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Modeling *Trichodesmium* And Nitrogen Fixation In The Atlantic: JGOFS Meets Biocomplexity

by Raleigh R. Hood, Victoria J. Coles, Mercedes Pascual and Douglas G. Capone

Modeling nutrient dynamics and carbon cycling in the ocean requires interdisciplinary research, combining geochemistry, biology, ecology and physics. All of these disciplines are represented in the U.S. JGOFS Synthesis and Modeling Project (SMP). However it is probably fair to say that the SMP, child of the U.S. JGOFS process studies, has focused primarily on characterizing and modeling biogeochemical cycles and their interactions with physical processes. Less attention has been paid to ecological considerations.

Yet ecological principles provide the foundation for most of the biogeochemical modeling efforts that are currently underway in the SMP. Simple ecosystem models with compartments for nutrients, phytoplankton and zooplankton (NPZ) and their more complex successors are widely used in three-dimensional biogeochemical models to simulate elemental cycling. These ecosystem models stem from early theoretical and numerical studies carried out by ecologists that were later adapted for application to the ocean.

Many of the central concerns of the SMP are essentially ecological. For example, variability over time and space in the export of carbon and other elements to the deep sea is largely determined by variability in phytoplankton species composition and the effect of grazing and egestion by different zooplankton species. Thus predicting the export flux of different elements is in good part an ecological problem that may require including the effects of competition, species succession and different forms of predation and egestion in models if we are to get the fluxes right.

Although ecology lurks in the background in the SMP, it is in the forefront of Biocomplexity in the Environment, another major interdisciplinary program of the National Science Foundation (NSF). Biocomplexity is fundamentally ecological in its orientation and embraces a wide range of studies in both aquatic and terrestrial systems.

The focus of the Biocomplexity initiative is on the study of "complex systems." This term does not simply refer to systems that are complicated; it has a specific ecological meaning with two key ingredients. One defining ingredient is a multiplicity of parts. Complex systems are composed of multiple heterogeneous components that interact locally in the absence of a global control. Another key ingredient is nonlinearity.

Many per-capita rates in pelagic ecosystem models, such as those associated with nutrient uptake and predation, are not constant but vary with the state of the system. The resulting equations for food-web dynamics are therefore nonlinear, which allows for a rich array of possible dynamics, even in relatively simple systems. These can include chaotic behavior, multiple stable states and low-frequency transients, as well as elaborate spatio-temporal patterns.

The study of complex systems is concerned with questions about the interplay between endogenous biological components and multiple exogenous forcing factors. It also addresses questions about the relevant level of detail, including the resolution of physical space, that must be incorporated in models to capture the global dynamics of ecosystems. These are also important concerns in research conducted as part of the SMP. Thus there is substantial overlap with the research conducted under the Biocomplexity initiative. Investigators in both programs grapple with complex three-dimensional systems that are both nonlinear and multi-dimensional.

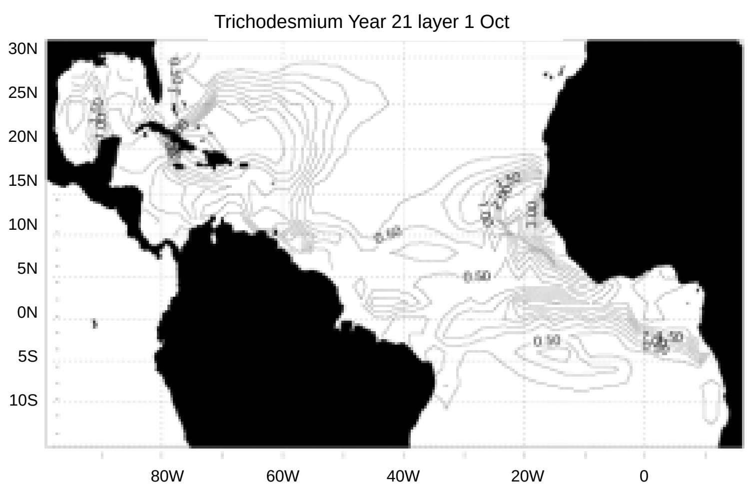

Figure 1: Model simulation of *Trichodesmium* concentrations in the mixed layer in the Atlantic during October. The concentration units are colonies per liter.

With SMP support, we have developed an ecosystem model that includes explicit, dynamic representation of the process of nitrogen fixation and *Trichodesmium*, a cyanobacterium that can fix molecular nitrogen (N_2) from the atmosphere. This model, which was developed to account for the effects of N_2 fixation at the Bermuda Atlantic Time-series Study (BATS) site, is a nitrogen-based system that includes six state variables: phytoplankton, dissolved inorganic nitrogen (DIN), dissolved organic nitrogen (DON), heterotrophs (zooplankton, microzooplankton and bacteria), detritus and *Trichodesmium*.

In this model *Trichodesmium* growth is controlled primarily by the availability of light and an intrinsically slow growth rate. Although relatively simple, the model reproduces the observed seasonal variability in *Trichodesmium* biomass at the BATS site. It is also highly nonlinear, and the *Trichodesmium* can interact with phytoplankton in a number of ways, both positive and negative. These include pumping nitrogen into the system, which stimulates phytoplankton growth, and competing for light, which depresses it.

With additional funding from the Biocomplexity initiative, we have coupled this model with an Atlantic application of an ocean general circulation model (the Miami Isopycnal Coordinate Model or MICOM). Although our ecosystem model does not include the effects of temperature or direct mechanical mixing on *Trichodemium* growth rate, it reproduces the approximate observed meridional distribution of this organism in the Atlantic as well as elevated concentrations in specific coastal and open ocean regions where we know *Trichodemium* occurs (Figure 1). The model also appears to reproduce the observed seasonal cycles of *Trichodesmium* populations in tropical and subtropical waters where concentrations are highest in summer and fall.

High *Trichodesmium* concentrations develop in model simulations in regions where the mixed layer is relatively thin, resulting in high mean light levels, and DIN concentrations and phytoplankton biomass are low for extended periods of time. The model also generates a three-step successional sequence: high DIN concentrations associated with upwelling and/or mixing stimulate phytoplankton growth, followed by *Trichodesmium* growth after DIN is depleted and the phytoplankton decline, followed in turn by increased phytoplankton growth associated with new nitrogen inputs from N_2 fixation.

When the model is tuned to observed biomasses of phytoplankton and *Trichodesmium*, atmospheric nitrogen is fixed at the rate of 14.7 x 10^{11} moles of nitrogen per year (mol N/yr) over the Atlantic basin. This rate is comparable to direct estimates of 10 to 15 x 10^{11} mol N/yr reported by Capone in a 1997 article in *Science*, but it is significantly less than the indirect geochemical estimates of 20 x 10^{11} mol N/yr reported by Nicolas Gruber and Jorge Sarmiento in *Global Biogeochemical Cycles* in 1997. This nitrogen fixation does not supplement upwelled nitrate sufficiently to bring the model's phytoplankton production rates and new production estimates into line with remote and geochemical estimates. However, the increases are substantial; new production is increased by 25% and total production by 5%.

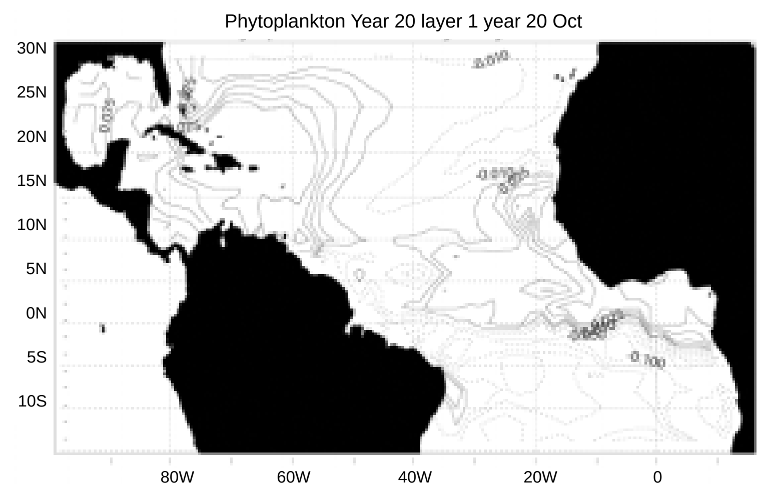

Figure 2: Point-to-point differences between phytoplankton biomass in model simulations with and without *Trichodesmium* in the Atlantic during October. Positive values (solid lines) indicate regions where phytoplankton concentrations are higher in the simulation with N_2 fixation, and negative values (dotted lines) indicate regions where they are lower. The units are differences in chlorophyll concentration in milligrams per cubic meter.

How important is the explicit representation of populations or functional groups that fix nitrogen in the planktonic food web? From a dynamic perspective, this question is interesting because diazotrophs in general and *Trichodesmium* in particular have two forms of nonlinear interaction with phytoplankton, as noted above: a negative feedback resulting from competition for light, and a positive one associated with the input of nitrogen. The role of *Trichodesmium*, as demonstrated by the model, goes well beyond increasing the input of nitrogen to the euphotic zone. It also mediates the spatial and temporal variability of the nitrogen inputs.

Figure 2 shows that the coupled physical-biological model generates very different patterns in phytoplankton biomass and productivity with and without *Trichodesmium*. The regional differences between the two runs are closely linked to positive feedbacks between the inputs of

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Atmospheric CO_2, The Ventilated Thermocline And Ocean Carbon-Cycle Models

by Mick Follows and Takamitsu Ito

Our view of the ocean carbon cycle has been shaped, illustrated and explored extensively with the help of highly idealized box models (Figure 1a). For example, results from the "Harvardton Bear" models, developed in the 1980s by groups at Harvard, Princeton and Berne universities, showed how a drawdown of sea-surface nutrients in the high latitudes might be sufficient to induce changes in the partial pressure of carbon dioxide (pCO_2) in the atmosphere comparable to those recorded in ice cores.

While simulations with simplified box models have supported the notion of a powerful high-latitude ocean control on atmospheric pCO_2, they have also been interpreted as suggesting that the low-latitude surface ocean has a negligible effect. For example, they indicate that atmospheric pCO_2 would change very little if sea-surface temperature changed (all else being equal) in the tropical and subtropical ocean.

In recent years it has become feasible to combine three-dimensional ocean circulation models with parameterizations of nutrient and carbon cycles, allowing more detailed and perhaps more realistic ocean carbon-cycle models. An example of results from this type of model is given in Figure 1b.

In recently published studies, Wallace Broecker of Lamont-Doherty Earth Observatory, David Archer of the University of Chicago and their colleagues have compared box models of the ocean carbon cycle with three-dimensional models with some provocative results. Atmospheric pCO_2 appears to be less sensitive to the drawdown of high-latitude surface nutrients in the three-dimensional models than in box models. Conversely, atmospheric pCO_2 in the general circulation models (GCMs) is much more sensitive to perturbations of low-latitude surface ocean properties.

These comparisons raise some significant questions: Is high-latitude nutrient drawdown really a single mechanism for driving glacial-interglacial changes in atmospheric pCO_2? Could low-latitude processes actually play a more significant role in regulating atmospheric pCO_2?

It is important that we understand why these different types of model have different sensitivities if they are to help us understand the ocean. With our colleague Jochem Marotzke of Southampton Oceanography Centre, we have reexamined the role of lower-latitude ocean processes in controlling atmospheric pCO_2. We believe that the increased effect of warm surface-water properties on atmospheric pCO_2 levels in three-dimensional models is linked to the explicit representation of the wind-driven ocean gyres and the ventilated thermocline.

The action of winds on the ocean basins leads to the formation of the cyclonic subpolar and anticyclonic subtropical gyres. In the subtropical gyres, Ekman pumping and geostrophic flow through the sloping winter mixed-layer base close to the subtropical/subpolar boundary subduct relatively warm surface waters into the ventilated thermocline. The thermocline thus forms a significant carbon reservoir, screened from the atmosphere and formed from warm, mid-latitude surface waters that are depleted in carbon.

We have tested this hypothesis with a variety of models, particularly a basin-scale ocean circulation and carbon-cycle model with a simple atmospheric carbon reservoir. This intermediate model represents the ocean as a single, closed basin with an abiotic carbon cycle. All our experiments with this model have thermohaline forcing. We run model simulations both with and without wind-stress forcing, resulting in significantly different circulation, temperature structure (Figure 2) and sensitivity of atmospheric pCO_2 to low-latitude surface properties in the simulations.

Perturbation experiments with this model reveal the sensitivity of the atmospheric pCO_2 to low-latitude and subtropical surface-water properties. In our experiments, sea-surface inorganic carbonate chemistry coefficients are perturbed as

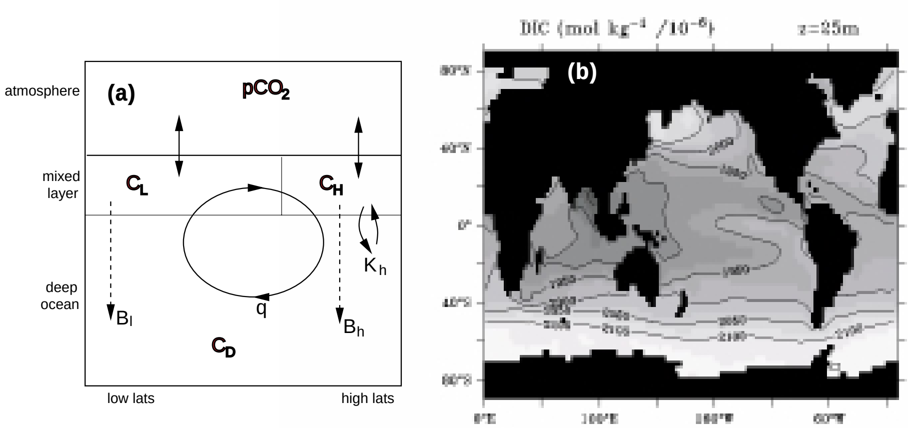

Figure 1: Why do different types of ocean carbon-cycle models exhibit different sensitivities to surface ocean processes? (a) Schematic depiction of an ocean carbon-cycle box model. (b) Simulation of global sea-surface dissolved inorganic carbon (DIC) with an ocean carbon-cycle model based upon a general circulation model.

though a 5°C rise in sea-surface temperature had taken place between the equator and 45° north and south latitude, and the model is integrated to a new steady state. Introducing wind forcing enhances the sensitivity of atmospheric pCO_2 to perturbations of the low-latitude surface waters by a factor of two (Figure 3).

We consider our no-wind experiments to be analogous to simulations with box models, which typically do not represent the ventilated thermocline, thus explaining their weak sensitivity to low-latitude processes. To illustrate this, we modify the classical three-box ocean model of Figure 1a, adding a box representing the ventilated thermocline and separating the low-latitude surface ocean into tropical upwelling and subtropical downwelling regions. In runs of this five-box model, we also switch on and off the Ekman circulation associated with wind forcing and mimic our experiments with the basin model.

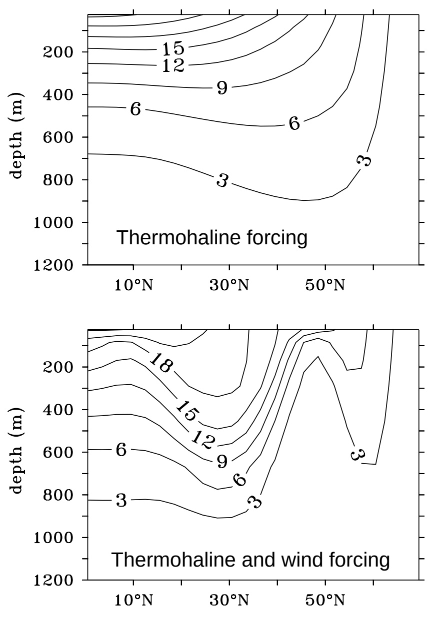

Figure 2: Upper-ocean temperature structure generated by an ocean general circulation and abiotic carbon-cycle model for an idealized ocean basin. The top panel shows the shallow diffusive thermocline that forms in the absence of wind forcing. The bottom panel depicts the solution with wind forcing in which the warm lens of the ventilated thermocline is evident in the subtropics.

To tie it all together, we have performed a similar perturbation experiment with a coarse-resolution, abiotic global carbon-cycle model similar to the one illustrated in Figure 1b. The results of all of our sensitivity experiments are summarized in Figure 3. All the models with wind forcing show sensitivities similar to that of the global GCM, and the models without winds or a ventilated thermocline behave like a classic three-box model.

Why are the models with wind forcing so much more sensitive? The subtropical ventilated thermocline represents a significant body of water, some hundreds of meters thick and extending over a large area. Its properties reflect those of the mid-latitude surface waters from which it is formed. This reservoir of carbon is shielded from the atmosphere by the overlying mixed layer and by relatively weak diapycnal mixing rates. Thus the ventilated thermocline acts as a smaller and warmer analog of the deep ocean reservoir in the classical three-box ocean carbon-cycle models.

Might the ventilated thermocline be significant in the changes that occur between glacial and inter-glacial eras? There is some evidence that the North Atlantic thermocline and mid-latitude sea surface was about 4°C cooler during the last glacial maximum. If this were representative of a global-scale change, a crude extrapolation from the model results suggests that changes in the thermocline solubility pump might account for glacial-era decreases in atmospheric pCO_2 on the order of 15 microatmospheres. Thus the ventilated thermocline is an unlikely candidate as a major control on glacial-interglacial changes in atmospheric pCO_2. It is possible that Southern Ocean water masses, such as Subantarctic Mode Water or Antarctic Intermediate Water, exert an analogous and more significant influence on the atmosphere.

We believe that we have been able

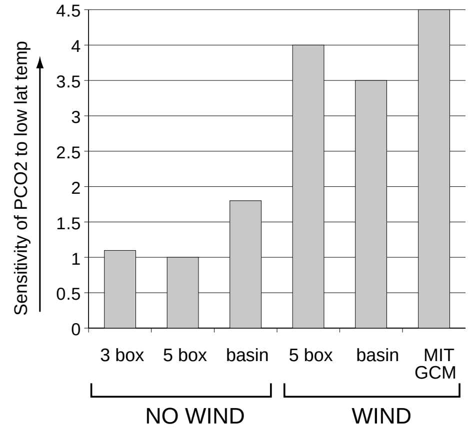

Figure 3: The sensitivity of atmospheric pCO_2 to low-latitude sea-surface temperature perturbations in a variety of ocean carbon-cycle models. The bars represent an index (microatmospheres/K) of the response in atmospheric pCO_2 to a unit temperature change in tropical and subtropical surface waters with a fixed circulation. A larger index indicates more sensitivity. In this set of experiments, we find that the models fall into two broad categories. Those without representation of wind-driven circulation have a low sensitivity index, and those with a wind-driven circulation have a high sensitivity index. The presence or absence of a ventilated thermocline is the important factor here, not whether the model is a box model or a GCM.

to reconcile the discrepancy in sensitivities of atmospheric pCO_2 to low-latitude surface ocean properties in a variety of models. More information on this project is available at **http://puddle.mit.edu/~mick**. The question of why GCMs show less response to the drawdown of high-latitude surface nutrients than box models do is still open. This may also be related to the wind-driven circulation that exerts a strong influence on nutrient distributions and patterns of ocean productivity. This is an active area of modeling research that we are sure to hear more about in the near future.❖

(Editor's note: The authors are in the Department of Earth, Atmospheric and Planetary Sciences at the Massachusetts Institute of Technology.)

An Update On Data Management In U.S. JGOFS

by David M. Glover and Cynthia L. Chandler

Changes have taken place at the U.S. JGOFS Data Management Office (DMO) during the last year as new players have joined the team, new projects have gotten underway, and new products have started to appear. With the final round of funding in place, the DMO is also working on plans for production of a final data product, such as a set of CD-ROMs, and for long-term archiving of the data amassed during the U.S. JGOFS field programs and the Synthesis and Modeling Project (SMP).

After many years of stalwart service to the DMO, data manager Christine Hammond has moved into an administrative position with the Woods Hole Oceanographic Institution (WHOI) computer and information services department. Her U.S. JGOFS responsibilities have been divided between two new staff members. David Glover of the WHOI Department of Marine Chemistry and Geochemistry has taken over the scientific direction of the DMO, and information systems associate Cynthia Chandler has taken charge of system management and programming. David Schneider continues to work with scientists who submit their data to the DMO and to carry out data verification and quality-assurance procedures with the help of George Heimerdinger, who has come out of retirement to assist the DMO with the final phase of data readiness.

For a long time, the duties of the U.S. JGOFS DMO centered primarily around the receipt and quality control of field data. This work produced many robust data objects that are available online via the U.S. JGOFS world wide web site. A little while ago, the DMO staff started work on software to harness the powerful distributed nature of the U.S. JGOFS database engine for the production of what are referred to as merged data products. The development of these products has been underway for some months, and a limited or "beta" release is planned for January 2002. The initial merged data products will be released to the public following the successful review of the beta release.

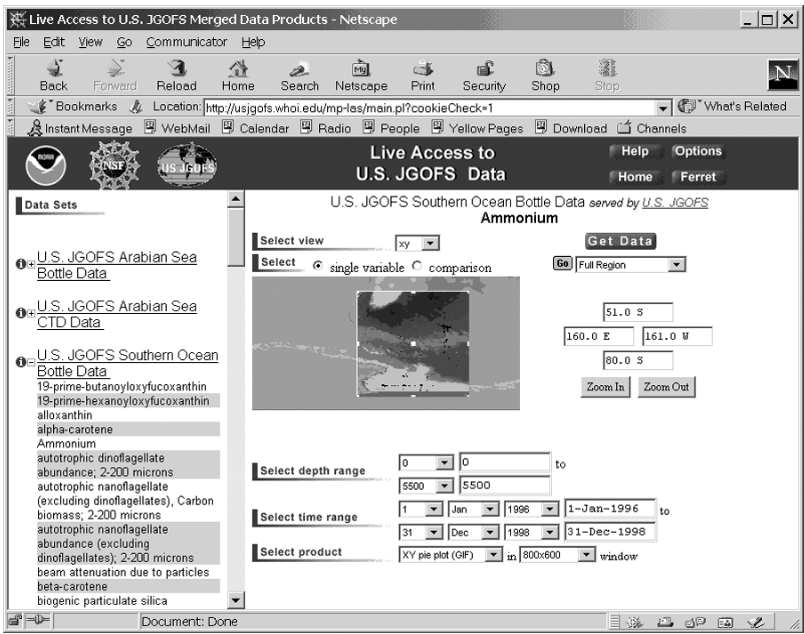

Figure 1: The U.S. JGOFS customized live access server (J-LAS) will be available for testing early next year. It will provide access to merged products from U.S. JGOFS process-study data. Users will be able to select parameters from lists of available data sets and set time and space limits before viewing the results in a variety of formats.

The merged products are produced by combining data objects that have common variables and collection methods to form larger data sets. We are currently producing both CTD and bottle merged data products for the Arabian Sea and Southern Ocean process studies; merged data products for the Equatorial Pacific Process Study and the North Atlantic Bloom Experiment are under development.

The process starts with the merging of related data objects from a given cruise into a single cruise-level object. Cruise-level objects are merged, in turn, into basin-level objects. Although the production of global-level merged data objects is under consideration, there is no plan to do so at the moment because of the disparate time periods involved.

In building the merged products, we are taking advantage of features of the database management system (DBMS) developed for U.S. JGOFS by Glenn Flierl of Massachusetts Institute of Technology, James Bishop of Lawrence Berkeley National Laboratory and David Glover of WHOI in the early days of the program. We use the DBMS "join" function to create the merged objects guided by the "pointer" files, laboriously prepared by Schneider and Heimerdinger, that point to the variables in each data object to be joined.

Logically the merged data products are not so much a union of data objects as they are a projection of the smaller data object into the larger data object space. All data that go into merged objects must have been collected by the same sampling device with the same methodology. This may cause problems with regard to investigators who collected water samples from both CTD and trace-metal-clean sample bottles. The solution is simply to create an additional merged product that combines data from both sampling systems.

After all of the data from the same sampling device have been identified at either the cruise or the basin level, the merge commences. If the event, station and bottle numbers are the same, the data are placed in the same row. If the variable name and methodology are the same, they are placed in the same column. An audit file keeps track of any mismatched attributes, such as units, and the DMO staff tracks down and resolves the mismatch.

One of the new projects undertaken by the DMO is the support of results from SMP projects. Because of the gridded nature and larger volume of output from modeling studies, the DMO is working with the Live Access Server (LAS) group at the University of Washington and the National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory in Seattle to provide a visualization and access interface for these results. The SMP data products must be in a format that is compatible with the LAS. Fortunately the preferred LAS format is netCDF, which is already used for storing many of the gridded SMP data products.

The LAS was not originally designed for work with non-gridded data sets. In an exciting collaboration, the programmers in Seattle and Woods Hole are putting together the additional modules necessary to allow LAS to work with profile data. This development comes at a time when the much larger merged data products are becoming available (Figure 1). The combination will allow scientists to navigate and visualize the merged data products in a much more convenient and rapid manner. In addition, SMP data products that are not gridded can, very likely, use this new capability of the JGOFS LAS. Clients will eventually be able to get access to merged process-study data sets and SMP data products via the same interface.

Farther down the road, new merged data products will be designed and produced, the SMP data products will be received and put on line, and a final data product will be produced and archived. The best way to ensure that users can get access to the U.S. JGOFS database long after the web interface has gone offline is to produce a product that contains all of the pertinent data on a semi-permanent medium. In the next year or two, we plan to identify all of the U.S. JGOFS data that should be saved long term as well as a storage medium that lends itself to mass production. The final product will be made available without charge to anyone who asks for it.

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A New Interface For U.S. JGOFS Data

by Steve Hankin, Jonathan Callahan and Joe Sirott

The Live Access Server (LAS), developed at the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory (PMEL), has been providing a means of visualizing, reformatting and selecting subsets of multi-dimensional scientific data for World Wide Web users since 1994 (**http://ferret.wrc.noaa.gov/Ferret/LAS/**). The initial priorities in designing the LAS were to reduce barriers erected by the size, location and format of files for investigators who wanted to get access to gridded data sets.

Visualization makes it possible to explore any given data set in a variety of ways with a web browser. Should further analysis be desirable, the subsetting capacity allows the investigator to download small units of data that move efficiently over the Internet. Reformatting makes it simple to incorporate data into the desktop environment.

Recent work on the LAS has focused on support for groups of collaborating researchers at disparate locations. LAS supports collaborations by providing common access to reference data sets, shared access to distributed data sets, and the ability to compare distributed data holdings.

The LAS creates a shared virtual data base as a natural extension of its modular design. LAS sites installed at separate locations exchange copies of the metadata that describe the data sets they serve, making each aware of the data sets held by the others. Each is able to direct users' requests to the LAS that serves a particular data set.

The goal of collaborative research is to create a whole that is greater than the sum of its parts. Data systems can support this goal by bringing information from distributed data sets together for merged calculations. Binary-level access to remote data sets is provided by the distributed ocean data system or DODS. The most extensive collection of distributed ocean data available through LAS is available via the Virtual Ocean Data Hub (VODHub) at **http://ferret.wrc.noaa.gov/nopp/** .

The LAS is currently used by U.S. JGOFS to provide access to gridded data sets, where data points are fairly regularly distributed in time and space (**http://usjgofs.whoi.edu/las/**). As part of a collaboration among staff members at the University of Washington, PMEL and the U.S. JGOFS Data Management Office in Woods Hole, LAS capacities will be extended to provide the same sort of access to non-gridded data, either from field studies or from the U.S. JGOFS Synthesis and Modeling Project. We expect to release a "beta" version of this system early next year.

(Editor's note: Steve Hankin is at the NOAA Pacific Marine Environmental Laboratory in Seattle, and Jonathan Callahan and Joe Sirott are at the Joint Institute for the Study of the Atmosphere and Ocean, University of Washington.)

U.S. JGOFS SMP Investigators Gather For Summer Meeting

by Scott C. Doney and Joan A. Kleypas

Some 80 investigators and students participated in the fourth annual summer workshop of U.S. JGOFS Synthesis and Modeling Project (SMP), held in mid July at Woods Hole Oceanographic Institution (WHOI). Attendees also included several invited speakers and agency representatives.

Now in its fifth year, the SMP comprises 38 active projects and 22 that have been completed (Figure 1). The emphasis at the July meeting was on providing a forum for principal investigators to present their results and plans for future research. Although only a few highlights are noted here, abstracts for all talks and posters presented at the meeting are available via the U.S. JGOFS web site (**http://usjgofs.whoi.edu/mzweb/whoi_agenda_2001.html**).

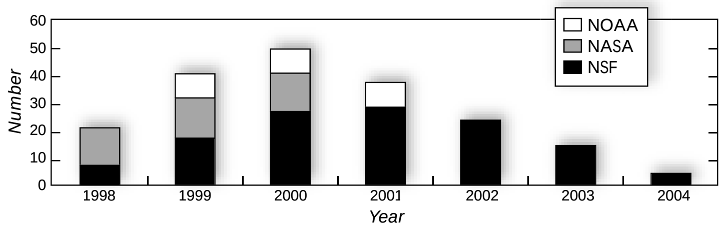

Figure 1: Number of SMP projects supported each year. Number of new projects to be funded on the final round in FY 2002 is expected to be five.

In the session on euphotic zone production and export, Edward Laws of the University of Hawaii reviewed the development of ideas about energy flow in ecosystems and their applicability to ocean food-web models. Michael Lizotte of Bigelow Laboratory presented results from high-performance liquid chromatography methods showing variation in phytoplankton community structure, which can in turn affect element ratios, nutrient utilization and bio-optical properties. James Christian, University of Maryland, discussed the importance of variable elemental stoichiometry in carbon-cycle models for accurate characterization of nutrient limitation. Michael Roman of Horn Point Environmental Laboratory offered an interesting explanation as to why mesozooplankton production at the Bermuda Atlantic Time-series Study (BATS) site is lower than it is at the Hawaii Ocean Time-series (HOT) site, despite similar levels of primary production.

The effects of processes in the subsurface "twilight zone," sediments and continental margins on the ocean carbon cycle are not well known. Talks in this session highlighted questions about export and remineralization. Ken Buesseler of WHOI offered explanations for the mismatch in export fluxes measured via sediment traps versus thorium-234. George Jackson of Texas A&M University (TAMU) demonstrated that particle aggregation could explain how a significant portion of export can occur in pulse events. Bill Martin of WHOI addressed the problem of organic matter remineralization in sediments. His model simulations indicate that high organic rain rates actually inhibit rather than enhance calcium carbonate ($CaCO_3$) dissolution in sediments, as previously thought.

Rick Jahnke of Skidaway Institute of Oceanography compared remotely sensed measurements of surface-ocean production with those of seafloor oxygen flux. One result is that the high surface ocean fluxes of the equatorial Pacific are not reflected in the sediments. Another is that the efficiency with which organic carbon is transferred to the sediments varies dramatically among regions. Low latitudes show much higher efficiency than high latitudes, and efficiency along the continental margins is 50 times greater than it is within mid-ocean gyres.

Continental margins were also featured in a talk by James Bauer of the Virginia Institute of Marine Science on the synthesis and modeling phase of the Ocean Margins Program. Major conclusions are that northwest Atlantic margin waters are a net sink for carbon dioxide (CO_2); that much of the dissolved organic carbon (DOC) and particulate organic carbon (POC) in shelf and shallow slope waters have both marine and terrestrial origins, and that 80% of the carbon export from shelf to open ocean is in the form of DOC.

In the session on satellite data and basin-scale biogeochemical modeling, Mary-Elena Carr of the Jet Propulsion Laboratory compared CO_2 exchange coefficients derived from two wind sensors. James Yoder, now at the National Science Foundation, presented a global chlorophyll data set with 8-day resolution amassed from SeaWiFS observations over three years. His analysis showed that six modes, such as the seasonal cycle and El Niño-Southern Oscillation (ENSO) variability, explain 70% of the variability in ocean chlorophyll patterns.

Dave Siegel of University of California (UC) at Santa Barbara also used SeaWiFS imagery, combined with field and model data, to test Harald Sverdrup's hypothesis that phytoplankton bloom in the spring when the mixed layer shoals to a certain depth. Although the poleward progression of the spring bloom suggests large variations in critical depth, the so-called compensation irradiance appears to be more uniform, supporting the basic hypothesis. Mick Follows of Massachusetts Institute of Technology looked specifically for factors associated with the North Atlantic spring bloom. He showed that subtropical blooms appear to respond to enhanced mixing, while subpolar blooms are largely modulated by factors such as changes in insolation, local mesoscale variability and grazing.

Nicolas Gruber of UC Los Angeles demonstrated with a box model how the North Atlantic Oscillation (NAO) influences CO_2 uptake in the North Atlantic. During negative NAO conditions, stronger winter convection in the nutrient-limited subtropics and weaker winter convection in the light-limited subpolar gyres both appear to contribute to greater net CO_2 uptake over the basin.

Reports from the SMP workshop on marine calcification last spring are reasserting the vital role of $CaCO_3$ as well as silica in the marine carbon cycle. In his analysis of CO_2 survey data from the Pacific, Richard Feely from the NOAA Pacific Marine Environmental Laboratory noted that up to 70% of $CaCO_3$ produced in the euphotic zone is dissolved above the calcite lysocline. Jorge Sarmiento of Princeton University pointed out that the ratio of $CaCO_3$ to organic carbon necessary to produce current ocean alkalinity distributions is probably much lower than the ratios typically used in older ocean biogeochemical models.

Princeton scientist Katsumi Matsumoto discussed the potential effect of silica on the global carbon cycle. His box-model results show that reduced silicic acid uptake in the southern ocean during the last glacial maximum could have led to increased silica supply to other oceans, resulting in a shift towards a plankton community dominated by diatoms and a lower ratio of $CaCO_3$ to organic carbon.

Like its predecessors, the SMP meeting provided a showcase for newly compiled global data sets. Christopher Sabine of the University of Washington (UW) gave an update on the synthesis of global CO_2 survey data, which is complete for the Indian and Pacific oceans and well underway for the Atlantic. Paulette Murphy of the National Oceanographic Data Center summarized the ongoing synthesis of carbon system parameters into a global database that includes historical data as well as CO_2 survey data. Alexey Mishonov and Wilf Gardner, TAMU, provided an update on their transmissometer-based POC data set.

During the session on CO_2 transport and storage, Alison Macdonald from WHOI showed that southward transport of carbon in the Atlantic has weakened since the preindustrial era. In his talk on the location of the "carbon equator," Paul Robbins of Scripps Institution of Oceanography pointed out that a major impediment to understanding interhemispheric carbon transport is the offset between the atmospheric and oceanic equators.

In the concluding session on global-scale modeling, Follows looked at why general circulation models show a higher sensitivity in pCO_2 levels to low-latitude perturbations than do box models (see article in this issue). He concluded that the difference has to do largely with the absence of wind-driven circulation in box models. Watson Gregg, NASA Goddard Space Flight Center, used a coupled, three-dimensional GCM/biogeochemistry/radiative model to see how changes in cloud cover and cloud liquid water affect primary production.

Raymond Najjar of Pennsylvania State University presented results from the Ocean Carbon-cycle Model Intercomparison Project that showed progress on the analysis and interpretation of a suite of tracer and carbon-cycle simulations among a dozen general circulation models. Striking differences in the physical circulation of the models show up in the predicted patterns of chlorofluorocarbon (CFC) and anthropogenic carbon uptake and the global integral of new production.

Sarmiento summarized results of coupled ocean-atmosphere climate simulations from six different models with an emphasis on how future changes in ocean circulation are likely to affect marine ecosystems. He concluded that decreased upwelling along western boundary currents and increased stratification in subtropical gyres will make possible an expansion of the oligotrophic gyres and decreased biological production in the future, whereas higher latitudes may have increased production because of reductions in light limitation.

Scott Doney of the National Center for Atmospheric Research looked at CFC-11 distributions in variants of the NCAR ocean model to examine the controls on the formation of Antarctic Bottom Water. He showed how incorporation of a simple bottom boundary-layer scheme combined with small adjustments in surface salinities improved the deep-water distribution of CFC-11.

The workshop program included two invited talks. Taro Takahashi of Lamont-Doherty Earth Observatory provided an updated seasonal reconstruction of air-sea CO_2 fluxes and a discussion of the associated physical and biological driving factors. James Bishop of Lawrence Berkeley National Laboratory discussed new instrumentation that can measure multiple carbon parameters and can be fitted to existing ARGO floats that transmit data via satellite at programmable intervals.

The U.S. JGOFS Data Management Office (DMO) is now actively collaborating with the UW/PMEL team of Christopher Sabine and Steven Hankin on the development of JGOFS Live Access Server (LAS) capabilities. Cyndy Chandler of the DMO presented an overview of the many new tools now available for accessing and retrieving JGOFS data, including the creation of "merged" data sets for each of the U.S. JGOFS process studies. These merged data can be displayed, subsampled and downloaded via the LAS, which can display discrete data along various dimensions.

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SMP Workshop Assesses Role Of Calcification In Ocean Carbon Cycle

by Debora Iglesias-Rodriguez, Robert Armstrong, Richard Feely, Raleigh Hood and Joan Kleypas

An interdisciplinary group of 35 scientists met at Woods Hole Oceanographic Institution (WHOI) last spring to discuss the role of calcification in the ocean carbon cycle. The goals of the U.S. JGOFS Synthesis and Modeling Project (SMP) workshop were to:

- synthesize our understanding of the mechanisms of production, sedimentation, dissolution and preservation of calcium carbonate ($CaCO_3$) in the ocean;
- compare global spatial and temporal patterns in carbon system parameters such as alkalinity, pH and total carbon dioxide (CO_2);
- compare approaches for estimating $CaCO_3$ fluxes, and
- develop parameterizations for processes that can be incorporated into models.

The first day of the workshop was devoted to the biology of the marine producers of $CaCO_3$, including coccolithophorids, foraminifera and corals. Participants spent the second day reviewing marine carbonate system budgets. On the final day, three plenary talks provided context for a discussion in which ideas were synthesized and recommendations made.

In the open ocean, calcifying organisms include coccolithophorids, planktonic foraminifera and pteropods, while in neritic environments most $CaCO_3$ production is carried out on the sea floor by coralline algae, corals, foraminifera, mollusks and bryozoans. Satellite data suggest that open-ocean coccolithophorid blooms are confined to high latitudes and are largely represented by *Emiliania huxleyi*, while *in-situ* data suggest that species such as *Coccolithus pelagicus* in the North Atlantic or *Florisphaera profunda* in tropical regions, may be important in the global $CaCO_3$ budget. In some ocean basins, zooplankton may account for as much as 60% of the total $CaCO_3$ flux.

Scientific highlights

Modeling efforts have concentrated on *Emiliana huxleyi* as the main contributor to open-ocean $CaCO_3$ flux. However, recent estimates indicate that this organism may contribute only a small part of the global carbonate production. Foramifera and pteropods are major $CaCO_3$ producers, yet the mechanisms governing their calcification, dissolution and occurrence are poorly known. As it is likely that major calcifiers in a region will shift in response to future environmental change, it is important to understand how such shifts will affect the overall ocean carbon cycle.

Many biogeochemical models use export ratios of organic carbon to $CaCO_3$ (the "rain ratio") on the order of 4 or 5. One presentation at the workshop reexamined these ratios and concluded that an export ratio of 15 is a more realistic estimate. An increase in the export ratio would result in more carbon storage in the deep sea. A decrease in the rain ratio could increase pH and the ocean's capacity to take up CO_2.

The gradient in the rain ratio with depth can change significantly, depending on the organisms involved. Large foraminifera, for example, can calcify below the euphotic zone, and their tests may have much higher sinking rates than those of coccoliths. Biological packaging and particle size also have an effect on dissolution rate, sinking rate dynamics and preservation of particles containing $CaCO_3$.

Coralline algae, corals and coccoliths are showing reduced calcification as the partial pressure of CO_2 (pCO_2) in the atmosphere increases and ocean carbonate ion concentrations are reduced. In addition, this change may bring about a shift in the phytoplankton community in favor of non-calcifying organisms.

In a talk on the role of ballast in export carbon fluxes, evidence was presented that the proportion of organic carbon to ballast reaches an asymptotic ratio with depth and that this relationship can be used to predict carbon flux to the sea floor. Differing views were expressed on whether silicate or $CaCO_3$ was the more efficient ballast material for transporting carbon.

Several talks addressed rates and depths of dissolution. Data from the Pacific Ocean show that up to 70% of $CaCO_3$ production is dissolved before material is buried in the sediments, and half of this dissolution occurs in the upper 1,300 meters. The more soluble carbonate phases tend to dissolve quite readily, and the least soluble carbonates remain preserved during transit to the sea floor. There remain, however, discrepancies between dissolution rates estimated from alkalinity-based measurements versus trap-based and seafloor sediment dissolution measurements.

A final focus of discussion was the flux of neritic $CaCO_3$ to the slope and deep sea. This flux is significant and could be important to both carbon burial and overall alkalinity flux in the deep ocean. Most carbonate production on continental shelves is benthic and remains uncharted for many shelf regions.

The workshop produced a number of recommendations for both modeling and field studies:

Synthesis and modeling studies

- Elucidate rates of $CaCO_3$ production and export, dissolution and remineralization to provide input for model parameterizations
- Determine mechanisms that control dissolution of ballast minerals and the relative importance of size fraction and biological packaging in ballasting
- Characterize differences in $CaCO_3$ production rates between

tropical and high-latitude coccolithophorid populations and the effect of species composition on fluxes

• Characterize the effect of grazing and biological repackaging on $CaCO_3$ dissolution and export

• Synthesize global CO_2, alkalinity, sediment trap and benthic data, and resolve discrepancies between alkalinity-based measurements and sediment-trap results for $CaCO_3$ dissolution in the ocean

Experiments and measurements

• Measure $CaCO_3$ fluxes from shelf to open ocean, combining satellite, profiling-float and sediment-trap measurements

• Establish time-series programs in representative areas for calcification, including the tropics

• Study the genetic basis of calcification and the genetic vs. physiological diversity of calcifying organisms

• Focus on understanding the mechanisms controlling the relative abundance of diatoms and coccolithophorids

• Analyze sediment trap records to determine fluxes of pteropod, foraminifera, diatom and coccolithophorid content, particulate inorganic carbon, fragments and ballast

• Characterize sinking rate dynamics of particles of different size, chemical composition and biological packaging

• Characterize spatial and temporal variability in rain ratio

• Obtain global coverage of benthic carbonate dissolution measurements

Conclusions

Although budgets are still being revised, it is evident that production, export and dissolution of $CaCO_3$ are higher than previously thought and that most of the accumulation of $CaCO_3$ is occurring on continental shelves. Evidence is also growing that export ratios of organic carbon to $CaCO_3$ are generally higher than previously assumed. And the potential importance of both silica and $CaCO_3$ as ballast for the export of organic carbon from the upper ocean is becoming evident.

Modeling $CaCO_3$ formation and dissolution in the oceans is a complicated problem. Simulating the time and space variability of *Emiliana huxleyi* calcite production and export, though a considerable challenge, will not be enough. We now know that zooplankton (foraminifera and pteropods) contribute to calcite flux and have a strong influence on when and where $CaCO_3$ is remineralized through processing and repackaging. Much of this activity is occurring just below the euphotic zone, where we have few measurements.

Increasing pCO_2 levels are likely to inhibit calcification in coral reefs and the open ocean in the future. However, changes in the dominance and distribution of $CaCO_3$ producers and consumers may have a larger effect on the oceanic $CaCO_3$ budget than thermodynamics. Much experimental and observational work must be done before we can tackle these issues in models and predict the future with any degree of certainty.

An in-depth workshop report is available at **http://usjgofs.whoi.edu/mzweb/caco3_rpt.html**❖

Workshop Participants

Debora Iglesias-Rodriguez, *University of Bristol, U.K. (chair)*
David Archer, *University of Chicago*
Robert Armstrong, *State University of New York at Stony Brook*
Marie-Pierre Aubry, *Rutgers University and WHOI*
Will Berelson, *University of Southern California*
James Bishop, *Lawrence Berkeley National Laboratory*
Robert Byrne, *University of South Florida*
Lei Chou, *Université Libre de Bruxelles, Belgium*
Lisa Dilling, *NOAA, Office of Global Programs*
Richard A. Feely, *NOAA Pacific Marine Environmental Laboratory*
Nicolas Gruber, *University of California at Los Angeles*
Christopher Guay, *Lawrence Berkeley National Laboratory*
Patrick Holligan, *Southampton Oceanography Center, U.K.*
Susumu Honjo, *Woods Hole Oceanographic Institution*
Raleigh Hood, *Horn Point Laboratory*
Anitra Ingalls, *State University of New York at Stony Brook*
Richard Jahnke, *Skidaway Institute of Oceanography*
Christine Klaas, *University of Chicago*
Joan Kleypas, *National Center for Atmospheric Research*
Edward Laws, *University of Hawaii*
Kitack Lee, *NOAA Atlantic Oceanographic and Meteorological Laboratory*
Michael Lizotte, *Bigelow Laboratory for Ocean Sciences*
Linda Medlin, *Alfred Wegener Institute, Germany*
John Milliman, *Virginia Institute of Marine Sciences*
Raymond Najjar, *Pennsylvania State University*
Warren Prell, *Brown University*
Ros Rickaby, *Harvard University*
Yair Rosenthal, *Rutgers University*
Christopher Sabine, *University of Washington*
Jorge Sarmiento, *Princeton University*
Kozo Takahashi, *Kyushu University, Japan*
Philippe Tortell, *Princeton University*
Toby Tyrrell, *Southampton Oceanography Center, U.K.*
Colomban de Vargas, *Harvard University*
Peter Verity, *Skidaway Institute of Oceanography*
Peter Westbroek, *Leiden Institute of Chemistry, The Netherlands*

Data Management – from page 6

At the same time a final submission of these data will be prepared for the NOAA National Oceanographic Data Center (NODC). By mandate of Congresss, NOAA is responsible for the long-term archival storage of oceanographic and other scientific data produced with federal dollars.

Both the final data product and the long-term archive will include all of the U.S. JGOFS process study field data as well as all data to date from the time-series studies at Bermuda and Hawaii. All of the web interface and DBMS software will be included as well. Because of the volume, the extent of the data that will be included from SMP projects is not yet decided.❖

Repeat Hydrography Working Group Formed

by Rik Wanninkhof

The steering committees of the U.S. Climate Variability and Predictability (CLIVAR) study and the U.S. Carbon Cycle Science Program have established a working group to make recommendations for a joint program of hydrographic sections. The charge of the working group is to plan repeat observations along certain of the World Ocean Circulation Experiment (WOCE) Hydrographic Programme lines. The scientific focus is on documenting changes in hydrography, ocean carbon dioxide system parameters, and compounds that serve as tracers for ventilation of water masses on decadal time scales.

Recommendations are being formulated in consultation with program managers at the National Science Foundation (NSF) and the National Oceanic and Atmospheric Administration (NOAA). The scale of the program will be on the order of one to two cruises a year, covering all major basins in close coordination with international hydrography studies and large-scale carbon programs.

The working group has made recommendations on which core measurements should be performed on all cruises, and which ancillary measurement would be desirable. It has put together a 10-year plan detailing the proposed cruises and their sequence as well as a data management plan. The current expectation is that data will be made available as close to completion of each cruise as practical without a proprietary period.

The recommendations are available online at **www.aoml.noaa.gov/ocd/repeathydro**. Comments on the plan are welcome in user forums at this site. Planning group members will provide overviews of the proposed program at workshops and national meetings.

Planning group members, who represent a diverse background in physical oceanography, biogeochemistry, observations and modeling, are:

Scott Doney, *National Center for Atmospheric Research*

Richard Feely, *NOAA Pacific Marine Environmental Laboratory*

Rana Fine, *Rosenstiel School of Marine and Atmospheric Science* (co-chair)

Nikki Gruber, *University of California at Los Angeles*

Greg Johnson, *NOAA Pacific Marine Environmental Laboratory*

Terry Joyce, *Woods Hole Oceanographic Institution*

Paul Robbins, *Scripps Institution of Oceanography*

Jim Swift, *Scripps Institution of Oceanography*

Peter Schlosser, *Lamont-Doherty Earth Observatory*

Lynne Talley, *Scripps Institution of Oceanography*

Rik Wanninkhof, *NOAA Atlantic Oceanographic and Meteorological Laboratory* (co-chair)

Modeling – from page 2

new nitrogen from N_2 fixation and phytoplankton growth. They are also linked to the negative feedback effect of phytoplankton on *Trichodesmium* through competition for light.

Once the ecosystem is perturbed by physical forces such as mixing or upwelling of nutrients, the sequence of events that follows (elevated DIN → phytoplankton growth → *Trichodesmium* growth → phytoplankton growth) is determined by the nonlinear interactions between phytoplankton and *Trichodesmium* in the food web. Although this sequence of events results from biological interactions, abiotic forcing is required to initiate it. Thus it may be essential to represent explicitly both functional groups, the phytoplankton and the N_2 fixers like *Trichodesmium*, in the ecosystem model if we are going to simulate accurately the timing and location of the effects of new nitrogen inputs from N_2 fixation.

In this project, the combination of the biogeochemical and physical perspective of the SMP with the ecological perspective of the Biocomplexity initiative is providing exciting new insights and results. We believe that a more ecological perspective could have a positive effect on SMP investigations. In fact, it may be crucial to achieve the predictive goals of the SMP. At the same time, Biocomplexity investigations would benefit from the modeling capabilities and geochemical expertise of the SMP, which are needed to answer key questions related to the effect of variable physical forcing on complex oceanic ecosystems.❖

SCIENTIFIC COMMITTEE ON OCEANIC RESEARCH

JGOFS

JOINT GLOBAL OCEAN FLUX STUDY

New JGOFS Global Synthesis Working Group Established

by Reiner Schlitzer

Ocean scientists use many different approaches to address one of the main objectives of JGOFS, which is to determine the fluxes of particulate and dissolved carbon and nutrients in the ocean and to quantify the processes that affect and modify them (Figure 1). Methods used differ in both the technology applied and the viewpoint from which the overall system is observed.

One such approach makes use of remote-sensing observations from instruments on satellites or aircraft that can observe the system from above and detect productivity signals from the upper tens of meters of the ocean. Another includes the *in-situ* measurements and process studies that provide more or less direct observations of productivity. A third employs moored or drifting sediment traps that collect sinking material in the water column for flux estimation and composition analysis. A fourth uses radionuclide measurements for better calibration of sediment trap data. And a fifth relies on benthic studies for estimating the material flux to the sea floor.

In addition, there exists a wide variety of global and regional models of differing resolution and complexity. These models simulate biogeochemical processes in the ocean and yield independent estimates for property fluxes and rate constants. The range includes high-resolution regional models with complex mixed-layer dynamics and elaborate ecosystem feedback loops that can explicitly simulate physical transport phenomena and the development of blooms on small space and time scales. It also includes a number of global models with medium resolution that are used to calculate global ocean budgets and fluxes of carbon, nutrients and oxygen. Although inverse models that derive property fluxes and rate constants from available data have been less frequently used in the past, this might change in the future as more and more JGOFS data sets become publicly available.

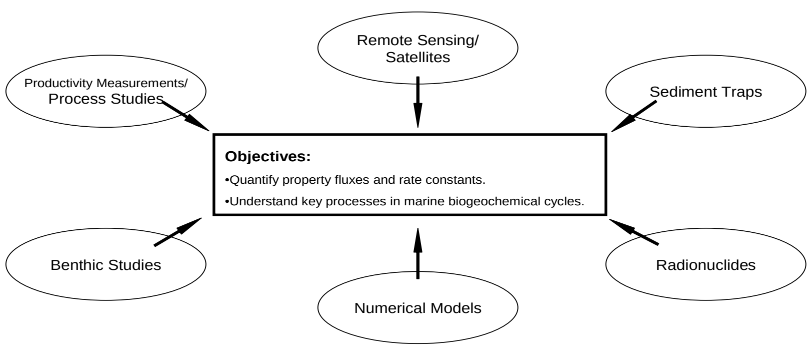

Figure 1: Key research activities addressing major JGOFS objectives

The diversity of methods for determining marine biogeochemical fluxes is fascinating, as is the important question of whether these different methods yield compatible results. With JGOFS now in the synthesis phase and the end of the programme in sight, this question is pressing. As a result, the JGOFS Scientific Steering Committee set up a Global Synthesis Working Group (GSWG) and asked Reiner Schlitzer of the Alfred Wegener Institute in Bremerhaven, Germany, to serve as its chairman.

One of the charges to the GSWG is to review and compare the results pertinent to ocean productivity, the export from the euphotic zone, and fluxes through the water column to the sediments that have been produced by the different approaches shown in Figure 1. This task requires that expertise from many research areas, including both observational and modelling approaches, be represented in the group.

The GSWG held its first meeting on July 6 at the Royal Netherlands Academy of Arts and Sciences in Amsterdam. Group members and invited speakers gave a series of overview talks addressing the various aspects of marine productivity and the vertical transport of carbon and nutrients mentioned above.

Janet Campbell from the University of New Hampshire reviewed the current status and future directions of remote sensing technologies that yield data for the estimation of primary production in the ocean. Two satellite-mounted instruments, SeaWiFS and MODIS, are currently providing global images of ocean color. Plans are underway in the U.S., Europe and Japan to deploy improved instruments with more spectral bands, better spectral resolution and better spatial or temporal sampling resolution.

Obtaining productivity values from the primary sensor data, radiance at the top of the atmosphere, requires application of atmospheric corrections and the estimation of surface-water chlorophyll or pigment concentrations as intermediate steps. Primary productivity is then obtained from the estimated surface chlorophyll values. This step involves the transformation of concentration data (chlorophyll) into rate constants (productivity), not a trivial procedure.

More than a dozen algorithms of varying complexity are now in use, all of which express productivity as a function of surface chlorophyll and a number of additional parameters, such as light availability, depth of euphotic zone and optimal water-column productivity. These free parameters have to be determined independently, which for some parameters requires *in-situ* productivity calibration measurements on a global scale.

Campbell reported on a round-robin comparison of satellite primary productivity algorithms conducted to determine the accuracy of 12 different approaches to predicting depth-integrated primary production from surface chlorophyll values. Observations at 89 stations in geographically diverse oceanic provinces were used for this comparison.

Comparisons between productivity values derived from algorithms and carbon-14 (^{14}C) uptake measurements showed deviations on the order of a factor of two. In addition, many satellite algorithms exhibited significant systematic deviations at low, medium or high productivity levels. Part of these discrepancies might be due to problems with the ^{14}C productivity measurements themselves. However, the large differences among the satellite algorithms suggest that more development and a much broader calibration database for the parameters of the algorithms is needed.

Remote sensing is undoubtedly an ideal tool for detecting spatial and temporal variability at the ocean surface because of its good spatial and temporal data coverage. But satellite-derived numerical values for ocean productivity on regional or global scales still have significant errors. Care must be taken when using them for large-scale or global budgets.

Schlitzer showed results of a comparison between carbon export fluxes from a global ocean inverse model and estimates based on satellite data. In his model, the downward particle fluxes are constrained by water-column dissolved nutrient, carbon and oxygen fields that contain structures produced by particle formation in the euphotic zone and remineralization below. Information from within as well as from below the productive surface layer is utilized in the model, while the satellite values derive from observations of surface processes alone.

Over most of the global ocean, the results from Schlitzer's model and the satellite values compare reasonably well. However, two large areas exhibit significant discrepancies independent of specific model solution or satellite field. One is in the Southern Ocean south of 50°S, where the export fluxes in the model simulations are more than two times higher than the fluxes detected from satellite instruments. Over most parts of the eastern North Atlantic, on the other hand, the model predicts much smaller carbon exports compared with satellite estimates (Figure 2).

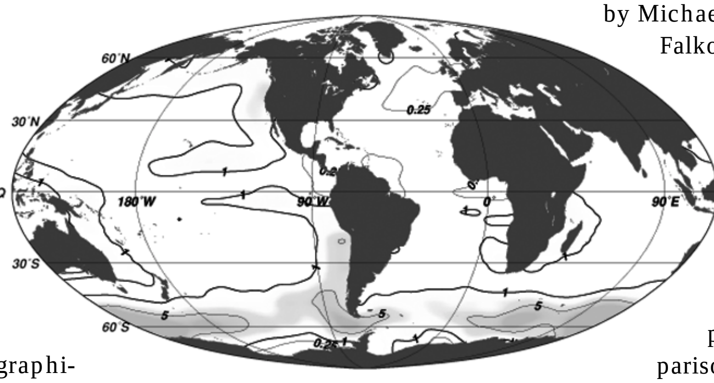

Figure 2: Global map of ratio of export fluxes of particulate organic carbon derived from inverse modeling simulations and from satellite imagery. The latter are derived from primary production estimates based on remotely sensed ocean color data.

Richard Jahnke from the Skidaway Institute of Oceanography presented maps of benthic oxygen consumption rates, which are believed to mirror the flux of organic carbon to the sea floor. He noted an overall agreement between benthic fluxes and large-scale surface productivity patterns (low in the gyres, high in the ocean margins). However, benthic fluxes are greater at low latitudes (30°S - 30°N), whereas the larger amount of primary productivity shown on satellite-based maps is at higher latitudes. As with the inverse model results, the productivity signal in the eastern North Atlantic shown in satellite maps put together by Michael Behrenfeld and Paul Falkowski of Rutgers University is not found in the benthic flux fields.

The three examples above demonstrate that, while in many cases there is a broad, qualitative agreement among different approaches, quantitative comparisons indicate significant discrepancies that deserve further study. We still have to ascertain just how productive the Southern Ocean really is. We also need to know why high primary productivity in the eastern North Atlantic does not appear produce a corresponding large benthic flux, when in other regions the two are correlated.

The GSWG is encouraging more synthesis projects aimed at combining and comparing results from different techniques. Together with the joint JGOFS-GAIM (Global Analysis, Integration and Modelling) Task Team, the GSWG is planning a workshop titled "Global Ocean Productivity and the Fluxes of Carbon and Nutrients: Combining Observations and Models." This workshop, to be held next

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Update From The JGOFS SSC

by Roger B. Hanson

Members of the JGOFS Scientific Steering Committee (SSC) held their annual meeting in early July at the Royal Netherlands Academy of Arts and Sciences in Amsterdam in conjunction with the third International Geosphere-Biosphere Programme (IGBP) Open Science Conference. As with earlier IGBP conferences in Germany and Japan, the goal was to insure the participation of a strong contingent of ocean scientists as well as to contribute JGOFS expertise, results and knowledge to the discussion of earth systems and climate change.

The SSC continues its oversight of the synthesis, interpretation, modelling and archiving of JGOFS observations. The work of JGOFS regional synthesis groups for the North Atlantic, Arabian Sea, equatorial Pacific, Southern Ocean and North Pacific is well underway, and most will finish in 2002. JGOFS scientists have published more than 2,200 peer-reviewed articles, and national and regional groups have produced, to date, some 27 special issues of *Deep-Sea Research II* on the process studies and time-series programs. Highlights from earlier articles, volumes and regional syntheses have appeared this year in two JGOFS publications for broad audiences: the *AMBIO* Special Report Number 10 on JGOFS, and "Ocean Biogeochemistry and Global Change: JGOFS Research Highlights 1988-2000," the second report in the *IGBP Science* series.

The JGOFS Open Science Conference in Bergen in April 2000 is yielding a conference book that will be published next summer in the IGBP Global Change series by Springer-Verlag. In addition, a book on the biogeochemistry of continental margins is planned for publication following a global margins synthesis workshop late next year.

Last June, representatives of JGOFS and the World Ocean Circulation Experiment (WOCE) organized a joint workshop in Southampton, UK, on ocean transport of carbon dioxide. It brought together research communities involved in assessing ocean transport and storage of carbon and nutrients, heat and fresh water. A strong proposal emerged from this meeting for a joint World Climate Research Programme (WCRP)-IGBP initiative on global hydrography (**http://clivar-search.cms.udel.edu/oceanobs/**).

With the aim of maintaining momentum and continuity through the synthesis phase of JGOFS, all at-large members of the SSC will serve until Dec. 31, 2003, when JGOFS comes to an end. These members include SSC chairman Hugh Ducklow (USA), Toshiro Saino (Japan), Huasheng Hong (China-Beijing), Peter Haugan (Norway), Robert Anderson (USA) and Bronte Tilbrook (Australia). All synthesis groups and task teams will continue until they complete their work, and their chairmen will remain on the SSC until JGOFS ends.

Global synthesis continues with a focus on modelling approaches and interpretation. A joint task team was established last spring in cooperation with the IGBP Global Analysis, Interpretation and Modelling (GAIM) initiative. This JGOFS-GAIM Task Team oversees the work of the Ocean Carbon-cycle Model Intercomparison Project (OCMIP), which focuses on advancing the development of ocean biogeochemical models.

The executive committee of the SSC also created a Global Synthesis Working Group (GSWG) earlier this year and asked Reiner Schlitzer of the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany, to serve as its chairman (see article by Schlitzer in this issue). A goal of the working group is to compare and evaluate estimates of marine productivity, sinking particle flux and water column and sediment respiration rates measured by different observational methods as well as in modelling simulations. The GSWG and JGTT are organizing a workshop on three-dimensional ocean carbon modelling and analysis to be held in Ispra, Italy, next spring.

An ongoing critical issue for JGOFS is completing the task of acquiring field data from all national programs and participating scientists. The synthesis group chairmen and Margarita Conkright, chairman of the Data Management Task Team (DMTT), are urging JGOFS investigators to submit field observations that are still outstanding to their national data centers. Another long-term goal is to make all JGOFS data available in a uniform format on CD-ROM.

The JGOFS International Project Office (IPO) continues to update and verify the inventory of JGOFS cruises since 1988. This information assists the DMTT in securing data and planning the long-term stewardship of the JGOFS data sets. The IPO is also developing a metadata catalogue that will be archived in the Global Change Master Directory of the U.S. National Aeronautics and Space Administration. When JGOFS ends, a master data set will be deposited in the World Data Center system of the International Council of Scientific Unions.

Many JGOFS meetings and workshops will be held before the end of 2003 (**http://ads.smr.uib.no/jgofs/jgofs.htm**). The SSC will meet next autumn in conjunction with a training course on ocean biogeochemistry, to be held at the University of Concepción, Chile. SSC members attending the AGU/ASLO Ocean Sciences meeting in Honolulu in February will meet there as well. The final SSC meeting will be held during the last JGOFS Open Science Conference in Washington, D.C., in May 2003.

A Note From Amsterdam

By Roger B. Hanson

In collaboration with the World Climate Research Programme (WCRP), the International Human Dimensions Programme and DIVERSITAS, the International Geosphere-Biosphere Programme (IGBP) sponsored an open science conference on global change, titled "Challenges of a Changing Earth," that drew more than 1,400 participants from a broad range of scientific disciplines to Amsterdam, The Netherlands, in mid July. Many IGBP core projects, JGOFS among them, took advantage of its attractions to hold meetings of their own in conjunction with the conference.

Faced with the impossibility of highlighting all of the excellent presentations, I would like to mention a few that I found particularly noteworthy. In his introductory talk, titled "Towards a Scientific Understanding of Global Change," IGBP scientific steering committee chairman Berrien Moore set the tone for the conference as he eloquently outlined present-day challenges to the natural systems of the earth and its inhabitants.

A theme that was woven throughout the plenary presentations on climate change concerned the range of natural variability of the earth exhibited over the last half million years and the changes at present that are well outside that range. Thomas Pedersen of the University of British Columbia presented a review of past climate change and described the stresses for human societies associated with warming, ground-water depletion and sea-level rise associated with climate change in the present era. Raymond Bradley of the University of Massachusetts continued Pedersen's arguments, stressing the enormous value of paleological proxies and sites for determining how climate has changed.

Plenary presentations by marine scientists described changes in the ocean and in its interactions with the land and the atmosphere. In "Ocean Biogeochemistry – A Sea of Change" David Karl of the University of Hawaii described ecosystem changes, such as alterations in nutrient cycles and community structure and function, that could lead to changes in net carbon storage.

Posters were organized around eight global change themes. Oceans and Coasts included posters on the Ocean Carbon-cycle Model Intercomparison Project that illustrated some of the early successes and advances in global ocean carbon modeling. Karin Lochte of the University of Kiel organized a parallel session on Oceans and Climate Change that attracted participants from many other IGBP core projects in addition to JGOFS. On behalf of the JGOFS community, the project office staff presented two synthesis posters from which a slide show was later prepared (**http://ads.smr.uib.no/jgofs/slide_show/s00.htm**).

Michael Zammit Cutajar, executive secretary of the United Nations Framework Convention on Climate Change, addressed the conference on the problems of getting the Kyoto Protocol ratified and the role that science can play in these negotiations. In advance of his address, leaders of the conference circulated an international statement titled the "Amsterdam Declaration on Global Change," which was endorsed by a majority of the conference participants. The declaration is available online at **http://www.sciconf.igbp.kva.se/Amsterdam_Declaration.html**❖

Synthesis Working Group – From page 13

spring in Ispra, Italy, is intended to foster interaction and cooperation among field investigators and modelers. It will be open to all scientists who contribute to the overall goal of determining marine productivity levels and the fluxes of carbon and nutrients. A call for abstracts will be issued in early December.

JGOFS Global Synthesis Working Group

Andreas Oschlies, *Institut für Meereskunde, Kiel, Germany*
Andrew Yool, *Southampton Oceanography Centre, U.K.*
Edward Laws, *University of Hawaii, U.S.*
Gerhard Fischer, *Universität Bremen, Germany*
Michael Behrenfeld, *Rutgers University, U.S.*
Nicolas Gruber, *University of California at Los Angeles, U.S.*
Patrick Monfray, *Institute Pierre Simon Laplace, France*
Reiner Schlitzer (chair), *Alfred Wegener Institute, Bremerhaven, Germany*
Richard Jahnke, *Skidaway Institute of Oceanography, U.S.*
Richard Matear, *Commonwealth Science and Industrial Research Organization, Australia*
Yasuhiro Yamanaka, *Institute for Global Change Research, Japan*❖

Summer Meeting – from page 8

The workshop concluded with discussion about the legacy of the SMP and the promotion of community activities. Suggestions included compilation of major findings in a synthesis book, promoting high-profile synthesis papers, and putting together workshops for students and postdoctoral scientists such as those sponsored by the NATO Advanced Study Institute. Participants agreed that more effort would be made to ensure that educators and the public have access to SMP results.❖

11-15 February: AGU/ASLO Ocean Sciences Meeting, Honolulu, HI. Check for JGOFS special sessions at **http://www.agu.org/meetings/os02spss.html** .

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, Alexandria, VA. Contact: Ken Buesseler, U.S. JGOFS Planning Office, WHOI, 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, WHOI, Woods Hole, MA (**mzawoysky@whoi.edu**)

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

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We welcome your comments and contributions for publication.

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

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