U.S. JGOFS: A Component of the U.S. Global Change Research Program

U.S. JGOFS NEWS

Volume 11, Number 4 April 2002

Collecting The Garbage Of The Sea: The Role Of Aggregation In Ocean Carbon Transport

by George A. Jackson

Sinking particles are the dominant agents for the vertical transport of carbon from the ocean surface to the deep waters. Much of the organic matter removed from the productive mixed layer is carried in aggregates, clumps of particles of differing sizes and often of differing origins. But the processes by which aggregates are formed and their consequences for marine ecosystems are hard to tease out, making it difficult to predict the effects of changes in surface-ocean productivity on the flux of carbon to the depths. Most models of carbon flux in the ocean use only crude parameterizations of particle removal.

Myriad physical, chemical and biological processes contribute to the formation of particles. These include atmospheric deposition, formation of colloids, precipitation and settling. Algae and bacteria pull in dissolved material to form new cells. Growth, molting, egg release and fecal production produce particles. The process of filter-feeding collects smaller particles into fewer, larger ones. Coagulation, a physical process, collects particles of various sizes into larger aggregates. This aggregation of particles functions, in a sense, as the garbage collection system of the sea (Figure 1).

Coagulation is the process whereby larger particles form from the repetitive collision and joining of smaller particles. The rate at which particles collide is calculated by summing the rates for the individual physical mechanisms that bring them together. These include shear, in which differential water motions bring particles together; differential sedimentation, in which faster settling particles overtake slower ones, and Brownian motion, in which diffusive motions bring particles together. To these physical mechanisms we can add biological ones such as particle feeding. Chemical interactions are also important because they determine the probability that two particles will stick upon contact and how strong the contact is.

Coagulation theory considers the formation of large particles from small ones, predicting the development of particle size distributions and losses to settling. It has been developed and tested most extensively by atmospheric scientists to discuss the formation and fate of atmospheric particles (aerosols) and by the environmental engineers to design water treatment systems. More recently it has been used to explain observations in the ocean.

Particle size spectra provide a useful way to characterize the relationship between abundance and size. As a light spectrum is used to characterize the relationship between intensity and wavelength or frequency, a particle size spectrum characterizes the concentration of particles as a function of size. Although small particles are far more abundant than large, the greater mass of larger particles can counterbalance the larger number of small ones, with the result that most particle mass is in larger particles. One of the goals of aggregation theory is to understand this distribution.

Central to understanding particle dynamics and flux are three related but distinct properties: mass, length and settling speed. The larger aggregates are, the more porous they tend to be. As a result, they do not have the simple mass-to-length relation-

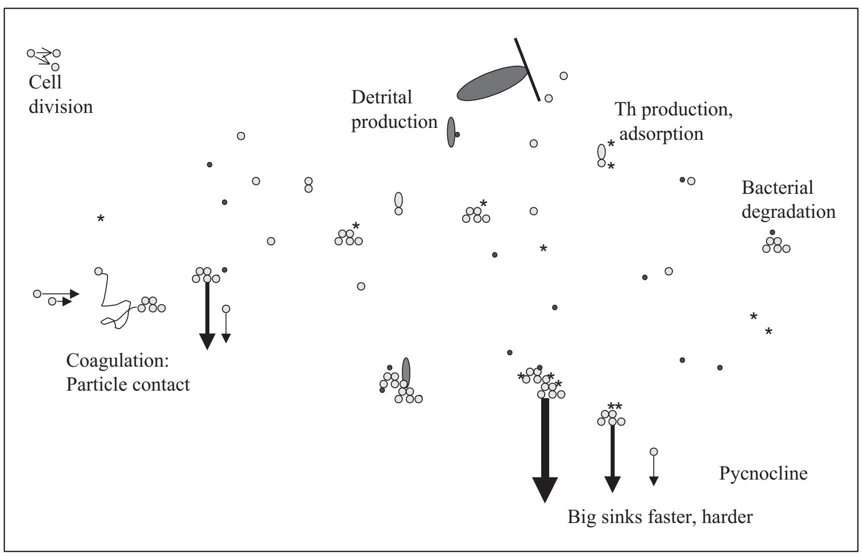


Figure 1: The set of processes that can affect particle concentrations, size distributions and fluxes. Asterisks represent thorium-234, which adsorbs onto particles and is removed from the surface ocean as particles sink.

ship that we associate with solid particles of constant density. Rather than being proportional to length cubed, the mass of aggregates formed from a single-source particle is proportional to the length raised to the power of the fractal dimension, which typically ranges from 1.8 to 2.3. The typical solid particle is equivalent to an aggregate with a fractal dimension of 3. Matters become more complicated when one tries to describe the mass-to-length relationship of aggregates composed of particles from multiple sources.

Fractal scaling and the variable porosity of particles complicates the task of measuring length. Different instruments use different ways of measuring physical properties that are affected differently by the fractal nature of aggregates. Electro-resistive methods, such as the Coulter Counter, report a length corresponding to that of a non-porous particle of the same mass as a fractal aggregate, whereas imaging techniques report a larger size. Calibrating instruments that measure aggregate size and comparing the results from several instruments is not simple.

The rate at which particle collisions occur is essentially a second-order reaction, as it is proportional to the concentrations of each particle involved in the collision. In contrast, the rate at which algae produce new particles (cells) by division is a linear process, proportional to the concentration of the algal cells. For a simple system in which algal cells are produced by cell division and lost by aggregation, this can lead to interesting dynamics.

Because second-order reactions are slow when particle concentrations are low and fast when particle concentrations are high, algal losses associated with collisions and subsequent aggregate formation are substantially less than algal growth when phytoplankton concentrations are low. They can become rapid enough at high particle concentrations to set limits to growth that even rapidly dividing cells cannot overcome.

An important result of particle aggregation is the formation of larger particles that sink faster than their

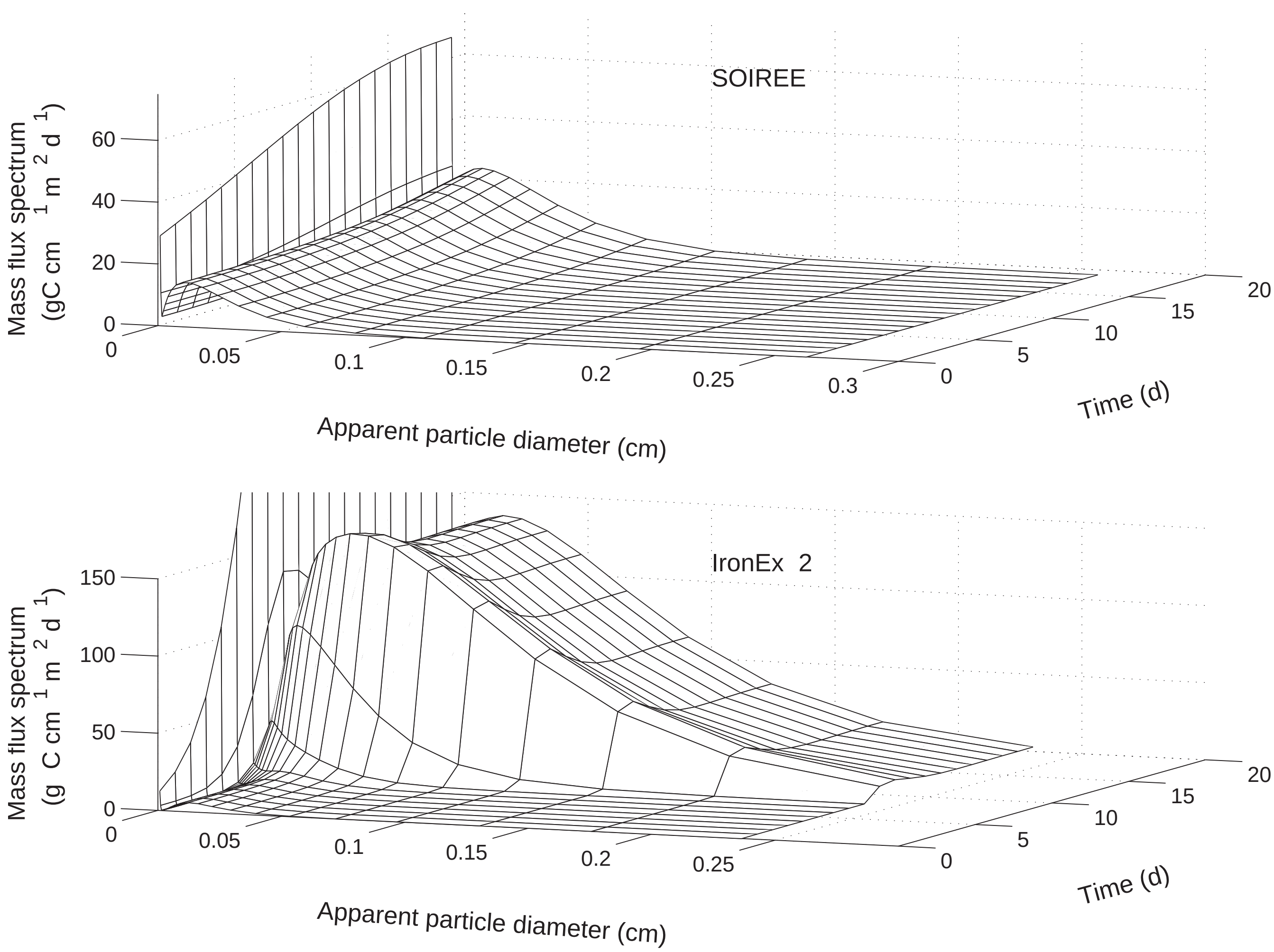


Figure 2: Particle export during SOIREE and IRONEX II as a function of time and particle size, calculated using a simple coagulation model. IRONEX II results show a rapid increase in the particle export, especially of large particles, at about day 10 as a result of rapid coagulation. SOIREE results show little activity because of the low algal abundances.

smaller component particles. For example, a 20 micron alga that settles at 2 meters per day by itself can fall at 300 meters per day when packed into a 1 millimeter aggregate. The average rate at which matter leaves the surface depends on the size distribution of the particles, which in turn depends on a balance of production of larger particles and their loss via settling.

For a system in which losses of single algal cells from collisions with other single cells balance the rate at which new particles are produced, a simple model can be used to describe the maximum concentration that algal cells can achieve, despite continuing to divide. This maximum, known as the critical concentration, depends on the properties of a single algal cell, including diameter, specific growth rate and stickiness, and the turbulent shear of the environment. The critical concentration provides a simple value to estimate algal concentrations at which rapid coagulation occurs.

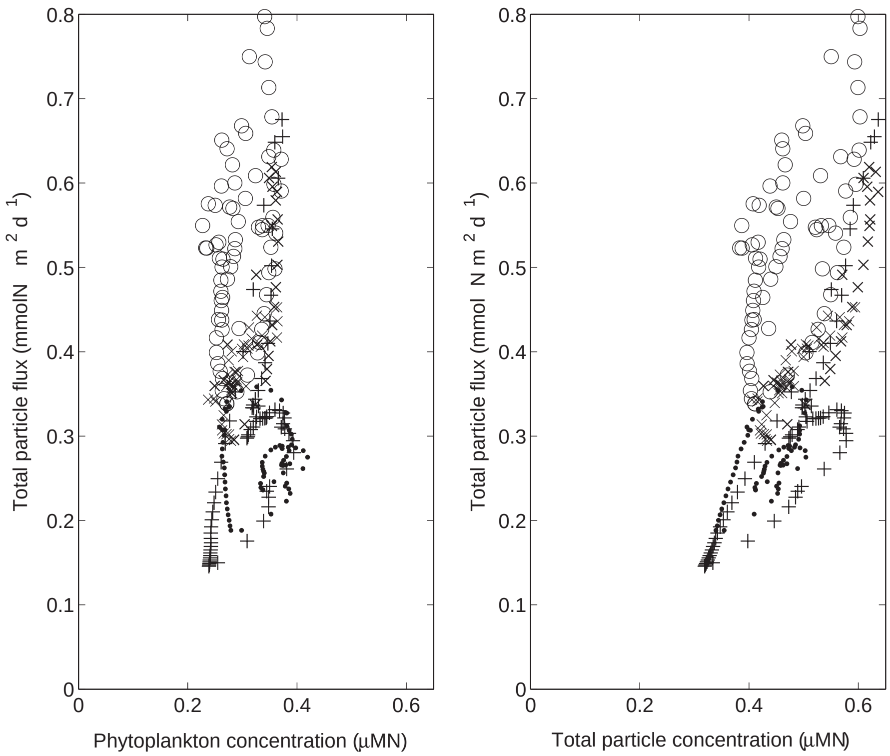


Figure 3: Simulated particle fluxes from the surface mixed layer over the course of a year. Different symbols represent periodic results for different particle simulations. Although global modelers would like simple relationships between phytoplankton concentrations and particle flux, our simulation results do not show it.

This simple model, in which particles are produced by algal division and lost by aggregation and sedimentation, has been remarkably successful at predicting maximum algal concentrations in blooms such as those observed by Ulf Riebesell of the Alfred Wegener Institute in the North Sea and by Thomas Kiørboe and collaborators at the Danish Institute of Marine Fisheries in a Danish fjord. It also helps to interpret particle export observed during iron fertilization experiments in high nutrient, low chlorophyll (HNLC) regions.

A number of such experiments conducted over the last decade have involved the fertilization of areas of the open ocean with iron solutions. IRONEX II was carried out in the tropical Pacific near the Galapagos Islands in 1995, and the Southern Ocean Iron Release Experiment (SOIREE), in antarctic waters south of Australia in 1999.

Investigators at both sites observed a substantial increase in surface-water productivity, especially of diatoms, following the addition of iron. At the SOIREE site, sediment traps showed no evidence of increased sedimentation despite the increase in productivity. At the IRONEX II site, a decrease in thorium-234 (^{234}Th) concentrations in surface waters a couple of weeks after the iron addition indicated rapid sedimentation during that period.

Simulations of the growth and coagulation of the dominant diatoms helps explain this difference. Model simulations of the IRONEX II situation by Philip Boyd of the National Institute of Water and Atmospheric Research in New Zealand and Anya Waite of the University of Western Australia show a rapid increase in diatom concentrations followed by rapid coagulation and population growth limitation around day 9. Their simulations of the SOIREE situation do not show such a transition (Figure 2).

The SOIREE simulations also describe the size dependence of the particle export during the experiment. The important difference between the two fertilization experiments from the coagulation perspective is in the rates of algal accumulation. Diatoms at the IRONEX II site had relatively high specific growth rates of about 0.6 per day. Diatoms at the SOIREE site had a lower rate of about 0.25 per day because of the cold water temperatures.

In addition, mixing rates of 0.1 per day at the SOIREE site decreased the accumulation of phytoplankton, yielding a net population accumulation rate of 0.15 per day. The lower population accumulation rates at SOIREE kept phytoplankton concentrations from becoming high enough for coagulation to be rapid. Although this analysis is based on simplistic descriptions of these systems, it does show the insight into particle export that coagulation theory can provide.

Following the lead of Bruce Honeyman of the Colorado School of Mines and Peter Santschi of Texas

Cont. on page 10

Running The Gauntlet In The Twilight Zone: The Effect Of Midwater Processes On The Biological Pump

by Roger François, Susumu Honjo, Richard Krishfield and Steven Manganini

The sinking of organic matter produced through photosynthesis in the ocean, often referred to as "the biological pump," is one of the most important natural processes that regulate carbon dioxide (CO_2) levels in the atmosphere. CO_2 is initially taken up by phytoplankton in surface waters during photosynthesis. The carbon thus fixed can be sequestered from the atmosphere if it is transferred from surface to deeper waters.

Two distinct features of the biological pump must be considered separately if we are to understand what affects its efficacy. First, only a fraction of the organic matter produced by phytoplankton, generally between 5% and 50%, is exported from the mixed layer. The higher this fraction, the higher the sequestration of CO_2 for a given rate of primary production. Second, as organic matter sinks into the deep sea, its carbon content is rapidly remineralized back to CO_2. The deeper the remineralization, the longer the regenerated CO_2 will be stored away from the atmosphere.

Of these two features, the factors affecting the fraction of primary production that is exported below the surface (often called the export ratio or f-ratio) have been extensively studied. The export ratio is controlled primarily by ecological and environmental factors. Cold, productive and highly seasonal ecosystems at higher latitudes have higher export ratios than warmer, less seasonal ecosystems at lower latitudes. In the lower latitudes, much of the organic carbon produced by photosynthesis sustains a complex food web and microbial loop in the mixed layer that recycles carbon rather than exporting it.

In the higher latitudes, on the other hand, a larger fraction of the organic matter produced by phytoplankton sinks out of the mixed layer, in part because of the effect of lower temperatures on the microbial loop and in part because of the seasonal character of primary productivity, especially the vernal blooms induced by thermal stratification and increased penetration of sunlight into the water column. In the early stages of a bloom, much of the organic matter escapes the mixed-layer grazers, which do not multiply fast enough to take full advantage of the bonanza.

Much less is known about the processes occurring at intermediate depths in the mesopelagic or "twilight" zone of the ocean. These processes control the efficiency of the transfer of organic matter from the surface to the deep sea. We know

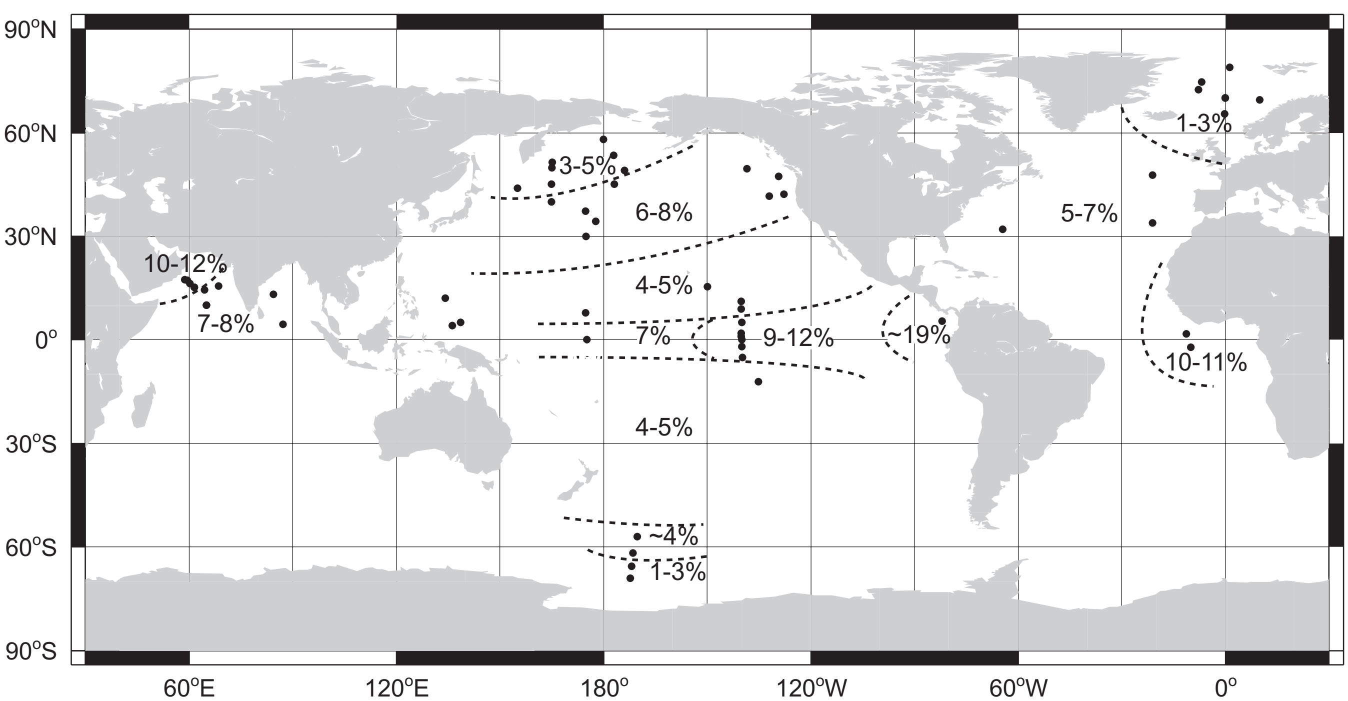


Figure 1: Fluxes of organic carbon reaching 2000 meters, expressed as percentages of organic carbon exported from surface waters. Also shown are the sites where organic carbon fluxes were measured with deep-sea moored sediment traps. Note that carbon fluxes at the three southernmost stations were obtained with pore-water modeling.

that more than 80% of the sinking organic matter is remineralized within the upper 1500-2000 meters of the water column, but we know little about regional variations in mesopelagic remineralization and the processes that control it. Yet this is a paramount consideration for assessing the efficiency of the biological pump. If export flux from the surface were to stay constant and mesopelagic remineralization were to increase from 80% to 95%, the flux of organic carbon reaching the deep sea would decrease by a factor of three, which would profoundly affect the level of CO_2 in the atmosphere.

With funding from the U.S. JGOFS Synthesis and Modeling Project, we have made an initial attempt to assess the extent and geographic variability of mesopelagic remineralization. In this project, we have compared the flux of organic carbon measured with moored sediment traps deployed at depths greater than 2000 meters with export production calculated from remote sensing measurements of ocean color and export ratios derived from a pelagic food-web model.

The comparison was conducted at 64 open-ocean sites encompassing oceanic regions as diverse as tropical gyres, equatorial upwelling regions, the nordic seas, the Arabian Sea and the Antarctic Polar Frontal Zone (APFZ). For the APFZ, productivity levels derived from satellite-based algorithms are too low; for this region we used export production measured during the U.S. JGOFS Antarctic Environment and Southern Ocean Process Study instead.

The results show clear contrasts between the low-latitude productive regions, such as equatorial upwelling zones and the Arabian Sea, and the high-latitude productive regions, such as the northwest Pacific, the Southern Ocean and the nordic seas (Figure 1). In the former, up to 18% of the organic matter exported from the surface reaches a depth of 2000 meters; in the latter, generally 3% or less of the exported organic matter survives transfer through the mesopelagic zone. In other regions, transfer efficiency clusters around 4 to 8%.

Linear regressions between transfer efficiency and measured fluxes of biogenic carbonate, biogenic silica and lithogenic particles derived from erosion of the continental crust show that the fraction of export flux that survives mesopelagic remineralization is directly and strongly proportional to the accompanying flux of carbonate. It is inversely but weakly proportional to the flux of silica and uncorrelated to the flux of lithogenic debris. Lithogenic fluxes to the deep sea are very small, compared to those of the biogenic minerals. Lithogenic material may, however, play a more important role in the continental margins.

The positive correlation of carbonate with the amount of organic material exported to the deep ocean suggests that the ballasting effect of this dense mineral may increase the settling rates of sinking particles. But the negative correlation with the flux of biogenic silica, which is also denser than organic matter, indicates that factors other than the density of the accompanying minerals affect the efficiency of the transfer of organic carbon to the deep sea.

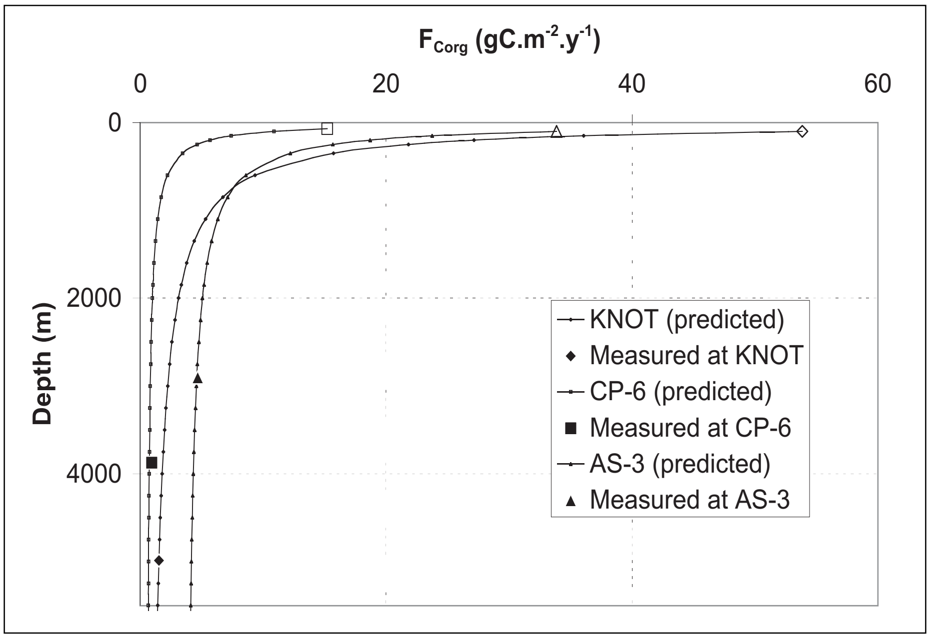


Figure 2: Measured and predicted organic carbon fluxes at a high-productivity silica-dominated site in the northwest Pacific (KNOT), high-productivity carbonate-dominated site in the Arabian Sea (AS-3) and an oligotrophic site in the Pacific central gyre (CP-6).

We found that transfer efficiency was also inversely related to sea surface temperature, export ratio and the degree of seasonality in primary production at each site. Based on these results, we have developed an algorithm that predicts more than 80% of the observed geographic variability in transfer efficiency from the flux of carbonate and any one of these three variables.

This finding leads us to formulate the working hypothesis that mesopelagic remineralization in low-latitude productive regions is comparatively low (80% to 90% of the exported flux) because these regions are characterized by higher carbonate fluxes, lower export ratios and lower seasonality. As a result, the organic matter exported is relatively refractory, having already been processed extensively by the food web in the mixed layer. It is carried by particles that consist primarily of fast-sinking fecal pellets heavily weighed by carbonate minerals.

In contrast, the more extensive mesopelagic remineralization in high-latitude productive regions (97% or more of the exported flux) could be linked to the more labile nature of the organic matter exported, which is mainly in the form of senescent phytoplankton aggregates, largely diatoms, which use silica to build their shells. Their less hydrodynamic shapes and lower carbonate content reduce their sinking rates.

In regions of lower productivity and seasonality, the organic carbon exported would also be relatively refractory, but the low carbonate fluxes in these regions would result in intermediate levels of transfer to the deep sea (92% to 96% mesopelagic remineralization). This working hypothesis could be directly tested by contrasting the mean sinking rates and the morphology of particles in the mesopelagic zone of different oceanic regions and by developing means of assessing the biodegradability of sinking organic matter in relation to export ratio, seasonality and mineral composition of settling particles.

Our findings suggest that export ratio in surface waters and efficiency of transfer through the mesopelagic zone tend to have antagonistic effects on the overall efficacy of the biological pump. Export ratios are higher in productive high-latitude regions dominated by diatoms, but the efficiency of transfer through the mesopelagic zone of these regions is very low. Their mesopelagic zones should provide a niche for a very dynamic biological community whose activity results in little transfer of organic carbon to the deep ocean.

The relatively shallow remineralization that occurs in the high-latitude regions lessens the effect of the biological pump in these regions on atmospheric CO_2 levels. Instead, the oceanic regions most efficient at transferring carbon below 2000 meters are the productive low-latitude regions such as the Arabian Sea and the equatorial upwelling zones.

This is best illustrated by comparing the organic carbon fluxes measured by sediment traps with our modeling prediction at three contrasting stations (Figure 2). One of these sites is the Kyodo North Pacific Ocean Time-series (KNOT) station in the productive, silica-dominated northwest Pacific. Another is AS-3, a site in the productive, carbonate-dominated Arabian Sea. The third is CP-6, a site in the oligotrophic central gyre of the North Pacific.

The transfer efficiency at 2000 meters is about three times higher at the low-latitude site in the Arabian Sea than at the high-latitude KNOT station (transfer efficiency = 0.12 vs 0.04) and intermediate in the oligotrophic ocean (0.07). Export production is nearly twice as high in the northwest Pacific at 78 grams of carbon per square meter per year ($gC/m^2/yr$) than in the Arabian Sea upwelling region at 44 $gC/m^2/yr$. Nonetheless the flux of organic carbon below 2000 meters is lower in the northwest Pacific (Figure 2).

At 5000 meters, a typical depth for deep-sea sediments, the flux of carbon at the KNOT station approaches that of the oligotrophic central gyre site (CP-6). Within the mesopelagic zone, however, 75 $gC/m^2/yr$ is remineralized at KNOT as opposed to 39 $gC/m^2/yr$ at AS-3 and 14 $gC/m^2/yr$ at CP-6.

These results also raise questions about the role of iron fertilization, which has been purported to improve the efficacy of the biological pump at removing CO_2 from the atmosphere, especially during glacial periods. Because iron fertilization appears to promote the growth of diatoms primarily, our findings suggest that the result could be an increased flux of carbon into the mesopelagic zone and its ecosystems with little long-term storage in the deep ocean or sediments.❖

(Editor's Note: The authors are all at the Woods Hole Oceanographic Institution.)

U.S. JGOFS Special Issue Of *Oceanography* Available

U.S. JGOFS accomplishments over the decade and a half since the program began are highlighted in a special issue of *Oceanography* (14:4), released last December. Ten full-length articles and a similar number of shorter pieces cover the results emerging from the regional process studies, the global-scale survey of CO_2 and the ongoing time-series programs near Bermuda and Hawaii as well as the synthesis and modeling project that is currently underway.

The issue also includes a brief history of data management in U.S. JGOFS and the compilation of a consistent, high-quality database that represents an important legacy to future programs in ocean biogeochemistry. Advances in methods described in this issue have contributed to changing perspectives on ocean properties and processes; new protocols and standards have allowed more accurate comparisons among studies.

Newsletter subscribers who have not received their copies of the U.S. JGOFS special issue of *Oceanography* or who would like more copies for teaching purposes should get in touch with the U.S. JGOFS Planning Office. Requests should be addressed to:

Mary Zawoysky
U.S. JGOFS Planning Office, MS #43
Woods Hole Oceanographic Institution
Woods Hole, MA 02543 USA
Phone: 508-289-2834
Fax: 508-457-2161
email: **mzawoysky@whoi.edu**

Climate Patterns, Phytoplankton Community Composition And Ocean Carbon Fluxes

by Michael W. Lomas

The subtropical ocean gyres have long been considered to be the aquatic equivalent of deserts, with minimal variability in both primary production and phytoplankton community structure. After more than a decade of observations in the Bermuda Atlantic Time-series Study (BATS), however, it is clear that changes occur in both these parameters in the Sargasso Sea, and that these changes have an effect on both the cycling of carbon in the surface ocean and the functioning of the ecosystem. Less clear is the linkage between large-scale climate patterns, such as the North Atlantic Oscillation (NAO), and this variability in biological parameters. Understanding the mechanisms of interactions among climate, physical forces and biological processses is key to helping us integrate biological factors into predictive ocean carbon models.

The BATS site is located in the northwest corner of the Sargasso Sea 85 kilometers southeast of the islands of Bermuda. This region is subject to a pattern of seasonal mixing with mixed layer depths approaching depths between 200 and 250 meters in the winter and spring and shoaling to 20 to 30 meters during the summer. This pattern in physical forcing leads to seasonal maxima in surface ocean chlorophyll biomass and primary production during the winter/spring period.

Just as chlorophyll serves as a measure of total phytoplankton biomass, the characteristics of accessory pigments allow us to examine changes in various taxonomic groups within the total phytoplankton assemblage. Within the seasonal pattern of bulk chlorophyll biomass we can use pigment analysis methods to observe seasonality in several key phytoplankton groups.

The single largest phytoplankton group during the winter/spring period is the eukaryotic class Haptophyceae, which contains species such as *Emiliania huxleyi*. During the stratified summer period, the picoprokaryotic phytoplankton *Synechococcus* and *Prochlorococcus* dominate the phytoplankton chlorophyll biomass. Although this general pattern of species succession is repeated each year, longer-term trends in this successional pattern appear to be correlated with larger-scale climatic forcing.

To separate these seasonal changes from longer-term changes, we generated anomalies normalized to chlorophyll *a* anomalies for specific algal classes that represent deviations from the long-term mean. The anomalies for the three most dominant phytoplankton taxonomic groups, haptophytes, cyanobacteria and prochlorophytes, show no significant trends for the latter two. The haptophyte organisms, on the other hand, have significantly increased their importance relative to other phytoplankton species throughout period of observations at the BATS site (Figure 1).

Most of the increase that made the overall relationship significant occurred between the beginning of the

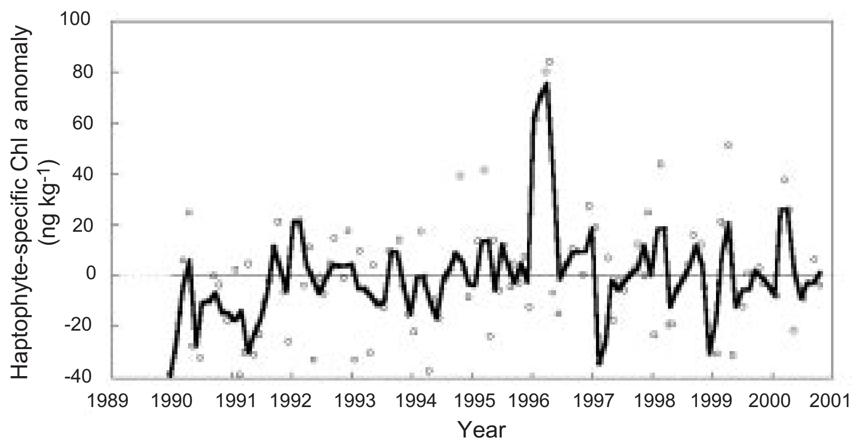


Figure 1: Time-series record of the anomaly in haptophyte-specific chlorophyll biomass at the BATS site from 1990 to 2000 with seasonal variation removed. The solid line represents the three-month running mean through the monthly to bimonthly data.

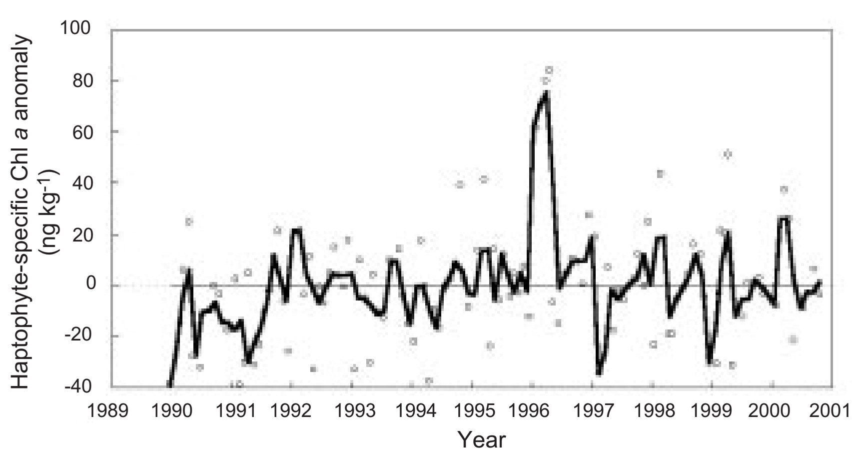


Figure 2: Relationship between the mean January-to-April haptophyte-specific chlorophyll biomass and the mean January-to-April North Atlantic Oscillation (NAO) index. The solid line represents the best fit linear regression to the solid data points.

BATS record in 1989 and the end of 1995 and immediately preceded an anomalously large bloom of haptophytes in the winter and spring of 1996. Since then contributions of haptophytes have been more variable but generally higher than the levels found in the early 1990s.

The anomalously large bloom of haptophytes during the winter and spring of 1996 coincided with a strong shift to a negative phase of the winter NAO index during the same period. During a negative phase in the NAO, storms tend to track along a more southerly route, which results in the more frequent passage of frontal systems during the winter/spring period in the Sargasso Sea and enhanced convective mixing.

Although the winter NAO index has generally been positive over recent decades, it does vary in magnitude. Over the course of the BATS data record, the relative abundance of haptophyte phytoplankton was negatively correlated with the winter NAO index (Figure 2). This negative relationship might suggest that the more vigorous the physical forcing during the winter/spring period, the more important haptophyte species are to overall phytoplankton biomass.

One of the dominant concepts of biological oceanography is that of the biological pump, used to describe the links between primary production in surface waters and the export of particles through the water column to the depths. Data from the U.S. JGOFS time-series studies has contributed to a broadening of the traditional view that the biological pump transports carbon from the ocean surface to the depths primarily through sinking particles. It is now recognized that the production, accumulation and subsequent removal of dissolved organic carbon (DOC) through deep mixing can be just as important to the functioning of the biological pump as the export of particulate organic matter.

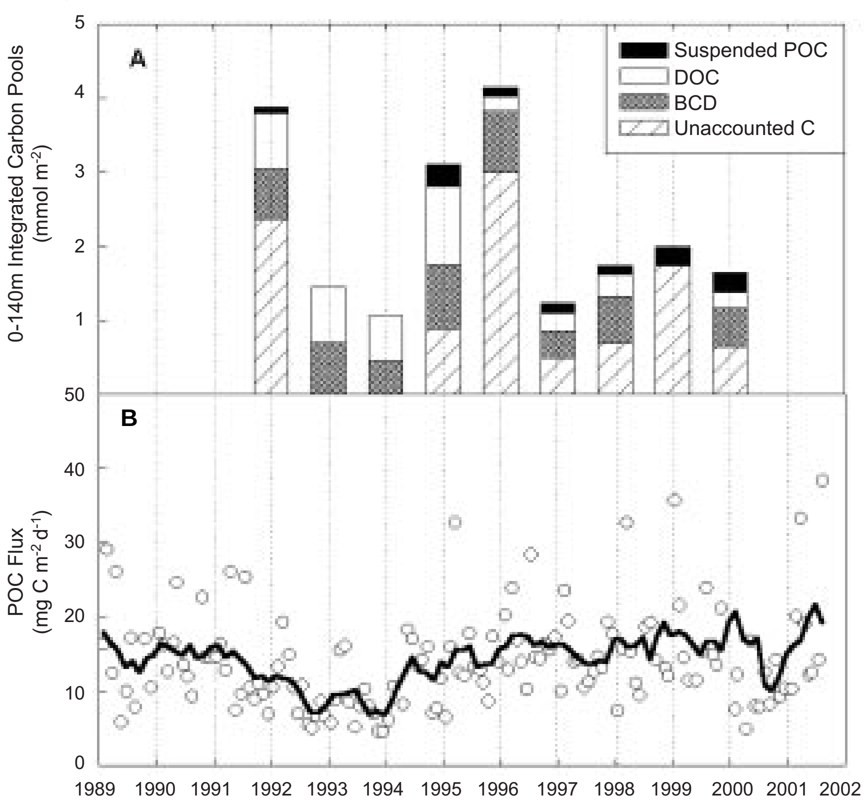


Figure 3: A) Partitioning of primary production (total height of each bar) between the suspended particulate organic carbon pool (POC), dissolved organic carbon (DOC) and bacterial carbon demand (BCD). The remainder is designated as unaccounted carbon, which may represent carbon that is respired or laterally advected, for example. B) Flux of POC at 300 meters from the surface ocean measured using the BATS particle interceptor traps. The solid line represents the six-month running mean through the monthly to bimonthly data.

Although the mechanisms that control the partitioning of carbon between dissolved and particulate pools in the ocean are not well understood, the decade of data from the BATS site suggests a possible correlation between the relative importance of haptophytes during the spring bloom and the partitioning of carbon. Beginning with the winter/spring period of 1996, there was a sharp reduction in the amount of DOC accumulation that has carried through to the present (Figure 3A). In prior years, on the other hand, DOC accumulation was very significant.

During the period of high DOC accumulation, mean particle flux rates from the surface ocean at BATS were lower, particularly between 1992 and 1994 (Figure 3B). Since then mean particle flux rates have increased roughly two-fold over the levels in the early 1990s, coinciding with the period of lower DOC accumulation. The cumulative particulate organic carbon (POC) flux and DOC accumulation (both normalized to primary production) are negatively correlated with each other, and the relative abundance of haptophyte species is negatively correlated with the cumulative POC flux.

This analysis highlights two important findings. First, there is interannual variability in the structure of the phytoplankton community at BATS. Second, this variability appears to have an effect on the fate of organic carbon produced by primary production in the euphotic zone. Although it is premature to conclude that there has been a real shift in the phytoplankton community structure as has been seen in the North Pacific subtropical gyre, the

Cont. on page 9

Shifting Paradigms: U.S. JGOFS Hosts Ocean Time-series Summit

by Michael W. Lomas

Representatives of eight ocean time-series programs assembled in Vancouver, British Columbia, April 9 to 12 to compare notes and discuss results. Hosted by the U.S. JGOFS time-series programs, Bermuda Atlantic Time-series Study (BATS) and the Hawaii Ocean Time-series (HOT) study, the meeting was expected to attract 60 researchers from eight nations.

Organizing committee members are BATS representatives Michael Lomas, Nicholas Bates and Anthony Knap of the Bermuda Biological Station for Research and HOT representatives David Karl and Roger Lukas of the University of Hawaii.

The time-series workshop took place at a critical time in the evolution of our understanding of ocean-atmosphere interactions as U.S. JGOFS winds down and other programs get underway. It had three principal objectives: to review the changes in our knowledge and assumptions about ocean systems since HOT and BATS began in 1988, to synthesize data from current research activities at both U.S. JGOFS sites, and to articulate a vision for the future evolution of ocean time-series studies in response to the needs of the broader scientific community. The latter objective incorporates the recommendations of several recently completed or ongoing science planning efforts.

The meeting was structured around several keynote plenary talks, brief scientific presentations from meeting participants and focused working groups. The purpose of the working groups was to facilitate discussion of current scientific issues and future needs that are common to the various time-series programs. Among the key questions for discussion were:

• What are the key scientific issues emerging from ocean time-series investigations?

• Are there interannual and longer-term patterns emerging, and are there demonstrable climate-ocean feedbacks and responses?

• What are the relevant time and space scales of sampling for time-series; can we identify critical knowledge gaps, and what new technologies are needed to address them?

• How should we approach model development for interpreting the vast amount of data generated by the time-series programs and for developing predictive capabilities?

• What has been the role of time-series programs in education and training of future ocean scientists, and how can we improve in this important area?

• How should the ocean time-series programs integrate with existing observing networks and other research efforts, and what role should U.S. time-series science play in national and international programs such as the Partnership for Observation of the Global Oceans (POGO) and the Global Ocean Time-series Observatory System?

The U.S. JGOFS time-series programs have been remarkably successful in furthering our understanding of the temporal variability of biogeochemical cycles in the open ocean. This meeting was intended to ensure that the momentum and success of these programs will not be lost.❖

Table 1: Participating Time-series Programs

Program Name	Location	Contact Person
BATS	Sargasso Sea	Mike Lomas and Nick Bates (mlomas@bbsr.edu, nick@bbsr.edu)
HOT	North Pacific	Dave Karl (dkarl@soest.hawaii.edu)
Monterey Bay Mooring	Monterey Bay and coastal California	Francisco Chavez (chfr@mbari.org)
SEATS (Southeast Asia Time-series)	South China Sea	KK Liu and Mao-chun Tseng (kkliu@ccms.ntu.edu.tw, ctseng@uconnvm.uconn.edu)
CaTS (Caribbean Time-series)	NE Caribbean Sea near Puerto Rico	Julio Morrell, Jorge Corredor (j_corredor@rumac.uprm.edu, oceano@coqui.net)
CARIACO	SE Caribbean Sea (Cariaco Basin)	Frank Muller-Karger (carib@seas.marine.usf.edu)
SPOTS (San Pedro Ocean Time-series)	Southern California	Tony Michaels (tony@usc.edu)
KNOT (Kyodo North Pacific Time-series)	Pacific subarctic gyre	Yukihiro Nojiri (nojiri@nies.go.jp)

Carbon Fluxes–From page 8

long-term BATS data set clearly shows these multiyear changes. As BATS and other time-series programs continue into the future, our understanding of how the complex linkages between ocean biology and seasonal physical forcing are affected by long-term, large-scale climate variability will continue to improve.❖

(Editor's note: Michael Lomas is an assistant scientist at Bermuda Biological Station for Research, where he is currently responsible for the oversight of the Bermuda Atlantic Time-series Study.)

DSR II Issues Available From U.S. JGOFS

Copies of the following special issues of *Deep-Sea Research, Part II* on JGOFS programs are available from the U.S. JGOFS Planning Office:

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

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

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

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

Smith, S.L., guest editor. *The 1994-1996 Arabian Sea Expedition: Oceanic Response to Monsoonal Forcing, Part 1*. Volume 45, nos. 10-11. 1998. $40

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

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

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

Smith, S.L., guest editor. *The 1994-1996 Arabian Sea Expedition: Oceanic Response to Monsoonal Forcing, Part 4*. Volume 48, nos. 6-7. 2001. $45

Siegel, D.A., D.M. Karl and A.F. Michaels, guest editors. *HOT and BATS: Interpretations of Open Ocean Biogeochemical Processes*. Volume 48, nos. 8-9. 2001. $45

Koeve, Wolfgang and Hugh Ducklow, guest editors. *North Atlantic Ocean Synthesis and Modelling*. Volume 48, no. 10. 2001. $45

Law, C.S., P.W. Boyd and A.J. Watson, guest editors. *SOIREE: The Southern Ocean Iron Release Experiment*. Volume 48, nos. 11-12. 2001. $45

Anderson, Robert F. and Walker O. Smith Jr., guest editors. *U.S. Southern Ocean JGOFS Program (AESOPS), Part II*. Volume 48, nos. 19-20. 2001. $40

Doney, Scott, Paul Falkowski and Jorge Sarmiento, guest editors. *The U.S. JGOFS Synthesis and Modeling Project, Part 1*. Volume 49, nos. 1-3, 2002. $40.

Shipping is included in the prices above. Requests for publications should be made to:

Mary Zawoysky
U.S. JGOFS Planning Office, MS #43
Woods Hole Oceanographic Institution
Woods Hole, MA 02543 USA
Phone: 508-289-2834
Fax: 508-457-2161

Carbon Transport– from page 3

A&M University at Galveston, Adrian Burd of the University of Georgia, Brad Moran of the University of Rhode Island and I have developed a model of ^{234}Th adsorption onto colloids. Colloids coagulate to form particles large enough to settle, taking the thorium with them. The model can predict observed effects of particle size on ^{234}Th adsorption.

More elaborate models have added coagulation to the plankton dynamics model that Michael Fasham of the Southampton Oceanographic Centre and his collaborators developed to describe seasonal plankton concentrations in the Sargasso Sea. Our work as part of the U.S. JGOFS Synthesis and Modeling Project has added coagulation of algae as well as colloids and fecal pellets to this model, enabling us to predict the removal of algae without invoking a fixed phytoplankton mortality rate.

The biggest lesson from developing and applying coagulation models is that particle size distribution and resulting vertical particle flux are not constant (Figure 3). Changes in particle size distribution can have substantial effects on the export of organic matter from the ocean surface.

Our efforts to construct coagulation models are pulled in two directions. Our models need to become more complex in order to incorporate observations that include the role of organic colloids in enhancing coagulation of algae, the degradation of aggregates by bacteria and zooplankton and particle disaggregation. But they also need to become simple enough so that they can be used in models of global carbon transport and transformations. We hope that the complex models will help us to develop the appropriate simplifications for use in global models.❖

(Editor's note: George Jackson is a professor of oceanography at Texas A&M University.)

SCIENTIFIC COMMITTEE ON OCEANIC RESEARCH

JGOFS

JOINT GLOBAL OCEAN FLUX STUDY

KNOT: Ocean Time-series Program In Western North Pacific Completes First Phase

by Nobuo Tsurushima, Keiri Imai, Yukihiro Nojiri and Paulette P. Murphy

In June 1998, Japanese ocean scientists established a time-series observation station in the western North Pacific (Figure 1). The station, located at 44°N, 155°E, is known as KNOT, short for Kyodo North Pacific Ocean Time-series (Kyodo is a Japanese word meaning "collaborative"). The scientific focus of the program at KNOT is the seasonal carbon cycle.

Although the study region exhibits high seasonal variability in sea surface temperature and biological activity, there have been few observations to document the seasonal variations in carbon concentrations and related parameters. The location was chosen because it is located in the western subarctic gyre, and the travel time from Japan to the station is less than three days. In addition, measurements made by Hokkaido University during summer between 1992 and 1997 can be used for comparison.

The KNOT program was proposed by the JGOFS-Japan committee, led by Nobuhiko Handa of Aichi Prefectural University, Shizuo Tsunogai of Hokkaido University and Toshiro Saino of Nagoya University. It is funded by the Japan Science and Technology Corporation (JST) as one of the Core Research for Evaluational Science and Technology (CREST) programs. The core members of the CREST program include the organizer Yukihiro Nojiri of the National Institute for Environmental Studies, JST post-doctoral fellows Keiri Imai and Nobuo Tsurushima, and JST technicians Fujio Shimano and Takeshi Egashira. Many other Japanese scientists have joined in this program as well.

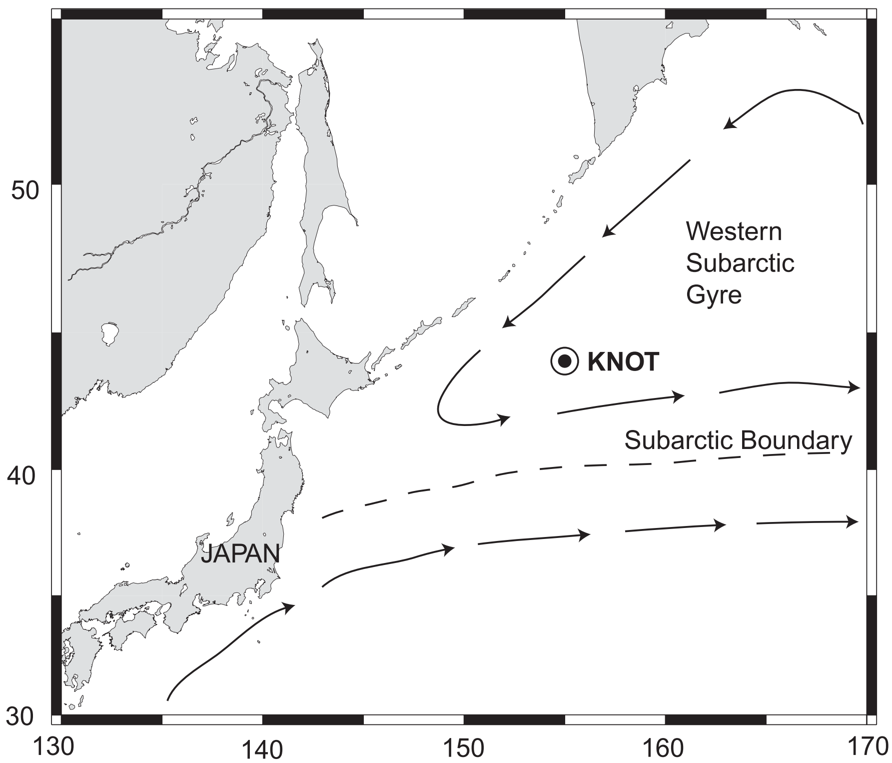


Figure 1: Location of station KNOT in the context of major currents in the western North Pacific.

The biggest challenge of the KNOT program was securing ship time for the fieldwork. There was no single ship dedicated to these time-series observations. Four research vessels have been used for the observations made to date: T/S *Hokusei-maru* from Hokkaido University, R/V *Bosei-maru* from Tokai University, R/V *Mirai* from Japan Marine Science and Technology and R/V *Hakuho* from the University of Tokyo. Scientific instruments were packed, moved and set up again to accommodate each ship change.

The KNOT station was occupied eight times in 1998 and 10 times in 1999 and 2000 respectively. In addition, observations were sometimes made along north-south transects near the KNOT station. In some cases, the KNOT station was occupied twice during one long cruise, with transect work between occupations.

Measurements made during KNOT include carbonate system parameters, including dissolved inorganic carbon (DIC), alkalinity and the fugacity of carbon dioxide (fCO_2) in surface waters, as well as temperature, salinity, nutrients and oxygen. Discrete water samples were collected throughout the water column from the surface to at least 3000 meters.

Surface layer measurements of biological activity, including chlorophyll *a* concentrations and primary productivity, were also made on nearly every cruise, along with collections of phyto- and zooplankton. For more than half the cruises, floating sediment traps were deployed, and measurements were made of particulate and dissolved organic carbon (POC and DOC), iron, trace metals, halocarbons, methane, nitrous oxide, stable isotopic ratios of DIC, the ratio of nitrogen to oxygen and argon, and thorium-234.

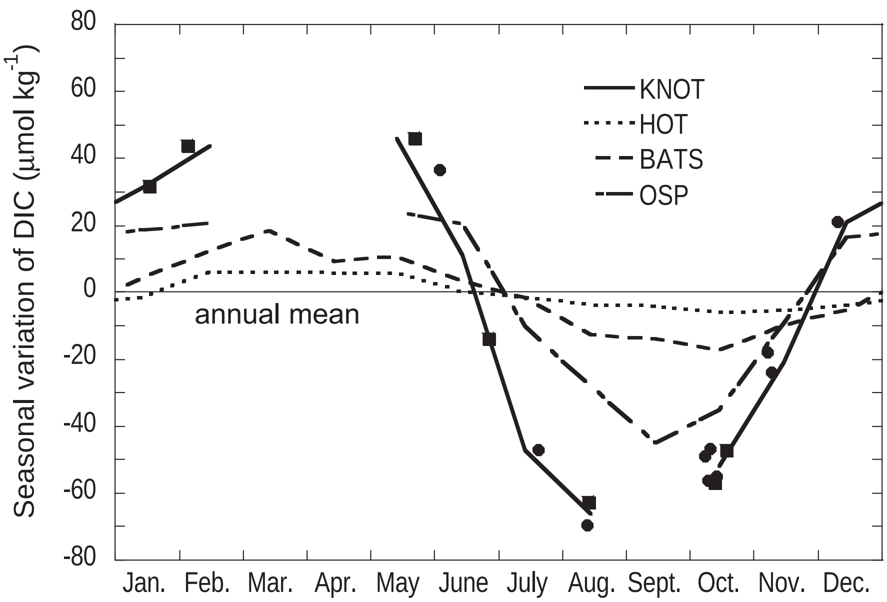


Figure 2: Seasonal amplitudes of dissolved inorganic carbon (DIC) in surface seawater at four ocean time-series sites. Note that the data for each site are normalized to the annual average of DIC at that site for ease of comparison. Data at station KNOT are shown with circles (1998 time series) and squares (1999-2000 time series). Monthly average DIC was calculated for 1988-1992 at the Hawaii Ocean Time-series (HOT) site, 1991-1994 at the Bermuda Atlantic Time-series Study (BATS) site and 1987-1998 at Ocean Station Papa (OSP).

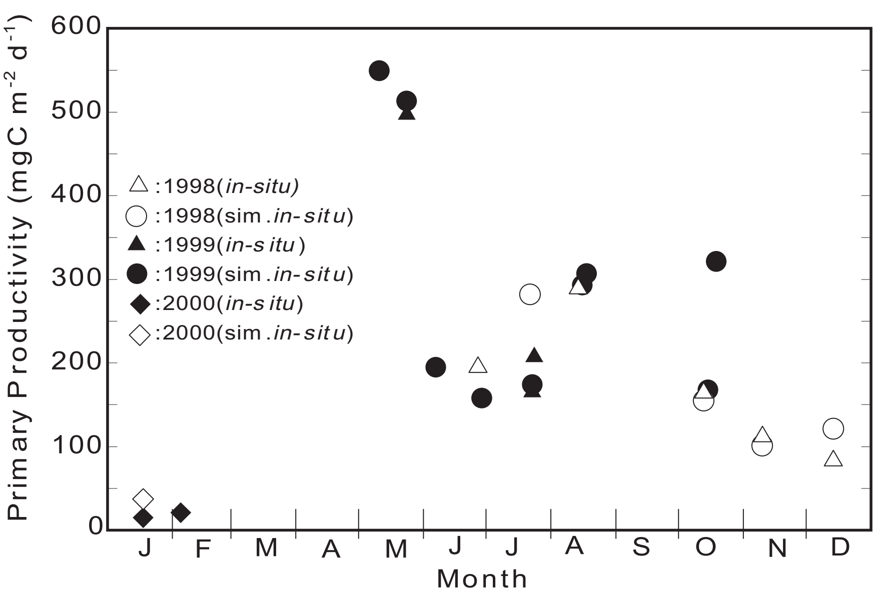


Figure 3: Seasonal variation in integrated primary productivity at station KNOT. Results from both *in-situ* incubation and on-deck incubation (simulated *in-situ*) are plotted.

Results from the three years of observations at KNOT are still being synthesized, but a few preliminary results can be given here. Large seasonal variations in surface chemical and biological parameters occur at the KNOT station. Observed seasonal variations in surface seawater nutrients and DIC at KNOT were larger than those observed at the Hawaii Ocean Time-series (HOT) station, the Bermuda Atlantic Time-series Study (BATS) station, or Ocean Station Papa (OSP) in the subarctic eastern North Pacific.

The seasonal amplitude of DIC at KNOT was more than 100 micromoles per kilogram, largely because of biological uptake in summer and strong vertical mixing in winter (Figure 2). As a result of these large DIC changes, surface water fCO_2 was lower than the atmospheric value in summer and autumn, and oceanic uptake of CO_2 was largest in autumn when the wind velocity starts to increase.

Primary productivity was highest in May, principally because of diatom production (Figure 3). Although the primary productivity had a distinct seasonal variation, with a 10-fold change during the winter and spring, the light utilization index was constant in all seasons.

Although the surface nutrient variability and chlorophyll *a* concentrations were higher at station KNOT than those at OSP, primary productivity and estimated new production were not higher. This may be a result of the lower regenerated production and shallower summer mixed layer in the western subarctic North Pacific. When the data on water column DOC and POC and the sinking flux of POC are available, we will be able to describe more precisely the

Cont. on page 13

SOSG Workshop Reviews Progress Toward Synthesis Of Southern Ocean Results

by Paul Tréguer and Robert F. Anderson

Some 32 scientists from six countries attended a mid February workshop on the biological pump and its responses to climate change that was organized by the JGOFS Southern Ocean Synthesis Group (SOSG). The workshop followed the 2002 AGU/ASLO Ocean Sciences Meeting in Honolulu, which included a special session on carbon cycling in the Southern Ocean.

The primary goal of this workshop was to contribute to the synthesis phase of JGOFS and particularly to identify synthesis contributions to the final JGOFS Open Science Conference, to be held May 5-8, 2003, in Washington, D.C. SOSG chairman Paul Tréguer of the Institut Universitaire Europeen de la Mer, Brest, France, opened the meeting by reviewing the six major research questions discussed at the Southern Ocean JGOFS Symposium held in Brest in July 2000 (**http://univ-brest.fr/IUEM/so-jgofs/synthesis**). He then identifed synthesis works already published as well as the gaps that remain.

Reiner Schlitzer of the Alfred-Wegener-Institut (AWI), Bremerhaven, Germany, chairman of the JGOFS Global Synthesis Working Group (GSWG), introduced plans for the next GSWG meeting, to be held in Ispra, Italy, in June 2002.

Two plenary talks set the stage for later discussion of synthesis topics. Patrick Monfray of the Laboratoire des Sciences du Climat et de l'Environnement, Gif-sur-Yvette, France, gave a provocative talk on possible responses of the Southern Ocean as well as of the world ocean to climate and other external forcing. This talk was based on outputs from a three-dimensional coupled ocean-atmosphere complex model that includes a relatively complex ocean biogeochemistry.

Monfray noted that increased stratification of the ocean with global warming is expected to play a major role in biogeochemical fluxes as the mixed layer decreases and the productive season lengthens. The model predicts a significant increase in both primary and export production in the high latitudes but a decrease in biogenic fluxes in the low

Cont. on page 14

KNOT—From page 12

carbon cycle at station KNOT.

Funding from JST is limited to five years, and the first cycle of intensive observations was completed in October 2000. Synthesis and interpretation of the three-year data set will take place throughout the coming year, and some of these results will be published in an upcoming *Deep-Sea Research II* special issue on North Pacific biogeochemical processes. The data set of the time-series observations will be available from the Marine Information Research Center (MIRC) home page this year.

This three-year program of observations will greatly expand our information about seasonal variations of chemical parameters in the KNOT region. However, any long-term changes in CO_2 concentrations will require both a long-term study and high-frequency observations to capture the extremes in the seasonal variations (Figure 4). The community of ocean scientists in Japan is currently assessing these initial results from KNOT and evaluating options for the next phase of the time-series observation program.❖

Editor's note: Authors and their institutional affiliations are Nobuo Tsurushima, National Institute of Advanced Industrial Science and Technology, Japan; Keiri Imai, Japan Science and Technology Corporation, Japan; Yukihiro Nojiri, National Institute for Environmental Studies, Japan, and Paulette P. Murphy, National Ocean Data Center, USA.)

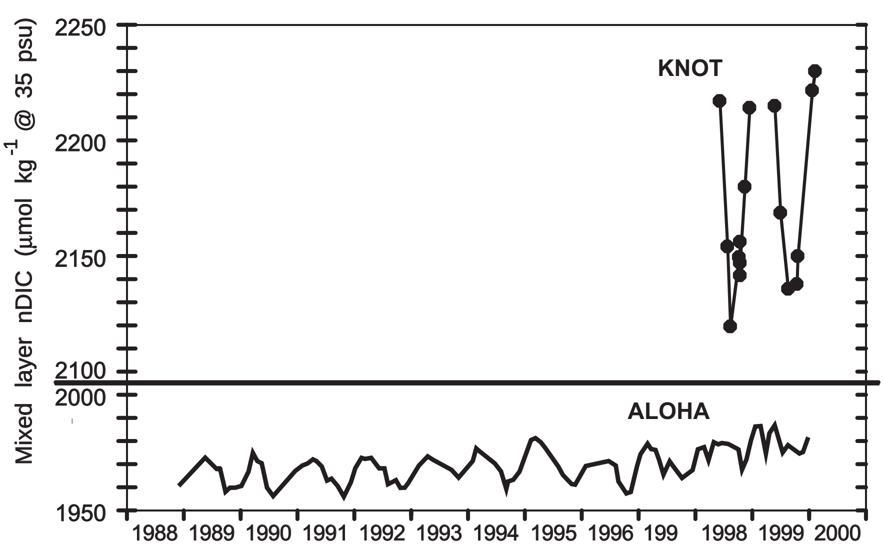


Figure 4: Comparison of mixed-layer dissolved inorganic carbon (DIC) concentration (normalized to salinity of 35) at station KNOT (1998 to 2000) and HOT station ALOHA (1988 to 1999).

SOSG—From page 13

latitudes. Iron upwelling from below also seems to play a role that has been underestimated because most present studies focus on iron inputs from above.

To validate model predictions for the near future, Monfray suggested that we should take into account the natural variability of biogeochemical fluxes and ecosystem structures associated with the Antarctic Circumpolar Wave (ACW). Indeed the ACW affects the mean sea surface temperature by ± 1°C and the mixed-layer depth by ± 50 meters, which is comparable to predicted changes in ocean features in response to a doubling of present atmospheric carbon dioxide (CO_2) concentration. Excerpts from this talk are available on the JGOFS Southern Ocean web site (**http://univ-brest.fr/IUEM/so-jgofs/**).

Tilla Roy of the Antarctic Cooperative Research Centre (ACRC), Hobart, Australia, presented a talk on inconsistencies between the outputs of atmospheric inversion models and the global synthesis of the air-sea delta pCO_2 data. Present estimates of the austral annual uptake of atmospheric CO_2 are still poorly contrained, varying between -0.1 and -0.6 gigatons of carbon per year for the part of the Southern Ocean south of 50°S.

Negative air-sea CO_2 fluxes such as these are not reconcilable with outputs from atmospheric inversion models validated with CO_2 data from the few land stations located in the Southern Hemisphere. Increasing the number of land stations is essential, especially for South Africa and South America. New approaches for better integration of ocean and atmospheric CO_2 and oxygen (O_2) data are also strongly recommended.

Following a discussion of the plenary talks, workshop participants divided into working groups to assess and promote synthesis of recent findings on three topics of particular importance to research on the Southern Ocean carbon cycle. Working group 1 considered the question of what physical and chemical factors regulate phytoplankton growth and species composition. Working group 2 discussed the fate of biogenic material in the ocean and asked whether that fate can be correlated with environmental conditions. Working group 3 asked whether satellite images of phytoplankton biomass in the Southern Ocean were consistent with what we know about regulation of phytoplankton populations and the fate of biogenic materials.

In his report on working group 1 deliberations, chairman Ulrich Bathmann, AWI, Bremerhaven, noted that the huge international effort undertaken during the last decade has drastically changed the simplistic vision of the Southern Ocean that preceded JGOFS. To better account for the complexity of Southern Ocean ecosystems and for the effects of climate change on primary production, the working group suggested that biogeochemical models should take a multistranded approach to the limitation of primary production, including the role of light, nitrate, phosphate, silicic acid, iron and grazing for the major players, including diatoms, phaeocystis, crytophyceans and other small phytoplankters.

Working group 1 also encouraged complementary approaches. Among them were building up a hierarchy of limiting factors and bifurcation models; designing an appropriate physical background that includes mesoscale features in the frontal zones, for example; measurements of winter values for state variables, and coupling between atmospheric parameters and sea ice conditions. New experiments in Lagrangian mode were recommended, including mesocosms, *in-situ* and model experiments.

Working group 2 chairman Tom Trull, ACRC, Hobart, reported on what we learned from the results of JGOFS field and modelling work about the fate of biogenic material in the Southern Ocean and the link with environmental conditions. Participants in this working group agreed that the export of organic carbon out of the euphotic layer is high, but new evidence shows that the export flux of carbon deeper than 2000 meters is almost comparable to fluxes in the rest of the world ocean. If this is so, then the mineralization of organic carbon in the twilight zone should be high. Some studies indicate that this conclusion is accurate.

But working group 2 also pointed out the gaps. We do not know which pathway, sinking, subduction or bioentrainment, is the most effective one for the export of carbon to the deep ocean. We also do not know which region or subsystem of the Southern Ocean is the most important for the export of organic carbon below the ventilation depth. New areas of research are needed to better understand and model aggregation/disaggregation mechanisms at the micro scale.

Greg Mitchell of the University of California at San Diego, USA, reported for working group 3 on the accuracy of satellite images of the Southern Ocean. SeaWiFS ocean colour data now allow realistic estimates of the seasonal and interannual variability of chlorophyll concentrations in antarctic surface waters, although persistent cloud coverage makes continuous determinations difficult. Improved algorithms will soon be available for accurate determinations of chlorophyll in the offshore waters of the Southern Ocean.

Working group 3 participants also debated the degree of confidence in primary production and export production levels deduced from satellite-based estimates of phytoplankton biomass. They recommended that future studies in the Southern Ocean conduct systematic *in-situ* optics measurements in parallel with traditional primary production measurements.

Cont. on page 19

Bangor Conference Assesses Half Century Of Progress In Study Of Production In Aquatic Ecosystems

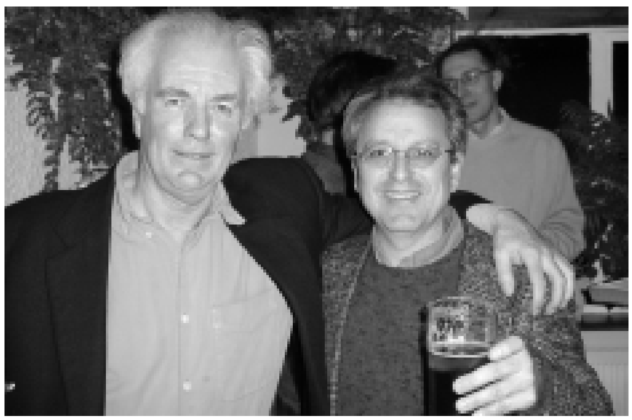
by David M. Karl

An opportunity to reflect on past achievements and consider future challenges in the measurement of phytoplankton productivity drew a diverse group of international aquatic scientists to Bangor, Wales, in mid March to attend a conference titled "An appreciation of 50 years of the study of production in oceans and lakes."

The meeting was timed to coincide with the 50th anniversary of the publication of Einer Steemann Nielsen's seminal paper on the use of the radioactive isotope carbon-14 (^{14}C) as a tool for measuring rates of photosynthesis in aquatic environments. Prior to the development of the ^{14}C method, net and gross photosynthesis were estimated using paired light/dark bottle incubation experiments. Although the oxygen method was based on sound physiological principles, the method required a fairly high threshold rate for detection, which precluded its use in most open-ocean ecosystems and oligotrophic lakes.

Conference leaders Peter J.leB. Williams and David N. Thomas, both of the School of Ocean Sciences of the University of Wales, used this anniversary to organize the meeting but developed a much broader view of the measurement and implications of phytoplankton productivity in aquatic habitats. Keynote presentations covered topics including the evolution of the carbon cycle, cell physiology and growth, and the effects of climate on ecosystem processes.

These talks were supplemented by two fascinating historical presentations, one by Richard Barber of Duke University on the evolution of concepts and the search for paradigms, and the other by Morten Søndergaard of the University of Copenhagen on the life and times of Einer Steemann Nielsen. Both talks traced the development of the ^{14}C method. Barber emphasized the key roles of George de Hevesy at the Institute of Theoretical Physics in Copenhagen, Melvin Calvin at the Lawrence Radiation Laboratory at Berkeley and Willard Libby at the University of Chicago. Steemann Nielsen was in the right place at the right time, Barber said, and he had the insight to tie their pioneering discoveries to aquatic ecology.



Courtesy of D. Karl

Peter Williams (left) and David Karl discuss microbes and the quality of Welsh beer.

Søndergaard provided a delightful account from the perspective of Steemann Nielsen in Copenhagen "looking west." Søndergaard's access to Steemann Nielsen's personal archives produced several dramatic props for his presentation, including original laboratory equipment and annotated reprints from the period of heated controversy with Gordon Riley, then at Woods Hole Oceanographic Institution, over the efficacy of the oxygen method for measuring primary productivity.

The 14 keynote lectures were supplemented by a diverse spectrum of 80 contributed talks and 50 poster presentations. The titles, abstracts and other materials and list of international participants are available at the conference website (**www.plankton-productivity.org**).

Advances in many disciplines can be traced back to the development of a novel method, instrument or other technical breakthrough. In the case of the ^{14}C method, two critical events were the availability of sensitive Geiger-Müller radioactivity counting technology and the post-World War II availability of ^{14}C, isolated in Berkeley less than a decade before its use as a tracer for organic productivity in aquatic ecosystems. These breakthroughs occurred just as plans were being finalized for the Galathea deep-sea expedition in 1950. The rest, as they say, is history.

From its inception, the ^{14}C method has been praised and criticized, used and abused, accepted and rejected by aquatic scientists. After 50 years of laboratory and field investigations, we are still not certain what the method actually measures in mixed natural microbial assemblages. Do field incubations return an estimate closer to gross photosynthesis or to net rates (photosynthesis minus respiration)? Because these values can differ by more than a factor of two, the answer is key to our understanding and interpretation of carbon and energy fluxes in the sea. Few other methods in biological oceanography have had as large an impact on our progress in the field. It was in this spirit that the conference was convened.

Unlike many scientific symposia that publish their proceedings long after the event, the Bangor Phytoplankton Productivity Conference unveiled its proceedings a few weeks ahead of the meeting. They took the form of a volume edited by Williams, Thomas and Colin S. Reynolds, titled

Phytoplankton Productivity: Carbon Assimilation in Marine and Freshwater Ecosystems. The book chapters largely coincide with the keynote lectures. It includes a foreword written by G.E. (Tony) Fogg of the University of Wales, a larger-than-life phytoplankton ecologist who also attended the conference. The book is available from Blackwell Science Ltd. (**www.blackwell-science.com**).

Conference convenors Williams and Thomas went all out to produce a stimulating and enjoyable meeting. One event in particular set a standard for all future meetings. On Tuesday evening, two of the conference exhibitors, ^{14}C Centralen and Chelsea Instruments, hosted a showing of the original 1916 film version of Jules Verne's classic undersea adventure "20,000 Leagues Under the Sea," complete with ushers in full Victorian dress and an introduction to the film by Jules Verne himself. The piano accompaniment by J. Maxwell Pemberton of the University of Wales included segments from the Beatles and the Star Wars theme.

On Thursday evening, Charles Yentsch of Bigelow Laboratory, a pioneer in measurements and interpretations of plankton rate processes and featured speaker at the conference banquet, entertained us with his own historical accounts of Steemann Nielsen. He provided insights into the sometimes acrimonious debates the eminent Dane carried on with various American scientists over the use of competing methods for the measurement of photosynthesis. We also enjoyed a tour of the university's new research vessel, R/V *Prince Madog*, beautifully appointed for its coastal ocean sciences mission.

I predict that the Bangor Phytoplankton Productivity Conference will be recorded as a grand success, and that the edited conference volume will serve as a benchmark summary of 50 years of progress in this important area of research.❖

Planning Underway For Final JGOFS Conference

In little more than a year, JGOFS will present results from its field programmes and modeling studies and their contributions toward resolving questions about the ocean's role in the global carbon cycle at its final open science conference. Titled "A Sea of Change: JGOFS Accomplishments and the Future of Ocean Biogeochemistry," the symposium will be held at the National Academy of Sciences in Washington, D.C., May 5-8, 2003.

The goal of the conference is to bring together the major accomplishments of studies conducted over the decade and a half since JGOFS was launched in 1987. Its focus will be on linking JGOFS science questions to broad issues of concern to resource managers and scientists charged with making policy decisions and planning future science programs in ocean biogeochemistry.

The scientific program committee for the conference is chaired by Deborah Steinberg of the Virginia Institute of Marine Science (VIMS), U.S. Other members are Véronique Garçon of the Centre National de la Recherche Scientifique, France; Peter Haugan, University of Bergen, Norway; David Karl, University of Hawaii, U.S.; Kon-Kee Liu, National Taiwan University, Taiwan, and Bronte Tilbrook, CSIRO Marine Research, Australia.

The local committee charged with the organization of the symposium comprises U.S. JGOFS Scientific Steering Committee (SSC) chair Mark Abbott, Oregon State University; JGOFS SSC chair Hugh Ducklow, VIMS; Roger Hanson, JGOFS International Planning Office, Bergen, Norway; Elizabeth Gross, Scientific Committee on Oceanic Research (SCOR), and Ken Buesseler, Margaret Bowles and Mary Zawoysky of the U.S. JGOFS Planning Office, Woods Hole Oceanographic Institution.

Each day will begin with one or two plenary sessions focusing on an overarching theme: from ocean color to ocean dynamics, ecosystem structure and dynamics, data assimilation and modeling, mysteries solved during JGOFS, and ocean dynamics in earth system science. Other plenary talks will focus on ocean observations, ocean margins, past oceans and ocean futures in biogeochemistry. Extensive poster sessions will be presented each afternoon.

Conference organizers also plan to present evening public sessions featuring speakers and topics of interest to broader audiences. They are also working on an afternoon presentation for elementary and secondary school students.

As plans are completed and speakers invited, more information will become available via the U.S. JGOFS web site (**http://usjgofs.whoi.edu**) or from Mary Zawoysky in the planning office (**mzawoysky@whoi.edu**).

IGBP Team Plans New Project On Ocean Biogeochemistry And Ecosystems

by Julie Hall

Recent decisions by the International Geosphere-Biosphere Programme (IGBP) Steering Committee and the executive of the Scientific Committee on Ocean Research (SCOR) have given the green light to the continued development of a new project, Ocean Biogeochemistry and Ecosystems, as part of the next phase of IGBP. This project will have strong collaborative links with the ongoing Global Ocean Ecosystems Dynamics (GLOBEC) project and will build on the results of JGOFS and other research programmes.

Over the next two years the Ocean Biogeochemistry and Ecosystems Transition Team, chaired by Julie Hall of the National Institute of Water and Atmospheric Research, New Zealand, will develop a science plan and implementation strategy for the new project. It will be based on the recently completed joint SCOR and IGBP *Draft Research Framework for Biological and Chemical Aspects of Global Change in the Ocean* and reviews of this framework by independent scientists and representatives of relevant research programmes.

The transition team will have wide representation from current IGBP projects, including JGOFS. It will meet in May to prepare a discussion document for an open science meeting, which will be held in mid January 2003. The purpose of this open science meeting will be to involve the wider scientific community in development of the new project.

The draft research framework has identified three overarching questions for the new project:

What controls the time-varying biogeochemical state of the ocean system, and how will it respond to global change?

Answering this question will require coupled studies of ocean physics, biology and chemistry on time scales longer than those used to investigate interannual variability. The focus will be on the transfer, transport and transformation (remineralization) of nutrients and materials between surface waters and the mesopelagic or "twilight" zone in the ocean and horizontally across the continental shelves and slopes.

Another important topic is the coupling of nutrient cycles between the water column and sediments, including reactions within the sediments that exert significant influence on the cycling of specific elements such as nitrogen. These processes are particularly significant in the shallower waters of the continental shelves. The role of benthic organisms in sediment-water interface processes and the effect of global change on such organisms have also been identified as hot topics for ocean research in the next 10 years.

How will marine food webs respond to global change?

A key challenge for the future will be to conduct fully integrated studies and analyses of pelagic food webs, from viruses to fish, in the continental margins, open ocean and mesopelagic zone. Effects of changes in the chemical and physical environment on marine organisms and food webs are also critical areas of future research.

Our understanding of the relationship between the diversity, stability and structure of food webs and biogeochemical cycles needs to be improved. Although we know that organisms in microbial food webs are responsible for remineralizing elements and mediating the flow of nutrients between the lower and higher levels of marine food webs, for example, we understand little about how the diversity of microbial organisms affects nutrient flows. Evidence is growing that marine ecosystems can experience dramatic and relatively rapid changes in productivity and ecosystem structure that can last for decades. These changes are known as "regime shifts." It will be important to identify the factors that trigger these important changes in marine food webs.

How does carbon accumulation in the ocean respond to global environmental change?

Our current understanding of the carbon cycle in the ocean interior, the continental margins and the high-flux regions of the ocean is limited. The potential effects of changing physical, chemical and biological parameters need to be studied to allow us to predict and possibly mitigate the impact of changing climate. Although the Land-Ocean Interactions in the Coastal Zone (LOICZ) project has made significant progress in quantifying the amount of carbon transported from the land to the ocean, our understanding of the transformation and transport of terrigenous carbon after it enters the ocean is still limited.

The intermediate waters of the ocean form a major storage reservoir for anthropogenic carbon dioxide (CO_2). Our understanding of the sensitivity of intermediate water-mass circulation to climate change is therefore a key issue for future CO_2 projections. Accurate representation of the circulation of intermediate-depth water masses and of the ocean's vertical circulation in biogeochemical models represents a challenge that will require significant collaboration between IGBP and the World Climate Research Programme (WCRP).

It will be important for the new project to focus on specific areas of

cont. on page 19

DMTT Update: Dissemination And Stewardship Of JGOFS Data

by Margarita E. Conkright and Bernard Avril

Members of the JGOFS Data Management Task Team met at the U.S. National Oceanographic Data Center (NODC) in Maryland during January to review the status of JGOFS data sets, discuss current activities and make plans for the future.

DMTT members attending were Margarita Conkright of the Ocean Climate Laboratory, NODC (chair); Bernard Avril of the JGOFS International Project Office (IPO) in Norway; Cynthia Chandler of the U.S. JGOFS data management office; Christine Hammond, Woods Hole Oceanographic Institution, U.S.; Joachim Herrmann of the German JGOFS data management office; Roy Lowry of the British Oceanographic Data Centre; Takeharu Miyake of the Japan Oceanographic Data Center; Jaswant Sarupria of the National Institute of Oceanography, India, and Donald Spear of the Canadian Marine Environmental Data Service.

Conkright and her NODC colleagues Lee Danzler and Sydney Levitus served as hosts to the gathering. Attending as guests were Michael Diepenbroek from the World Data Centre for Marine Environmental Sciences (WDC-MARE) in Germany and Robert Gelfeld, Todd O'Brien and Renée Tatusko from the NODC/World Data Centre for Oceanography in the U.S.

The DMTT has completed the list of JGOFS cruises from all participating countries, thanks to ongoing efforts at the JGOFS IPO. The web address for this site is **http://ads.smr.uib.no/jgofs/inventory/index.htm#Cruises**

Preparation of the JGOFS master data set, recommendations for data management in future projects and lessons learned from JGOFS were central topics at the DMTT meeting. Discussion centered first around the experiences of DMTT members in securing both data and funding for data management. Among the points made was that data management should be more efficiently reviewed or be given adequate weight in research proposals. Meeting participants also noted that interaction of investigators and data managers from the start of each project would result in higher quality, integrated datasets available in a timely manner. They also agreed that data managers need to present a clear plan with clearly defined products at the beginning of each project, and that data management should be a clearly stated rather than implicit part of any science plan.

DMTT members concluded that an international framework with adequate financing and a coherent framework for data management is essential for future programs. They agreed to send a letter providing advice on data management for future international projects to the International Group of Funding Agencies for Global Change Research (IGFA) as well as to national funding agencies. This letter would recommend:

- Establishment of a centralized international project data center responsible for acquisition, access, and distribution of data to the World Data Center system to ensure its long-term archive;
- Establishment of full-time national data coordinators who will identify cruises and investigators associated with a program, work with principal investigators to ensure that data and associated metadata are complete and in common file and data formats, submit them to the international data center, and attach pertinent citations;
- Setting of a time limit after which all countries participating in a program must submit the data;
- Establishment of a minimum set of standards for reporting data and metadata.

Efforts to secure funding in the U.S. for the production of a JGOFS master CD-ROM data set did not succeed. The recently established WDC-MARE has offered its support, especially thanks to a new initiative of the German Ministry for Research and Technology called Information Systems for Earth Management.

The new plans address the need to compile all JGOFS data sets into a comprehensive, uniform database that will ensure its rapid, worldwide dissemination and long-term stewardship. The focus will be on data acquisition from national JGOFS programmes and from individual scientists in participating countries without designated data managers, quality control and conversion into a common format.

The data sets will be imported into an information system called Pangaea that is accessible through the web (**http://www.pangaea.de**). The WDC-MARE, in collaboration with the JGOFS DMTT and IPO, will conduct the work and serve as the distributor of the JGOFS biogeochemical database.

Diepenbroek, who serves as technical director for Pangaea, reported on the progress of the proposal. Work will proceed with the assembly and transfer of data from the DMTT to the Pangaea information system. Once all data are in a common format with all available metadata, CD-ROMs will be produced for distribution to JGOFS investigators. The U.S. NODC/WDC will provide funding for the production and distribution of 500 CD-ROM sets. A first version of this series of CD-ROMs will be presented at the final JGOFS Open Science Conference in May 2003.

Representatives from various countries presented reports on their national JGOFS programs. Avril reported on the status of data management for national programs not represented in the DMTT, and the group discussed specific recommendations for the integration of data sets from these countries.

Finally, the DMTT agreed upon the core parameters to be included in the JGOFS data set and their designation, units and format, as well as the accompanying metadata and a user interface for both the online database and the series of CD-ROMs. Each CD-ROM will include JGOFS data, web links, metadata description, associated publications list and acknowledgement of principal investigators and funding agencies.❖

Table 1: JGOFS and related data products available

CD-ROM	Source	Date
Biogeochemical Ocean Flux Study (BOFS)	BODC, UK	1994
Ocean Margin Exchange Project (OMEX I)	BODC, UK	1997
Southern Ocean JGOFS Cruise ANT X/6	NIOZ, NL	1997
Netherlands Indian Ocean Programme	NIOZ, NL	1997
Arabesque (U.K. Arabian Sea cruises)	BODC, UK	1998
Hawaii Ocean Time-series (HOT)	U.Hawaii, US	1999
JGOFS International Collection: Arabian Sea	DMTT	1999
JGOFS-India	NIO, India	1999
Northwest Pacific Carbon Cycle Study (NoPaCCS)	JODC, Japan	1999
Japan zooplankton data, western Pacific (K. Odate collection 1951-1990)	JODC	1999
European Sub-polar Ocean Prog. (ESOP-2)	U.Bergen, Norway	1999
WOCE Hydrographic Data	SIO, US	1999
LOICZ Shelf Edge Study	BODC, UK	1999
Plankton Reactivity in the Marine Environment (Prime)	BODC, UK	2000
Canary Is. Azores Gibraltar Observations (CANIGO)	IMDC, Ireland	2000
Southern Ocean Iron Release Experiment (SOIREE)	NIWA, NZ	2001
Canada JGOFS Data Sets	MEDS	2001
OMEX II	BODC, UK	2001
OzGOFS Equatorial Pacific	CSIRO, Australia	2001
BOFS Version 2 plus Sterna data	BODC, UK	2002
Etude de Processus dans l'Océan Pacifique Equatorial (EPOPE)	OOV, France	ann. 2002
DYFAMED/SODYF	OOV, France	ann. 2002
UK World Ocean Circulation Experiment	BODC, UK	ann. 2002
Marginal Sea Flux Experiment (MASFLUX)	JODC, Japan	ann.

These CD-ROMs are available from national data managers or via the JGOFS IPO.

Data Available Online

Australian JGOFS (**http//:www.marine.csiro.au/datacentre/JGOFSweb/cmr_jgofs.htm**)

U.S. JGOFS (**http://usjgofs.whoi.edu/general_info/data_management.html**)

Canadian JGOFS (**http://www.meds-sdmm.dfo-mpo.gc.ca/jgofs/**)

German JGOFS (**http://www.ifm.uni-kiel.de/jgofs/dm or http://www.pangaea.de**)

JGOFS-France (**http://www.obs-vlfr.fr/jgofs**)

Japan JGOFS (**http://www.kanso.co.jp/ocean/html-doc/english/top2.html**) or (**http://www.jodc.go.jp/JGOFS_DMO/index.html**)

Indian JGOFS (**http://www.indian-ocean.org/progfund/programs.htm#jgofs**) or (**http://www.indian-ocean.org/support/main.htm**)

BODC online database (**http://www.bodc.uk**)

SOSG–from page 14

Robert Anderson of Lamont-Doherty Earth Observatory, USA, presented some preliminary information on the agenda of the final JGOFS Open Science Conference. Oral communications will focus on scientific themes rather than on regions, although regional reports can be presented in posters. The SOSG workshop identified possible poster presentations on synthesis answers to the six major questions of Southern Ocean JGOFS, as well as contributions to thematic oral presentations.❖

IGBP Team – from page 17

the ocean that are likely to be particularly sensitive to gradual long-term changes in climate. These "hot spots" include regions of upwelling and deep mixing, continental margins, high-latitude areas and the interfaces of the ocean with the atmosphere, continents and seafloor. It will be important to conduct both long-term monitoring and process studies, particularly in these hot spots, to address the research questions posed above. Knowledge of the correlation of factors in the past, ascertained through paleoceanography and paleoclimatology studies, will provide key information for understanding present conditions and predicting the future.

We hope to see significant representation from the JGOFS community at the Ocean Biogeochemistry and Ecosystems Open Science Meeting in mid-January 2003. We will post the discussion document and details of this activity on **www.jhu.edu/scor/obe.htm** and **www.igbp.kva.se/ocean/**.

• U.S. JGOFS Calendar 2002 •

2002

9-12 April: Time-series workshop, "Shifting Paradigms: A U.S. JGOFS Time-series Summit," Vancouver, Canada. Contact: Michael Lomas, Bermuda Biological Station for Research, Bermuda (**mlomas@bbsr.edu**).

22-26 July: U.S. JGOFS Synthesis and Modeling Project workshop, Woods Hole Oceanographic Institution, Woods Hole. Contact: Scott Doney or Joanie Kleypas, National Center for Atmospheric Research, Boulder, CO (**kleypas@ncar.ucar.edu**).

23-25 October: U.S. JGOFS Scientific Steering Committee meeting, Washington, D.C. Contact: Ken Buesseler, U.S. JGOFS Planning Office, Woods Hole, MA (**kbuesseler@whoi.edu**).

2003

5-8 May: JGOFS Open Science Conference, "A Sea of Change: JGOFS Accomplishments and the Future of Ocean Biogeochemistry," National Academy of Sciences, Washington, D.C., USA. Contact: Mary Zawoysky, U.S. JGOFS Planning Office, Woods Hole Oceanographic Institution, Woods Hole, MA (**mzawoysky@whoi.edu**).

5-8 May: JGOFS Scientific Steering Committee meeting, Washington, D.C., USA. Contact: Roger Hanson, JGOFS International Project Office, Bergen, Norway (**Roger.Hanson@jgofs.uib.no**).

Getting Access to U.S. JGOFS Data and Information

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

http://usjgofs.whoi.edu/

Inquiries may be addressed to the U.S. JGOFS data management office via electronic mail to **dmomail@dataone.whoi.edu** or by phone to David Schneider (508-289-2873).

Data from U.S. JGOFS process study cruises are available through the U.S. JGOFS data management system at the Web site above.

Data from the U.S. JGOFS time-series programs are also available via the World Wide Web at the following sites:

HOT **http://hahana.soest.hawaii.edu/hot/hot-dogs/interface.html**

BATS **http://www.bbsr.edu/ctd**

Data from the Survey of Carbon Dioxide in the Oceans are available from the Carbon Dioxide Information Analysis Center at

http://cdiac.esd.ornl.gov/oceans/home.html

U.S. JGOFS News

Published by the U.S. JGOFS Scientific Steering Committee

Editor: Margaret C. Bowles

Designer: Jeannine M. Pires

U.S. JGOFS News reports on U.S. contributions to the Joint Global Ocean Flux Study (JGOFS) of the Scientific Committee on Oceanic Research (SCOR), a permanent committee of the International Council of Scientific Unions (ICSU). JGOFS is a core project of the International Geosphere-Biosphere Programme (IGBP).

We welcome your comments and contributions for publication.

To obtain a free subscription, write to:

Mary Zawoysky
U.S. JGOFS Planning Office, MS #43
Woods Hole Oceanographic Institution
Woods Hole MA 02543-1047 U.S.A.
(508) 289-2834

U.S. JGOFS

U.S. Planning Office at Woods Hole Oceanographic Institution
Woods Hole, MA 02543-1047

Address service requested

Nonprofit organization
U.S. POSTAGE
PAID
Permit No. 46
Woods Hole, MA 02543