - include a significant reduction in pH in the surface ocean relative to preindustrial levels. Lower pH can decrease calcification rates for corals, coccolithophorids, and other carbonate-secreting organisms, which in turn may act as a small negative feedback on atmospheric pCO_2 due to the buffering action of carbonates. It remains unknown whether such changes will disrupt ocean ecosystems enough to prevent or outweigh such positive feedback.

Feedbacks may result from linkages between biological and physical processes in the ocean. On one hand, phytoplankton growth can affect surface mixed layer heating, and thus impact climatic events via stratification and air-sea heat exchange. On the other hand, large-scale changes induced by anthropogenic activities in ocean stratification, sea-ice retreat, and river discharge can switch the ocean system to a different equilibrium state. Consequent increases in phosphate-depleted ocean regions could disrupt ecosystem functions, food web dynamics, and marine resource availability. Observational, experimental, and modeling approaches are needed to refine our understanding and improve our predictive abilities for these and other feedbacks to the Earth System.

10. Coupled models of biogeochemical cycles and ecosystems

There is a need for a comprehensive model-based approach to the ocean system, as well as identification of key processes coupling ocean transport and mixing, nutrient cycling and food web dynamics. Overall, this challenges the modeling community to design, evaluate and improve a new generation of coupled ocean models, which embed physical, chemical and biological processes. Models sometimes couple physics and primary production, or marine resources and climate, but rarely couple physics, chemistry, biology and marine resources. Such a design is crucial to understanding the ocean as a component of the Earth System with its responses and feedbacks to the other components. This implies tight connections between several modeling research areas.

For example, the need to link climate variability to CO_2 and DMS cycles, as well as to marine resources, implies that we must deal with a common crossroad: phytoplankton dynamics. This will require us to simulate the dynamics of key plankton groups in relation to macro- and micro-nutrient dynamics, such as terrestrial nitrogen sources and iron from terrestrial and atmospheric sources. It will also require various representations of food web dynamics and biodiversity, including both bottom-up and top-down controls, implying lower and upper trophic levels coupling, and fisheries pressure.

Advances in marine biology and biogeochemistry must be integrated into and coupled with similar advances in physical oceanography from programmes such as CLIVAR and GODAE. This will provide a new understanding of ocean processes in the open ocean, and in the coastal region where tides and river discharges play a significant role. To understand the Ocean System as a whole will require us to identify knowledge gaps, new technical approaches, modeling strategies, assimilation schemes and hierarchy of models.

Linkages with other projects and activities

Ocean research in IGBP II will be carried out by two closely integrated, collaborative projects, jointly sponsored by IGBP and SCOR. These are the already established Global Ocean Ecosystem Dynamics project (GLOBEC, also sponsored by IOC) and the new project under development, Ocean Biogeochemistry and Ecosystems Analysis (OCEANS). Ocean research within IGBP will also interface with atmospheric research (primarily through the Surface Ocean-Lower Atmosphere Study [SOLAS]) and with terrestrial research (via the Land-Ocean Interactions in the Coastal Zone [LOICZ] project). Collaboration is being developed with other IGBP projects (eg. GAIM and PAGES), the WCRP, DIVERSITAS and human dimensions communities, including the IHDP and the IGBP-IHDP-WCRP Global Carbon Project. An integral tool for this research is palaeo-oceanography, including the reliable calibration of proxies for macro and micro-nutrients, productivity, plankton composition, temperature, and other physical changes.

OCEANS Open Science Conference Programme

The conference will have three components:

- Plenary presentations from leading scientists in the field to address the overarching questions from different perspectives.
- Posters presented by participants at the meeting.
- Two full days of working group discussions, which will form the core of the meeting, and will be summarized on the final day of the meeting.

The output from the meeting will be used to develop the Science Plan/Implementation Strategy for the new OCEANS project. For full programme and registration details, visit: www.igbp.kva.se/obe/

References

A Draft Framework for Future Research on Biological and Chemical Aspects of Global Change in the Ocean: an IGBP/SCOR Collaboration (available at http://www.igbp.kva.se/obe/background.html)
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Appendix 2: List of acronyms

ACW	Antarctic Circumpolar Wave
AO	Arctic Oscillation
CLIVAR	Climate Variability and Prediction project
DIVERSITAS	An international programme of biodiversity science
ENSO	El Niño-Southern Oscillation
GAIM	Global Analysis, Integration and Modelling project
GLOBEC	Global Ocean Ecosystem Dynamics project
GODAE	Global Ocean Data Assimilation Experiment
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme on Global Environmental Change
IOC	Intergovernmental Oceanographic Commission
JGOFS	Joint Global Ocean Flux Study
LOICZ	Land-Ocean Interactions in the Coastal Zone project
NAO	North Atlantic Oscillation

PAGES	Past Global Changes project
PDO	Pacific Decadal Oscillation
SCOR	Scientific Committee on Oceanic Research
SOLAS	Surface Ocean – Lower Atmosphere Study
WCRP	World Climate Research Programme