A New Vision of Ocean Biogeochemistry

Results from a major international study focusing on Ocean Biogeochemistry and Ecosystem Dynamics

Introduction

The Joint Global Ocean Flux Study (JGOFS) project is an international multi-disciplinary study that was launched under the auspices of SCOR (Scientific Committee on Oceanic Research) and became one of the first core projects of IGBP (International Geosphere-Biosphere Programme). Since 1996, the Research Council of Norway and the University of Bergen have hosted the JGOFS International Project Office and contributed to the administrative activities of JGOFS.
Scientific Goals of the JGOFS Project

To determine and understand on a global scale the processes controlling the time-varying fluxes of carbon and associated biogenic elements in the ocean and to evaluate the related exchanges with the atmosphere, sea floor, and continental boundaries.

To develop a capability to predict on a global scale the response of oceanic biogeochemical processes to anthropogenic perturbation, in particular those related to climate change.

Research Plan of the JGOFS Project

The strategy includes a series of process studies in key ocean regions, a global survey of carbon parameters, long-term time-series sites, data management and modelling. JGOFS continues to develop diagnostic and prognostic models that assimilate the comprehensive database built from field studies.

A conceptual view of the JGOFS science

The Biological Carbon Pump

The oceanic "Biological Carbon Pump" is a collective expression for planktonic, biological processes and feedback pathways that play a role in the carbon transfer from the photic zone to the deep ocean. This complex ecosystem begins with phytoplankton using sunlight and dissolved inorganic nutrients to photosynthetically convert atmospheric $CO_2$ into biogenic matter, which forms the base of the marine food web. The autotrophic and heterotrophic organisms excrete particles and dissolved matter as they grow and die. The particles sink through the water column carrying carbon to the deep ocean. The biological pump is thus one of the pathways that regulate atmospheric $CO_2$ concentrations, the other being the physical, "Solubility Pump". Generally the food web is efficient and most of the produced particles and dissolved organic matter is recycled through the "microbial loop" to $CO_2$ and released back to the atmosphere.
Biological Carbon Pump in the Oceans

1. Deposition
2. Physical Processes
3. Autotrophy
4. Nutrient Exchange
5. Consumption
6. Respiration
7. Export Flux

1000 m

CO₂

O₂

CO₂

CO₂

mixing depth
The Biological Carbon Pump (continued)

The remaining matter, small particles and dissolved matter, reaggregates with minerals as it sinks through the water column and mainly escapes complete remineralization before it reaches the sea floor sediments. The overall efficiency of the biological pump is influenced by (i) food web structure, function and feedbacks, (ii) availability of inorganic macronutrients, such as nitrogen, phosphorus and silicon, (iii) micronutrients, such as iron, (iv) ocean basin hydrological characteristics, such as the Equatorial Pacific, the Arabian Sea, the North Atlantic, and the Southern Ocean, (v) local to regional circulation features, such as internal waves and mesoscale eddies, (vi) seasonal constraints, such as sunlight, clouds and winds, and (vii) regional to global climate patterns, such as ENSO and NAO.
CO₂ Flux


Anthropogenic CO₂ distribution


Annual primary production (mol-C m$^{-2}$ a$^{-1}$) estimated using SeaWiFS data and model. Courtesy of Paul Falkowski and Dorota Kolber, Environmental Biophysics and Molecular Ecology Laboratory, Institute of Marine and Coastal Sciences, Rutgers University, USA.
Observed Chlorophyll $a$ gradients (mg m$^{-3}$) on the East China continental margin, after CZCS data and in situ measurements (courtesy of Kon-Kee Liu, Institute of Oceanography, National Taiwan University, R. o. China - Taiwan)

Chlorophyll $a$ (mg m$^{-3}$) estimated from SeaWiFS data, downstream of the sub-Antarctic islands in the Indian Ocean. Courtesy of Paul Tréguer, IUEM, Université de Bretagne Occidentale, France. © NASA / GSFC and ORBIMAGE
Nutrients Availability and Patchiness (part 2)

CO₂ fugacity (µatm) time-series recorded inside (blue) and outside (red) an iron-enriched patch during SOIREE in the Southern Ocean, as identified by the sulphur hexafluoride tracer used to mark the iron release. The dashed line indicates the atmospheric fCO₂ during the experiment. Courtesy of Andrew Watson, Univ. of East Anglia, UK. Modified after: Watson A.J et al. (2000). Effect of iron supply on Southern Ocean CO₂ uptake and implications for glacial atmospheric CO₂. Nature, 407, 730-733.

Export Production

Export of Particulate Organic Carbon

![Graph showing the relationship between POC flux and primary production for various sites.](image)

Observational relationship between POC flux (mmol-C m^{-2} d^{-1}; derived from $^{234}$Th) and primary production (mmol-C m^{-2} d^{-1}; derived from $^{14}$C incubation) for various JGOFS sites. Lines of constant POC flux/primary production ("ThE" ratio) for 2%, 10% and 50% are shown. Courtesy of K. Buesseler, Dept of Marine Chemistry and Geochemistry, WHOI, USA. Modified after Buesseler K.O. 1998. The decoupling of production and particulate export in the surface ocean. *Global Biogeochemical Cycles*, 12, 297-310.

Export of Dissolved Organic Carbon

![Graph showing the theoretical annual distribution of DOC concentration (µmol-C l^{-1}).](image)

Theoretical annual distribution of DOC concentration (µmol-C l^{-1}), with summer-fall surface DOC accumulation and winter-spring vertical DOC transfer in central area of oceanic gyres (Bernard Avril, JGOFS IPO, Univ. of Bergen, Norway).
Benthic Respiration


A simplified view of the global carbon cycle with emphasis on the oceanic compartment

Average annual fluxes between global carbon pools are given in petagrams of carbon per year (Pg C a$^{-1}$). Figures in black in each box denote the global inventory in Pg C, while figures in red show the average annual increase in the inventory associated with anthropogenic input. The fluxes associated with the shelf and slope waters are still uncertain. Figures based on the 1995 Intergovernmental Panel on Climate Change (IPCC) analysis with additions from JGOFS research. (after *Ambio* Special Report 10, May 2001, fig. 3)
A simplified view of the global carbon cycle with emphasis on the oceanic compartment.
A Few Significant Achievements

- Contributed a major effort to the sea-surface pCO$_2$ inventory and to new, reliable estimates of the global air-sea CO$_2$ exchange
- Completed a global survey of dissolved inorganic carbon (DIC), in cooperation with WOCE, and determined the global distribution, transport and inventory of anthropogenic carbon in the ocean
- Improved the understanding of the marine food web in the production of larger phytoplankton, and revealed the predominance of large diatoms and subsequent sedimentation during episodic or spring blooms, and the dominant role of microzooplankton in the grazing
- Quantified the seasonal changes in primary production and the subsequent fate of biogenic carbon through food webs and export to the deep sea for key oceanic areas
- Clarified the role of dissolved organic carbon (DOC) in the carbon cycle, its bacterial control, and assessed its contribution to export flux at regional scale
- Provided a better understanding of the elemental composition variations of particulate and dissolved organic matter, and of the associated utilization and remineralization rates during organic matter transport to the deep ocean

A Few Significant Achievements (continued)

- Showed that elemental ratios in marine organic matter can vary widely from the Redfield ratios measured in freshly synthesized matter and that its transformation can have important implications for the biological pump efficiency under different hydrological and climatic conditions
- Uncovered strong links between large-scale climate patterns, such as the El Niño - Southern Oscillation (ENSO) or the North Atlantic Oscillation (NAO), and interannual variability in the air-sea CO$_2$ exchange
- Detected the decadal variability in plankton species assemblages from long-term observations at time-series sites
- Demonstrated the role played by nitrogen (N$_2$)-fixing phytoplankters in the nitrogen cycle of the subtropical ocean and estimated the contribution of N$_2$ fixation to shifts in nutrient limitation in oligotrophic ecosystems
- Developed and tested a hierarchy of new ecosystem models with the support of high-resolution JGOFS datasets and global synoptic observations from ocean color satellites
A Few Challenges for a Future Ocean Biogeochemistry Program

- Expand the CO₂ observation program and air-sea CO₂ exchange studies in other oceanic basins and over continental margins
- Focus greater attention on the rate measurements of food web processes and carbon cycling in the mixed layer
- Reduce the uncertainties of biological rate measurements, carbon export, storage capacity and transformation pathways in the ocean interior
- Assess the impact of climate change scenarios on the biological pump
- Implement stronger practices in data management for synthesis and modeling programs
- Strengthen the research design and strategies using the experience gained from JGOFS

Project Sponsors

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Contacts

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