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Decoupling Surface Production From Deep Remineralization and Benthic Deposition: The Role of Mineral Ballasts

by Robert A. Armstrong and Richard A. Jahnke

Global models of the ocean carbon cycle have two moving parts. First, a production part is used to calculate primary production of organic matter in the upper ocean in terms of light and nutrient availability. Second, an export-and-remineralization part is used to partition primary production into a portion that is returned to inorganic form in the surface layer through remineralization and a portion that is exported to the deep ocean.

Much effort has been expended on representing the processes and controls on surface-layer production in models because of the general belief that production has the greatest influence on the ability of the ocean to take up and store carbon. For example, production in the high nutrient-low chlorophyll (HNLC) regions of the global ocean appears to be sensitive to inputs of micronutrients, especially iron. As a consequence, most recent models of ocean production contain some representation of iron limitation.

In contrast, the remineralization side of the ocean carbon-cycle equation has not received the attention it deserves. Since organic matter production at the ocean surface now appears to be a much weaker predictor of carbon transport into the deep ocean than we had previously thought, we are recognizing that an accurate, mechanistic description of the coupling between surface production and export to the deep ocean is of paramount importance.

Current global simulation models typically assume that a fixed fraction of the particulate organic carbon (POC) exported from the sunlit euphotic zone of the ocean is remineralized at each depth horizon in the water column. The assumption is that this depth distribution does not change geographically or over time. The most commonly used remineralization profile embodying this concept is the "Martin curve" (Figure 1a), which is a power-law function of depth. This curve is used widely in global simulations to represent the remineralization profile.

In a recent model-supported analysis of flux data from U.S. JGOFS process studies in the equatorial Pacific and the Arabian Sea, Robert Armstrong and Cindy Lee of the State University of New York at Stony Brook, John Hedges of the University of Washington, Susumu Honjo of Woods Hole Oceanographic Institution and Stuart Wakeham of Skidaway Institute of Oceanography have suggested that the concept behind the Martin curve, that remineralization of POC can be specified as a function of depth alone, is flawed. Instead their analysis suggests that fluxes of POC at deep stations are linked mechanistically to fluxes of mineral "ballasts." Because mineral ballasts are much denser than sea water, they are also in large part responsible for the sinking of POC. Mineral ballasts may be either biogenic or lithogenic in origin.

The Armstrong et al. model of flux regulated by ballast is shown in Figure 1b. In this figure, the flux of organic carbon is divided into a component that is in direct proportion to the flux of mineral ballasts and a component that is in excess of this amount. The "excess" POC flux is assumed to decay exponentially with depth, while the POC that is associated with the ballast flux is exposed to remineralization only upon dissolution of the mineral matter with which it is associated.

Figure 2 shows the result of fitting this model to U.S. JGOFS flux data

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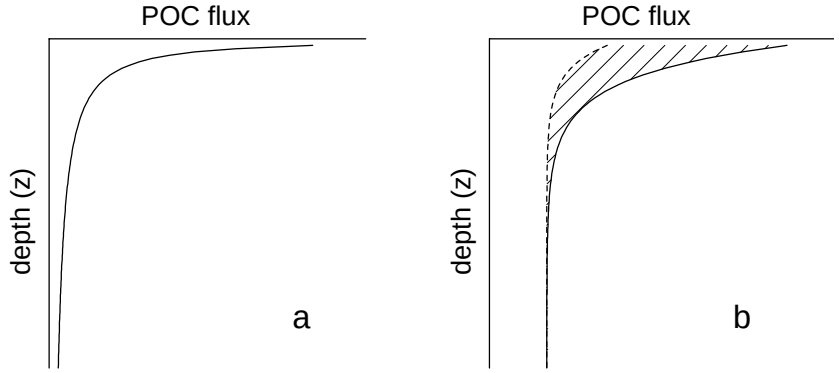

Figure 1: Functional relationships between organic carbon flux and depth. a) The "Martin curve," in which flux at any depth is assumed to be a fixed fraction of flux at the base of the mixed layer. b) The model of Armstrong and colleagues, in which total flux (solid line) is assumed to comprise a ballasted flux (dashed line) that is remineralized only when the ballast minerals dissolve, and an "excess" flux (crosshatched region) that is remineralized exponentially with depth.

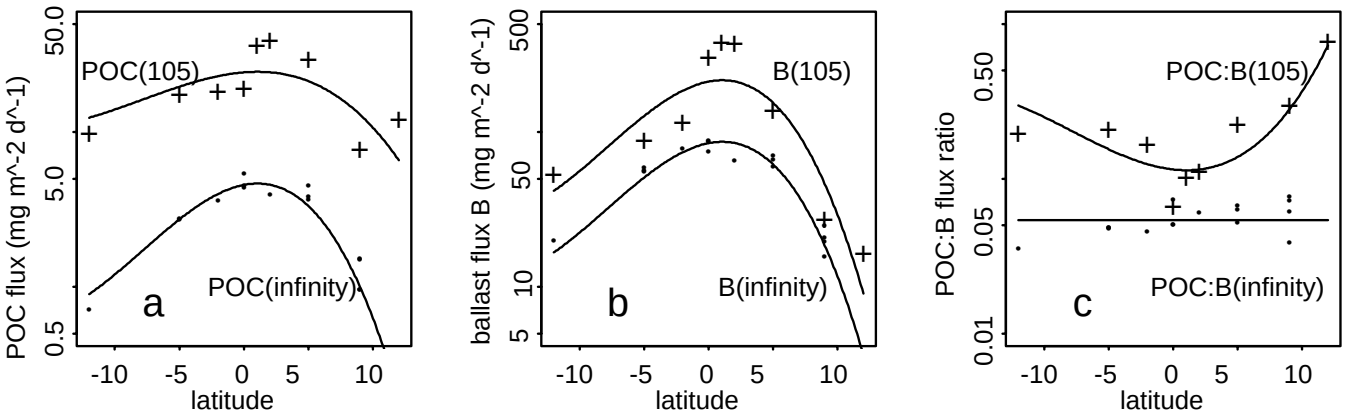

Figure 2: Data from the U.S. JGOFS Equatorial Pacific Process study and fits to modeling simulations by Armstrong and colleagues. Pluses represent data from the base of the mixed layer at 105 meters, and dots represent data from depths greater than 1,800 meters. Lines represent model fits to these data.

from the equatorial Pacific. Figure 2a shows POC fluxes at a depth of 105 meters, and at depths greater than 1,800 meters. Figure 2b shows corresponding ballast fluxes. Figure 2c shows ratios of POC to ballast. Even though absolute POC and ballast fluxes are strong functions of latitude, as is the ratio of POC to ballast at 105 meters, the ratio of POC to ballast at depths greater than 1,800 meters is virtually independent of latitude. The implication is that POC delivery to the deep ocean is not a constant fraction of export production; it is instead determined by the biological production of ballast minerals and by the import of ballast minerals from the land and ocean margins.

A second line of evidence for the primacy of mineral ballast in determining the delivery of organic carbon to the deep ocean comes from studies by Richard Jahnke of Skidaway that compare satellite-derived estimates of primary production to measurements of benthic oxygen demand. Figure 3a shows primary production for the North Atlantic as estimated by Michael Behrenfeld and Paul Falkowski of Rutgers University. We would expect the steep north-south gradient in production shown here to correspond to a steep gradient in organic carbon export. Indeed, the export gradient should be even steeper than the gradient in primary production if Edward Laws of the University of Hawaii and his coworkers are correct in their prediction that the fraction of production exported is higher in colder regions than in the equatorial zone.

Figure 3b, in comparison, shows an estimate of benthic oxygen demand, which we believe to be directly proportional to the rate of delivery of organic carbon to the sea floor. As the figure shows, major gradients run parallel to the continental margins, and there is little north-south gradient in the critical region between 30°N and 50°N.

We hypothesize that this pattern could be produced if production in the high latitudes of the North Atlantic is lightly ballasted, so that not much of it sinks to the sea floor, and if coastal processes, both wind-driven and water-driven, deliver ballast to the ocean margins and increase deep delivery there. This pattern is consistent with a recent global analysis of organic carbon transfer to deep ocean sediments by Jahnke, in which variations in efficiency greater than a factor of 50 are observed, and in which the major gradients in transfer efficiency parallel the continental margins.

In summary, we believe that the relationship between organic carbon flux and mineral ballast flux may be key to understanding and predicting the response of the oceanic carbon system in a changing climate, and that a new generation of ocean ecosystem models, capable of predicting fluxes of biogenic ballast minerals and the association between POC and mineral fluxes, will be required to carry out this agenda.❖

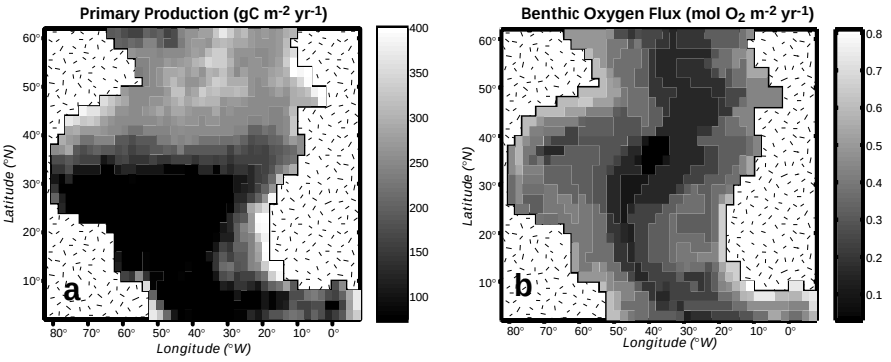

Figure 3: a) Primary productivity for the North Atlantic as estimated by Michael Behrenfeld and Paul Falkowski, digitized onto the 2° by 2° grid used to display the distribution of benthic fluxes. b) Benthic oxygen flux distribution in the North Atlantic as estimated by Richard Jahnke.

DIC, TAlk, The Clock Strikes Twelve: HOT-SIO Intercomparison Completes First Dozen Years

by John E. Dore, Peter R. Guenther, Charles D. Keeling and David M. Karl

A central goal of JGOFS is to improve our understanding of the processes that govern carbon cycling in the ocean. Fundamental to this effort has been a focus on the measurement of carbon dioxide (CO_2) in seawater. As human activities increase the CO_2 levels in the atmosphere, we need to know how much of this greenhouse gas can be taken up by the surface ocean. At the same time, we want to understand the biogeochemical mechanisms that allow surface ocean carbon to be exported to the deep sea.

Field observations over years or decades improve our ability to understand and model the response of the ocean to rising levels of anthropogenic CO_2. JGOFS has included both a global survey of carbonate parameters in the surface ocean, which can be compared with past and future surveys to infer changes, and long-term time-series measurement programs, which provide comprehensive high-frequency observations at strategic sites, some for more than a decade. Crucial to the success of both is the achievement of accurate and precise measurements, without which subtle temporal changes might go undetected or be misinterpreted.

To maintain the quality of oceanic CO_2 measurements, JGOFS scientists have adopted stringent criteria for standards and certified reference materials (CRMs) in common and have conducted numerous laboratory intercomparisons. The mercury manometer operated by the Carbon Dioxide Research Group (CDRG) at Scripps Institution of Oceanography (SIO) has been the "gold standard" for analysis of dissolved inorganic carbon (DIC) in seawater throughout JGOFS. This manometer was originally calibrated to 1 part in 4,000 in connection with the ongoing time-series studies of CO_2 in the atmosphere that first documented rising levels of this gas some 40 years ago.

Seawater DIC samples are weighed and extracted cryogenically under vacuum prior to manometric measurement of the evolved CO_2. The original CDRG mercury manometer and a newer electronic constant-volume manometer have been used to analyze surface seawater samples from around the globe and to provide "certified" values for CRMs. Thousands of these reference samples are produced by Andrew Dickson of SIO and distributed to analytical laboratories worldwide to help investigators maintain accuracy in their measurements and facilitate comparisons among laboratories.

Measurements of total alkalinity (TAlk) in seawater, another important inorganic carbon parameter, continue to be less accurate and less precise than DIC measurements. Many analytical improvements have been made, however, and SIO has recently begun providing certified values for CRM total alkalinity.

The TAlk certification analyses are carried out by open-cell potentiometric titration with an acid of independently established normality. Closed-cell titrations were carried out by CDRG until June 1997, when they were replaced with open-cell titrations; no change in accuracy or precision has been noted. The analytical errors reported by SIO are typically around ± 0.5 micromoles per kilogram (µmol/kg) for DIC and ± 1.0 microequivalent per kilogram (µeq/kg) for TAlk.

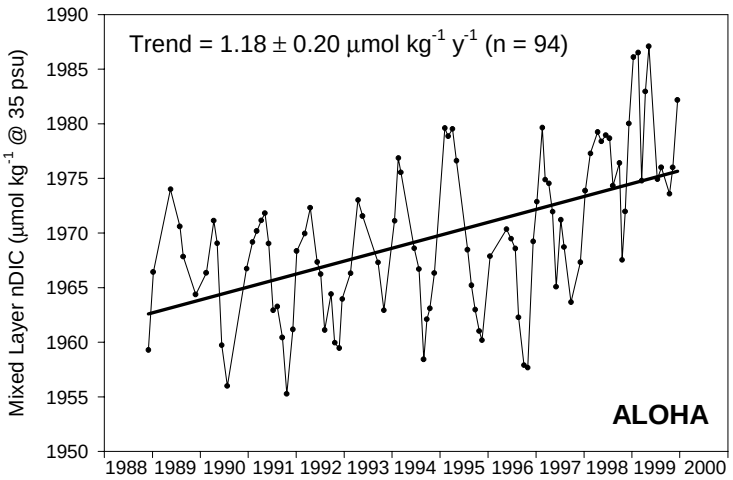

Figure 1: HOT measurements of mixed-layer dissolved inorganic carbon (DIC) normalized to a salinity of 35 from 1988 through 1999. The 95% confidence interval for this trend is 0.79-1.58 µmol/kg/yr.

The ongoing Hawaii Ocean Time-series (HOT) program was established in 1988 as a long-term study of biogeochemical and physical variability over time in the North Pacific subtropical gyre. The principal study site is located at 22°45'N, 158°W. A joint enterprise between U.S. JGOFS and the U.S. World Ocean Circulation Experiment (WOCE), HOT has included CO_2 measurements since it began.

Full water-column profiles are sampled by HOT investigators for a suite of properties, including DIC and TAlk, at nearly monthly intervals. This sampling program was begun by Chris Winn, who is now at Hawaii Pacific University, and carried out by many analysts during their years at the University of Hawaii, including Chris Sabine, Chris Carrillo, Dan Sadler, Pat Driscoll, Rolf Schottle and Dale Hebel.

DIC samples have been analyzed

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by coulometry, originally with manual gravimetric sample addition, but since 1993 using a semi-automated Single-Operator Multiparameter Metabolic Analyzer (SOMMA) system. Pure gaseous CO_2, injected using a temperature-controlled sample loop, is the standard for this analysis. TAlk is analyzed by open-cell potentiometric titration with a hydrochloric acid titrant, the normality of which has been precisely determined coulometrically at SIO. The HOT program maintains a typical field precision (standard deviation of replicate samples) of ± 1-2 µmol/kg for DIC and ± 3-5 µeq/kg for TAlk. The accuracy of the HOT DIC and TAlk measurements and the performance of the analytical systems are verified regularly with analyses of CRMs.

HOT data have been used to demonstrate a long-term rise in surface ocean DIC in the North Pacific oligotrophic gyre (Figure 1), consistent with the observed rise in atmospheric CO_2. Uncovering this trend has required precise and accurate DIC measurements over more than a decade; its magnitude (1.2 µmol/kg/yr) is small compared to the normal seasonal cycle of surface DIC, where the range is on the order of 15 µmol/kg. These data are available at **http://hahana.soest.hawaii.edu/hot/hot.html**

October 2000 marked a significant milestone for the HOT CO_2 program. Some 12 years earlier HOT scientists at the University of Hawaii and in the CDRG at SIO had launched an intercomparison of surface ocean DIC and TAlk measurements, beginning with the first HOT cruise. Since that time, pairs of mixed-layer samples, usually two replicates each at depths of 5 and 25 meters, have been collected on most HOT cruises and shipped to SIO for independent analyses of DIC and TAlk.

During 1988-89, DIC and TAlk sampling by HOT was not always carried out on the same casts and depths as the CDRG sampling; thus direct comparisons are spotty in these early years. In total, however, 166 direct comparisons of DIC and 151 of TAlk can be made from cruises HOT-1 through HOT-110.

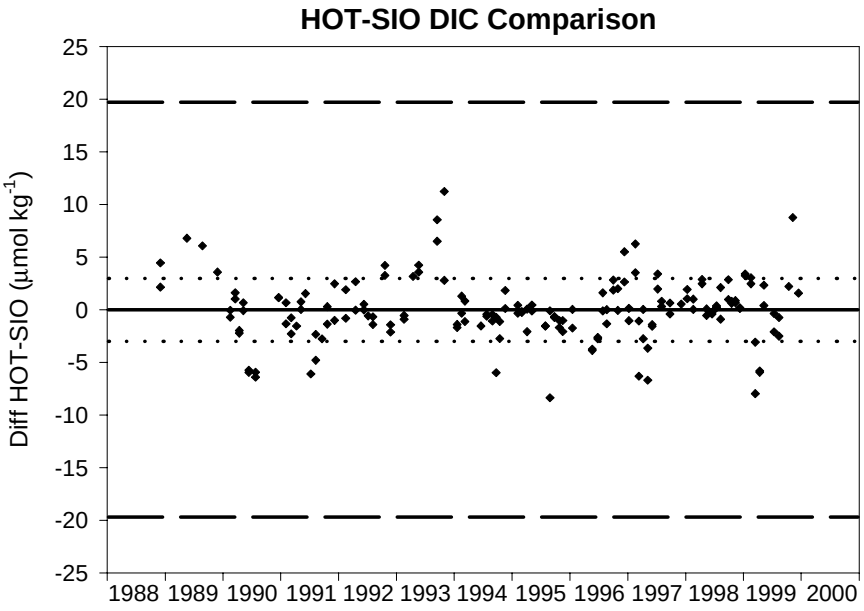

Figure 2: Difference between HOT and SIO measurements of dissolved inorganic carbon (DIC) from 1988 to 1999. Mean difference ± one standard deviation (n = 166) indicated by solid and dotted lines respectively. Dashed lines indicate ± 1% of mean DIC value for reference.

Figure 2 presents the differences between HOT and SIO DIC measurements for all samples collected from the same casts and depths between 1988 and 1999. For each HOT cruise, replicate samples at a given depth were averaged and the differences between the means (HOT minus SIO) plotted against time. Without data rejection, the mean difference (± one standard deviation) between HOT and SIO is -0.01 ± 2.98 µmol/kg. With limited data rejection following statistical quality control guidelines established by CDRG, 142 direct DIC comparisons remain, yielding a difference between the laboratories of -0.01 ± 2.51 µmol/kg.

Figure 3 presents a comparison between HOT and SIO TAlk measurements. Without data rejection, the mean difference between the laboratories is 0.36 ± 5.73 µeq/kg. After rejecting 17 statistically aberrant comparisons, we get a difference in TAlk of -0.24 ± 4.97 µeq/kg. There is a slight tendency for HOT TAlk values to exceed SIO values, largely because of differences in two time periods, early 1994 and early 1999. We do not know the reasons for the discrepancies during these two periods.

The overall errors associated with the differences between HOT and SIO, as fractions of the mean values, are approximately ± 0.13%-0.15% for DIC and ± 0.22%-0.25% for TAlk. These figures compare well with the estimated overall accuracy of CO_2 measurements made during the JGOFS global survey of oceanic CO_2, conducted in cooperation with the WOCE Hydrographic Program. The survey yielded errors of about 0.1% for DIC and 0.2% for TAlk.

The overall differences between the two laboratories in their DIC and TAlk measurements are extremely small, indicating a high level of accuracy and close agreement between the two time-series data sets. Such long-term consistency is essential for detecting subtle temporal trends. In addition, the errors surrounding these differences are only slightly larger than one could expect from the propagation of analytical errors alone between laboratories.

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S2O2: Coordinating Long-Term Time-series Studies In The Southwest North Atlantic

by Dennis A. Hansell and Dennis J. McGillicuddy, Jr.

International efforts to develop global-scale oceanic and atmospheric observing systems will be aided by coordination of current observational efforts and ready access to their results. One such effort is underway to coordinate studies in the southwestern quadrant of the North Atlantic.

This region, which comprises the Sargasso Sea and the Caribbean Sea, is one of the most intensively studied in the global ocean. Representative of the extensive subtropical oceanic gyre systems, this region is subject to strong atmospheric inputs of dust from the east and pollutants from human activities that come from the west.

The U.S. National Science Foundation (NSF), National Oceanographic and Aeronautics Administration (NOAA) and National Atmospheric and Space Administration (NASA), as well as agencies of other national governments in the region, support oceanic and atmospheric observations in the Sargasso and Caribbean seas through numerous research projects totaling more than $10 million a year. Despite the large number of intensive studies, however, important aspects of the linkages between the physical and biogeochemical processes and properties of the region remain enigmatic.

The Sargasso Sea Ocean/Atmosphere Observatory (S2O2) has been formed to coordinate and enhance the contributions of the many marine biogeochemical, hydrographic and atmospheric time-series studies in the southwestern North Atlantic (Table 1). It also provides a forum for communication among investigators with strong scientific interests in the region (Table 2). The focus of S2O2 is on oceanic and atmospheric phenomena in the area bounded by the Gulf Stream in the west and north, the return flow of the gyre circulation over the mid-ocean ridge to the east and the Antilles/Guyana currents through the Caribbean to the south (Figure 1).

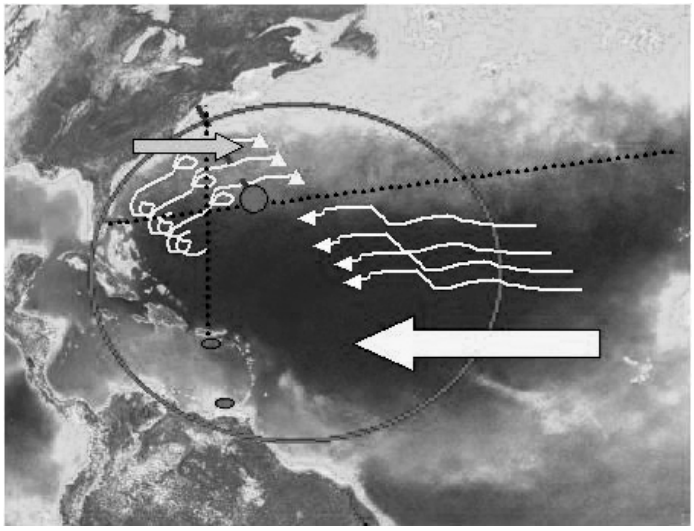

Figure 1: Sargasso Sea Ocean/Atmosphere Observatory (S2O2) region of interest (circle) and some of its components. S2O2 links the existing atmospheric, hydrographic and biogeochemical time-series and other observing programs in the area. Thick arrows represent the atmospheric transport and deposition of dust from the east and and anthropogenic pollutants from the west with the prevailing winds. Thin arrows represent ongoing PALACE float programs. Circle and ovals represent the time-series programs near Bermuda and Puerto Rico and in the Cariaco Basin. Thick line across the Florida Strait indicates time-series measurements of volume transport in that passage. Cross-basin dotted lines indicate data collection from ships of opportunity. Many other elements of S2O2 are not depicted here.

Some 30 scientists with long-term interests in the S2O2 region met for a workshop at the Bermuda Biological Station for Research (BBSR) in early March. One of the goals of the event was to acquaint the participants with the details of the many components of S2O2.

The first half of the three-day workshop was dedicated to presenting each S2O2 element with a focus on the essential scientific questions and methodologies employed. In the latter half of the workshop, several sessions offered an opportunity to discuss the evolution of S2O2, taking into account both what is already known and what questions remain unanswered.

Tommy Dickey of the University of California at Santa Barbara led a session that provided context for S2O2. We learned about the various national observing programs currently underway that are relevant to S2O2.

Dan Frye of Woods Hole Oceanographic Institution (WHOI) introduced the group to the evolving technologies that are steadily becoming available to marine scientists. These include gliders, autonomous underwater vehicles (AUVs), new instruments for moorings and new means of data transmission.

Maureen Conte of WHOI led a session focused on improving and extending collaboration among S2O2 investigators and the optimal use of current resources. These include the various platforms, such as ships, moorings, AUVs, gliders, floats and towers, and collective data and models.

Nick Bates of BBSR then led a session designed to articulate goals that can be achieved only through the implementation of a coordinating program such as S2O2. Among the questions addressed were: What are the specific scientific, technological and long-term observation results

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that S2O2 should try to achieve? What specific contributions we can make now or in the future to international observing efforts? How will these results be obtained in the near future? What should our next steps be toward realizing goals and achieving results?

Tom Church of the University of Delaware concluded the meeting with a session on the nuts and bolts of S2O2. Participants discussed organizational structure and the merits of developing a charter, among other topics. As part of this session, Dennis Hansell and Dennis McGillicuddy were elected chair and co-chair of S2O2 for two-year terms.

The workshop engendered much excitement about the potential S2O2 offers for individual research programs and interests as well as for the international observing programs that are developing. We established two primary goals: to strengthen interactions between elements of S2O2, and to provide data, models and knowledge to the global oceanic and atmospheric observing programs and related projects, such as the U.S. coastal observatories and consortia.

Although many of the participating investigators have already established strong ties among their programs, other workshop participants knew little about the ongoing observing efforts in the southwestern North Atlantic. The first S2O2 goal is to enhance the value of individual research projects by providing opportunities for interaction. To achieve this goal, we must first determine what kinds of coverage or facilities are not available in the S2O2 region and to work toward providing that coverage.

As for the second goal, there are many active users of currently available data from S2O2 components. These include the U.S. JGOFS Synthesis and Modeling Project, individual investigators and students in a variety of educational institutions. The number of users will increase greatly with the development of international observing programs such as the Global Ocean Observing System (GOOS) or Climate Variability and Predictability (CLIVAR) and new national and international carbon-cycle research programs that are in various stages of planning. Our goal will be to make high-quality data available as these programs get underway.

The difficult task of amassing long-term time-series records over large regions has been completed in the southwest quadrant of the North Atlantic. The contribution of S2O2 will be to establish and improve the links required to magnify the value of these efforts.❖

Table 1: Components of the Sargasso Sea Ocean/Atmosphere Observatory

Time Series Studies

- Bermuda Atlantic Time-series Study (BATS)
- Hydrostation S (Panulirus Station)
- Oceanic Flux Program (OFP)
- Bermuda Testbed Mooring (BTM)
- PALACE floats: Western North Atlantic
- PALACE floats: Subtropical and Tropical North Atlantic
- Oleander Section
- Bermuda Bio-Optics Project
- Aerosol Robotic Network (AERONET)
- Ultraviolet radiation monitoring system
- Moored *In-situ* Trace Element Serial Sampling Program (MITESS)
- High-density XBT lines
- Florida Current Time-Series
- Surface pCO_2 monitoring
- Carbon Retention In A Colored Ocean (CARIACO)
- Caribbean Time-Series (CaTS)

Technology

- Bermuda Testbed Mooring
- Ocean-Systems for Chemical, Optical and Physical Experiments (O-SCOPE)
- Microbial observatory
- Moored profiler stations
- Satellite observations
- Aerosol Composition/Flux at the Air Sea Boundary
- Slocum Bermuda Pilot Experiment

Facilities

- Atmosphere/Ocean Chemistry Experiment (AEROCE) tower
- RV *Weatherbird II*
- Bermuda Weather Service

Modeling

- Modeling Mesoscale Biogeochemical Processes
- Gyre Scale Biogeochemical Modeling and Data Analysis

Table 2: S2O2 participants and institutions

- Nick Bates, Rod Johnson, Tony Knap, Fred Lipschultz, Mike Lomas: *Bermuda Biological Station for Research*
- Ed Boyle, Mick Follows: *Massachusetts Institute of Technology*
- Jorge Capella, Jorge Corredor, Julio Morell: *University of Puerto Rico at Mayaguez*
- Craig Carlson, Tommy Dickey, Norm Nelson, Dave Siegel: *University of California at Santa Barbara*
- Tom Church: *University of Delaware*
- Maureen Conte, David Fratantoni, Dan Frye, Eric Hintsa, Dennis McGillicuddy, Ed Sholkovitz, John Toole: *Woods Hole Oceanographic Institution*
- Hugh Ducklow, Debbie Steinberg: *Virginia Institute of Marine Science*
- Jim Galloway: *University of Virginia*
- Steve Giovanonni: *Oregon State University*
- Dennis Hansell: *University of Miami*
- Brent Holben: *NASA Goddard Space Flight Center*
- Tony Michaels: *University of Southern California*
- Frank Muller-Karger: *University of South Florida*
- Molly O'Neil Baringer, Rik Wanninkhof, Doug Wilson: *NOAA Atlantic Oceanographic and Meteorological Laboratory*
- Steve Riser: *University of Washington*
- Petra Stegmann, Tom Rossby, Huai-Min Zhang: *University of Rhode Island*
- Taro Takahashi: *Lamont-Doherty Earth Observatory*
- Roger Williams: *Bermuda Weather Service*

U.S. SOLAS Holds First Science Workshop

by Rik Wanninkhof

Some 70 scientists representing a wide variety of oceanic and atmospheric disciplines attended the first community science workshop for the proposed U.S. Surface Ocean-Lower Atmosphere Study (U.S. SOLAS). The workshop, held at the Bolger Center in Potomac, Maryland, in mid-May, attracted researchers in paleo-oceanography, boundary-layer physics, ocean biogeochemistry, atmospheric chemistry and cloud physics.

U.S. SOLAS is part of a larger international program, which was recently adopted as a component of the International Geosphere-Biosphere Programme (IGBP). The purposes of the workshop were to familiarize participants with the goals of SOLAS, to formulate relevant science questions for the U.S. component of the study and to discuss implementation strategies for the U.S. program.

The mission of SOLAS is "to achieve a quantitative understanding of the key biogeochemical-physical interactions between the ocean and atmosphere, and of how this coupled system affects and is affected by climate and environmental change." These goals served as guiding principles for workshop discussions.

The meeting started with presentations on international and national research programs that U.S. SOLAS would be likely to interact with. International SOLAS is forming a scientific steering committee led by Peter Liss of the University of East Anglia, United Kingdom. Close ties are likely with the International Global Atmospheric Chemistry (IGAC) program, which has included studies of the marine atmospheric boundary layer as part of the Aerosol Characterization Program (ACE) and the Marine Aerosol and Gas Exchange Experiment (MAGE).

Short presentations were made on the fledging carbon-cycle science programs of the U.S. National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA). The problem of quantifying the exchange of carbon dioxide (CO_2) across the air-sea interface is a major focus of these planning efforts as well as of SOLAS.

Two continental and coastal field experiments planned for North America in 2004, one focusing on atmospheric chemistry and one on the terrestrial carbon sink, offer possibilities for collaboration. A representative from Canadian SOLAS, the first national SOLAS program that has gotten underway, invited collaborations with studies planned in the sub-polar North Pacific and North Atlantic.

Four plenary talks offered context for the working groups, which convened to discuss science ideas and formulate priorities. Several overarching themes emerged from their efforts. For example, we need to quantify basic physical constants for a variety of compounds that have an important effect on climate. Issues include the solubility and diffusivities of halogenated trace gases; the characterization of organic compounds, both in aerosols and in dissolved organic matter; biological consumption and production estimates for various compounds, and rates of photolysis.

Coastal margins, including the large arctic shelves, were singled out as requiring more attention. The high biological productivity and sedimentary processes of these regions contribute disproportionately to the fluxes of many compounds that affect climate, and critical interactions between continental runoff and the marine domain occur there.

The boundary-layer physics working group homed in on problems of quantifying the physical factors controlling fluxes and deposition of compounds, including gas-transfer velocity and wet and dry deposition mechanisms. Sustained coastal time-series measurements of fluxes of compounds that affect climate were suggested as one way to improve our understanding of the factors controlling gas transfer and deposition processes. The group also advocated studying the effects of high wind speeds on these processes.

The working group on the dynamics of long-lived compounds emphasized the need for regional flux information, particularly in the coastal regions. A lively discussion revolved around the question of U.S. SOLAS participation in a survey of the partial pressure of CO_2 (pCO_2) in global surface water that is recommended in the large-scale oceanic and atmospheric carbon observing plan. The final recommendation was to support this effort and to strive for augmentation of pCO_2 surveys with near real-time flux estimates utilizing remote sensing and measurements of other compounds that affect climate. The group also noted a need for controlled studies of biological production and degradation rates of halogenated, nitrogen-bearing and sulfur-bearing compounds.

The working group on dynamics of short-lived compounds had the daunting task of setting science goals with regard to a myriad of compounds that are reactive on both sides of the air-sea interface. Several questions revolved around heterogeneous chemistry between compounds in their gas phase and cloud/water droplets or sea-salt aerosols. The dynamics of sea-salt aerosols, particularly the inorganic and organic halogen chemistry, was considered a priority issue. Photochemistry on both sides of the interface and ultraviolet radiation and penetration

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received considerable attention. Air-sea flux and biological controls on formation of organic material were identified as important issues as well.

The fourth working group focused on atmospheric effects on marine biogeochemical processes, including the cycling of iron and nitrogen. Highlighted issues were dust transport and deposition on the ocean and subsequent transformation of iron in dust into bioavailable form. Participants noted that questions about wet and dry deposition and chemical transformation in the air phase were not fully addressed in other programs. They also discussed nitrogen fixation and deposition in different forms and noted the importance of coastal regions for studies of deposition.

This group put forth two overarching themes for SOLAS research on upper-ocean biogeochemistry: How do atmospheric fluxes affect the nitrogen-to-phosphorus ratios of inorganic nutrients in the upper ocean? How do changes in biogeochemical processes in the surface ocean affect the air/sea exchange of compounds important to climate and thereby have a feedback effect on radiative forcing? These themes were broken down into more specific research objectives and field experiments that would address these issues.

All groups highlighted the importance of using information gathered by remote-sensing instruments to assess regional variability, to understand the effects of physical forces on biogeochemical processes and to extrapolate the results in time and space. The critical importance of maintaining and fostering long-term time-series observations was pointed out. Modeling priorities included coupling ocean biogeochemical process models with models describing the atmospheric marine boundary layer for both long- and short-lived compounds. Participants urged the incorporation of both modeling and remote-sensing efforts into the initial stages of experimental design and their use in site selection and the generation of hypotheses.

The last part of the meeting was devoted to presentations from representatives of NSF, NOAA, NASA and the Office of Naval Research (ONR), the agencies that sponsored the event. Agency representatives pointed out programs with which U.S. SOLAS could collaborate and provided suggestions on the priorities and scope of the study.

The deliberations and input of the meeting, along with the material presented in the draft of the international science plan, will serve as background for a report laying out overall science ideas and priorities within the U.S. SOLAS effort. Our goal is to have the report written by the end of summer. More information about U.S. SOLAS and the workshop is available at **www.aoml.noaa.gov/ocd/solas**, while the latest draft of the international science plan can be found at **www.ifm.uni-kiel.de/ch/solas/main.html** .❖

(Editor's note: Rik Wanninkhof, a scientist at the NOAA Atlantic Oceanographic and Meteorological Laboratory in Miami, is the first chairman of the U.S. SOLAS Planning Committee. Russell R. Dickerson of the University of Maryland was chosen to be co-chairman during the meeting.)

DIC TAlk – from page 4

These conclusions are particularly gratifying because these results were derived by different analysts in different laboratories, employing different methods and using different sampling bottles with very different storage histories. Such a successful intercomparison is a testament to the fine field and analytical personnel involved and highlights the importance of analytical quality control in oceanic measurement programs.

(Editor's note: John Dore and David Karl of the University of Hawaii are long-time participants in the Hawaii Ocean Time-series program. Dore began as a graduate student with the HOT-10 cruise in 1989 and now serves as co-principal investigator of the HOT core measurement program. Peter Guenther and Charles Keeling are members of the Carbon Dioxide Research Group at Scripps Institution of Oceanography.)

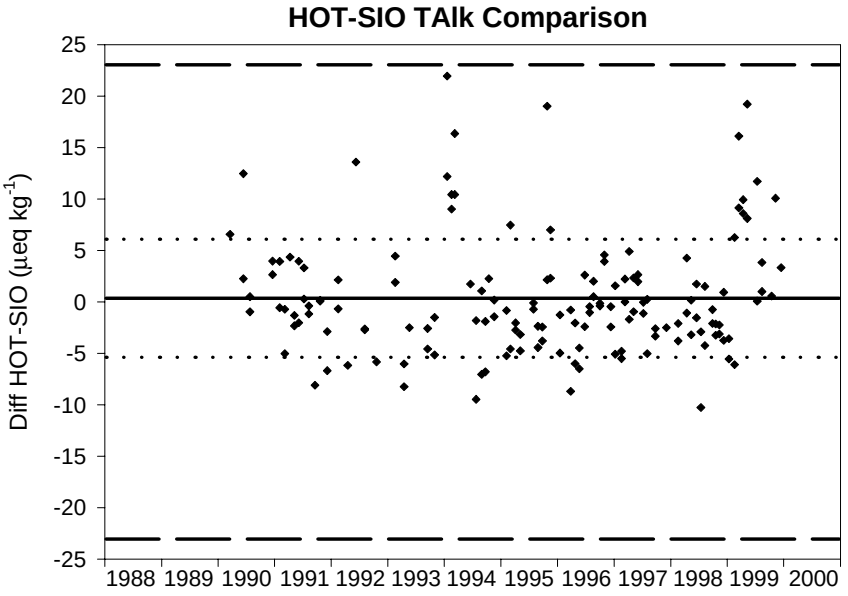

Figure 3: Difference between HOT and SIO measurements of total alkalinity (TAlk) from 1988 to 1999. Mean difference ± one standard deviation (n = 151) indicated by solid and dotted lines respectively. Dashed lines indicate ± 1% of mean TAlk value for reference.

Advances In Autonomous Biogeochemical Observations

by Tommy D. Dickey

Investigators concerned with elucidating the response of ocean biogeochemical processes to changing climate conditions and predicting future developments are hampered in their efforts by insufficient data. Differentiating natural from anthropogenically-induced variability in the ocean requires vast numbers of measurements made on spatial and temporal scales that range over many orders of magnitude.

Autonomous *in-situ* measurements made from moorings, drifters, floats, gliders and underwater vehicles as well as remote-sensing measurements made from instruments mounted on satellites have widened the observable portion of the temporal and spatial spectrum of biogeochemical variability. JGOFS has taken advantage of several of the autonomous bio-optical and biogeochemical sampling systems that have been developed over more than a decade since its field studies began.

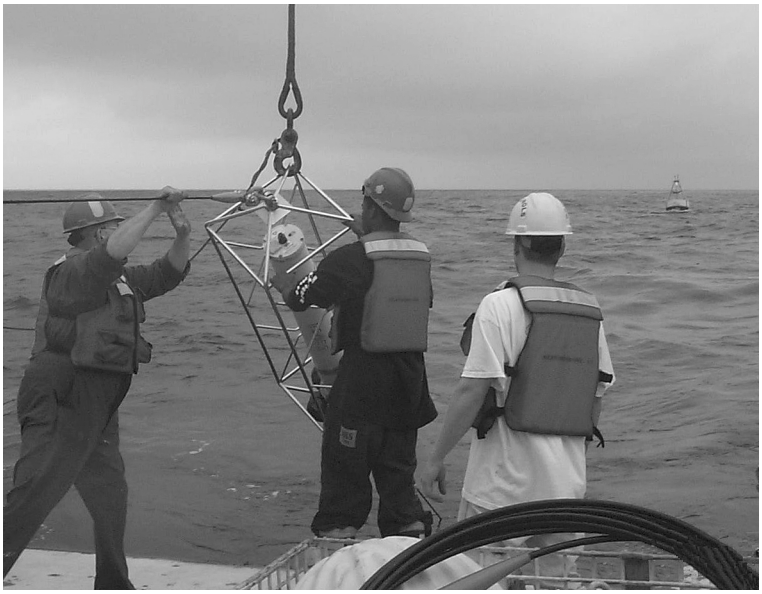

photo by T. Dickey

Deployment of instrumentation on Bermuda testbed mooring.

The North Atlantic Bloom Experiment (NABE), an international pilot study for JGOFS, was conducted in 1989 with the primary aim of studying the massive spring phytoplankton bloom and its associated biogeochemical effects in the North Atlantic. Marine Light in the Mixed Layer (MLML), a U.S. Office of Naval Research field study that took place at the same time, focused on upper ocean bio-optical variability as affected by physical forcing at a site south of Iceland.

A mooring at the MLML site was equipped with instruments measuring physical and bio-optical variables that sampled every few minutes. These systems were used to quantify the abrupt onset of stratification with shoaling of the mixed layer in the spring and the onset of the seasonal phytoplankton bloom. An increase in near-surface temperature of 0.2°C was associated with the phytoplankton increase, an effect suggested by model studies but rarely observed because of sampling limitations.

One of the methodological innovations of the NABE/MLML studies was the use of diverse sampling platforms, including ships, airborne LIDAR, drifting sediment traps, a satellite altimeter and the multi-instrument mooring described above. The resulting data sets and models were used to characterize and analyze the temporal and spatial complexities of the spring bloom as well as for prediction.

The physical dynamics of the equatorial Pacific have become increasingly well understood over the past two decades. But our understanding of biological and optical variability has been limited because few shipboard programs can be carried out in such a remote region. During the U.S. JGOFS Equatorial Pacific Process Study, which took place in 1992-1993, shipboard studies in the central equatorial Pacific were augmented with autonomous physical and biogeochemical measurements made from a mooring at 0°, 140°W over a period of 18 months.

The choice of sampling period was fortuitous as the observations took place during both El Niño and non-El Niño conditions. Mooring results demonstrated that westward propagating tropical instability waves with periods of 20 days contribute to large vertical upwelling cycles and large-amplitude signals in chlorophyll and primary productivity. Newly developed bio-optical drifters were released at the mooring site on the equator and provided spatial data as they drifted poleward, enabling estimates of net phytoplankton growth rates during the tropical instability waves.

Sampling strategies employed during the U.S. JGOFS Arabian Sea Expedition between 1994 and 1996 included a variety of shipboard measurements, moorings and satellite-mounted instruments for sea-surface temperature and altimetry. One of the novel aspects of the observational program was the deployment of an array of five moorings with meteorological and physical instruments covering a square roughly 7 kilometers on a side. The mooring at the center of the square included a variety of physical, bio-optical and biogeochemical sensors, and a sediment trap mooring was located nearby.

Seasonal blooms associated with the monsoons as well as major eddy

(Cont. on page 10)

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passages were evident in chlorophyll measurements from the mooring systems and deep sediment trap records of carbon and other elemental fluxes. SeaSoar measurements from shipboard and satellite altimeter measurements also emphasized the importance of submesoscale and mesoscale features for the biogeochemistry of the region.

JGOFS studies in the Southern Ocean used similar sampling arrangements. One of the unique aspects of the U.S. JGOFS Antarctic Environment and Southern Ocean Process Study was the deployment of an array of 12 moorings equipped with physical and bio-optical sensors in the Antarctic Polar Frontal Zone. This array captured a strong spring bloom beginning in December 1997. The mooring time-series measurements, complemented by ship-based data sets, indicated that phytoplankton populations were initially limited by light levels, then by silicate levels and zooplankton grazing, and finally by iron. The spring bloom lasted only a few weeks, which argues for the importance of the fast sampling rates possible with autonomous moored instruments.

The U.S. JGOFS Bermuda Atlantic Time-series Study (BATS) and Hawaii Ocean Time-series (HOT) programs, established in 1988, have depended on shipboard sampling at two- to four-week intervals. This mode of observation, however, cannot capture important phenomena with time scales from minutes to weeks. Therefore high-frequency, long-term, autonomous mooring observations were begun with the Bermuda testbed mooring at the BATS sampling site in 1994 and with the HALE ALOHA mooring at the HOT site.

The mooring efforts at the time-series sites have included meteorological, physical, chemical and bio-optical data as core biogeochemical measurements. Key processes at the two sites that are resolvable only with high temporal resolution mooring data include mesoscale eddies, storms, hurricanes, dust deposition events, rapid shoaling of the mixed layer and transient phytoplankton blooms, inertial oscillations, diel and shorter time-scale variability in phytoplankton and bio-optical properties, and internal gravity waves. Instruments on both moorings have captured the passage of mesoscale physical features with high nutrient and phytoplankton concentrations.

The mooring programs have been used to test emerging autonomous biogeochemical and bio-optical sensors and systems designed to measure nitrate, the partial pressure of carbon dioxide, dissolved oxygen, trace metals, primary production using serial carbon-14 samplers, and spectral optical properties. The optical measurements have been also used to provide verification for remote-sensing observations by the SeaWiFS ocean-color instrument.

Looking toward the future, investigators are developing many innovative technologies involving computing, robotics, communications, space exploration, and physical, chemical, biomolecular and biomedical research for a host of applications. Recent workshops have focused on ways to accelerate progress in measuring biogeochemical and bio-optical variables from existing platforms as well as from autonomous underwater vehicles, gliders and profiling floats. Efforts are underway to synthesize *in-situ* and remotely sensed observations with models in order to develop truly three-dimensional time-series measurements on even broader ranges of time and space scales. One example of this approach is the nascent Sargasso Sea Ocean Observatory (S2O2) program described elsewhere in this issue.

(Editor's note: Tommy Dickey is a professor at the Ocean Physics Laboratory of the University of California at Santa Barbara. An expanded version of this article will appear in a forthcoming issue of Oceanography on U.S. JGOFS.)

Final Announcement For U.S. JGOFS SMP

Investigators interested in the synthesis of data from U.S. JGOFS and other ocean programs and their use in the development of predictive models have one more opportunity to submit proposals. The National Science Foundation has issued a final announcement of opportunity for the U.S. JGOFS Synthesis and Modeling Project (SMP).

The U.S. JGOFS SMP Implementation Plan, which describes the scientific rationale and structure of this project, is available from the U.S. JGOFS Planning Office at Woods Hole Oceanographic Institution, Woods Hole, MA, 02543, or via the U.S. JGOFS home page (**http://usjgofs.whoi.edu**).

The focus of the SMP as it draws to a close will be on the integrative synthesis of the modern ocean carbon cycle and projections of its past and future behavior. The major emphasis for this funding round will be on global and regional studies that link the biological, physical and chemical components of the marine carbon system. Proposals for the Southern Ocean and for the global scale are particularly relevant. Synthesis and modeling efforts that effectively combine field data sets and diagnostic and prognostic models are encouraged.

Proposals are due Aug. 16, 2001. Funds available for this initiative during fiscal year 2002 are expected to be approximately $2 million. Awards of up to four years' duration will be considered. March 1, 2002, is the latest date for decisions on awards.

The full text of the announcement is posted on the U.S. JGOFS home page as well as on the NSF home page (**http://www.nsf.gov**). Information on proposal submission may be obtained from NSF program directors Donald L. Rice, Chemical Oceanography (**drice@nsf.gov**), or Phillip R. Taylor, Biological Oceanography (**prtaylor@nsf.gov**).

NSF Ocean Carbon Cycle Planning Group Formed

Assistant Director for Geosciences Margaret Leinen of the National Science Foundation (NSF) has charged the directorate that she heads with the development of a plan for carbon-cycle research for the next decade that is global in scope and integrates studies of land, sea and air.

The NSF's Division of Ocean Sciences (OCE) has formed the Ocean Carbon Cycle Research (OCCR) planning group to develop a vision of priorities in carbon-cycle research. Terrestrial and atmospheric carbon-cycle research initiatives are under development in other Geosciences divisions. The OCCR committee will provide OCE advice and assistance with planning the design of a carbon-cycle research program that is oceanic and, as appropriate, global in scope. The purpose of this group is to develop a programmatic vision of research priorities rather than a plan for implementing a specific research initiative.

Cindy Lee of the State University of New York at Stony Brook will chair the OCCR planning group, which held its first meeting at NSF headquarters in Arlington, Virginia, in early April. Hugh Ducklow of the Virginia Institute of Marine Science will serve as liaison between the OCCR committee and the U.S. Global Change Research Program's Carbon Cycle Science Plan committee.

Other members of the OCCR committee are Robert Anderson, Lamont-Doherty Earth Observatory; Virginia Armbrust, University of Washington; Douglas Capone, University of Southern California; Scott Doney, National Center for Atmospheric Research; Nicolas Gruber, University of California at Los Angeles; David Hutchins, University of Delaware; Richard Jahnke, Skidaway Institute of Oceanography; Kenneth Johnson, Moss Landing Marine Laboratory; Edward Laws, University of Hawaii; James Ledwell, Woods Hole Oceanographic Institution; Ricardo Letelier, Oregon State University; Dennis McGillicuddy, Woods Hole Oceanographic Institution; Brent McKee, Tulane University; Peter Niiler, Scripps Institution of Oceanography; Paul Quay, University of Washington; Kevin Speer, Florida State University, and Suzanne Strom, Western Washington University.❖

Coming Next Issue:

Data Management Update

Several articles in the fall issue will introduce the new personnel involved in the U.S. JGOFS data management program, the new projects they are undertaking, and the new data products that are becoming available, as well as emerging plans for long-term archiving and publication of data from the U.S. JGOFS field programs and the Synthesis and Modeling Project.

U.S. JGOFS SMP New Grants

The National Science Foundation has announced a fourth round of awards for participation in the U.S. JGOFS Synthesis and Modeling Project. Investigators, their institutional affiliations and their projects are:

• Ken Buesseler, Woods Hole Oceanographic Institution: "Magnitude, variability and controls of particulate export in the upper ocean."

• Scott Doney, National Center for Atmospheric Research, and Christopher Sabine, NOAA Pacific Marine Environmental Laboratory and University of Washington: "Collaborative research: Coordination and management of the U.S. JGOFS Synthesis and Modeling Project. The second and final phase."

• Hugh Ducklow, Virginia Institute of Marine Science, Michael Roman, Horn Point Environmental Laboratory, and George Jackson, Texas A & M University: "Collaborative research: Ecosystem structure, biogeochemical fluxes and vulnerability to climate change perturbations."

• Marjorie Friedrichs, Eileen Hofmann, et al., Old Dominion University: "Regional ecosystem model testbeds. A JGOFS synthesis and modeling project."

• David Glover and Maureen Conte, Woods Hole Oceanographic Institution: "A coupled epipelagic-meso/bathypelagic particle flux model for the Bermuda Atlantic Time-series Station (BATS) Oceanic Flux Program (OFP) site."

• Nicolas Gruber, University of California at Los Angeles: "Analyzing and modeling interannual to decadal variability in the carbon cycle of the subtropical and subpolar gyres."

• Edward Laws, University of Hawaii, Kenneth Caldeira and Jose Milovich, Lawrence Livermore National Laboratory: "Development of a coupled global circulation/adaptive food web model to explain carbon cycling in the ocean."

• Dennis McGillicuddy, Woods Hole Oceanographic Institution: "Impacts of mesoscale processes on biogeochemical fluxes in the North Atlantic: Basin-scale eddy-resolving simulations."

• Jorge Sarmiento, Princeton University: "Examination of the oceanic uptake of anthropogenic CO_2 and other trace gases using multiple tracer relationships."

• LuAnne Thompson, Steven Emerson and Paul Quay, University of Washington: "Mechanisms controlling the biological pump and CO_2 uptake rates in the North Pacific."

JGOFS Synthesis: An Interim Report

by Hugh W. Ducklow

As JGOFS draws to a close, its participants are focusing their attention on the synthesis of results from interdisciplinary field studies conducted over more than a decade in most of the major biogeochemical provinces of the global ocean. Over the last three years, various JGOFS planning and oversight groups have concentrated their efforts on synthesis at regional, program-wide and global levels.

At its annual meeting in Cape Town, South Africa, in April 1998, the members of the JGOFS Scientific Steering Committee (SSC) accepted responsibility for integrating regional synthesis and modeling activities and for maintaining links to other ocean observing programs. The JGOFS planning groups responsible for coordinating field studies were transformed into regional synthesis groups responsible for encouraging data submission and sharing, meetings and publications and the development of regional biogeochemical ocean models.

Later that year JGOFS initiated a coordinated program of synthesis at a workshop held at the Southampton Oceanography Centre in the United Kingdom (U.K.). At that meeting, the JGOFS SSC under the leadership of then chairman Michael Fasham laid out a plan for international synthesis of JGOFS field observations and for participation in the program-level synthesis planned by the International Geosphere-Biosphere Programme along with other IGBP core projects.

At its annual meeting in Durham, New Hampshire, in October 2000, the executive committee of the JGOFS SSC assessed progress and plotted its course toward the final synthesis goals for the JGOFS concluding years. Figure 1 presents the overall structure of the JGOFS synthesis program and some of its current and planned products.

As the figure on the next page shows, the work is divided into three phases. The first of these covers the completion of regional and thematic syntheses by JGOFS synthesis groups. The second comprises program-wide synthesis events and activities that are designed to blend the products of the regional syntheses. The third is intended to focus on a global synthesis that will conclude JGOFS efforts to develop an integrated and quantitative understanding of the biogeochemical fluxes of carbon in the ocean and their role in the global carbon cycle.

JGOFS groups responsible for regional and/or disciplinary syntheses are the North Atlantic Synthesis Group (NASG), the Equatorial Pacific Synthesis Group (EPSG), the Indian Ocean Synthesis Group (IOSG), the Southern Ocean Synthesis Group (SOSG), the North Pacific Synthesis Group (NPSG), the Continental Margins Task Team (CMTT) and the Paleo-JGOFS Task Team (PJTT). Several of these groups are working on synthesis volumes or special issues of *Deep-Sea Research, Part II*.

Other activities include a series of continental margins workshops on specific coastal systems like the Eastern and Western Boundary Currents, each to culminate in a book. This ambitious project is directed by the CMTT, which is a joint JGOFS and Land Ocean Interactions in the Coastal Zone (LOICZ) committee. This project is supported in part by an award from the International Oceanographic Commission (IOC), a valuable supplement to the core funding that the Scientific Committee on Oceanic Research (SCOR) provides to JGOFS for synthesis work.

Thematic synthesis is continuing with a workshop on ocean transport of carbon dioxide (CO_2), at Southampton Oceanography Centre in June. This event, hosted by the international project office of the World Ocean Circulation Experiment (WOCE), is a joint JGOFS/WOCE activity. This workshop will launch a unique effort to blend diagnoses of ocean circulation with extensive analyses of ocean dissolved inorganic carbon to estimate intra- and interbasin carbon transports.

Program-wide synthesis began at the Southampton Synthesis Workshop and was defined at the JGOFS open science conference "Ocean Biogeochemistry: A New Paradigm" in Bergen, Norway, in April 2000. The Bergen conference attracted 218 participants from 27 countries and a large number of presentations and posters reporting on models and other synthesis projects. Keynote speakers at the Bergen conference have submitted draft chapters for a book to be edited by Fasham and published by Springer-Verlag in the IGBP Global Change series in early 2002.

Two general JGOFS publications are coming out as part of the IGBP-wide synthesis effort. At its Southampton workshop, the SSC commissioned a number of JGOFS scientists to draft brief synthetic reports on the components of the program.

A longer version, directed at the wider scientific audience, was pub-

lished in May as a special report in *AMBIO*. A shorter version of the *AMBIO* report is being published as the second volume in the *IGBP Science* series. This version, intended for policymakers and the interested public, describes the operation and role of the ocean carbon cycle in global change. Both documents provide an in-depth summary of more than a decade of JGOFS research and lay the groundwork for planning new efforts in ocean biogeochemistry.

A final piece of the program-wide synthesis will be the third JGOFS open science conference, which will be hosted by the U.S. JGOFS Planning and Implementation Office. It will be held at the National Academy of Sciences in Washington, D.C., in May 2003. As with earlier JGOFS conferences, a book will be published afterwards.

The third phase of JGOFS synthesis activity will be led by a new group currently being formed under the leadership of Reiner Schlitzer of the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany. The idea for this group came out of discussions among JGOFS scientists attending the IGBP Global Carbon Cycle Synthesis Workshop in Durham, New Hampshire, last fall.

While exploring different ideas around which the JGOFS global synthesis could begin to focus, JGOFS executive committee member Robert Anderson of Lamont-Doherty Earth Observatory described a talk that Schlitzer had presented at the Southern Ocean Synthesis Workshop in Brest, France, last summer. Schlitzer showed the results of inverse solutions to a global model of ocean biogeochemistry, focusing on export production in the Southern Ocean.

The inverse solution Schlitzer described reproduces a large data set of measurements of nutrients, CO_2 and oxygen in the full water column. Its representation of the distribution and magnitude of the export flux differs significantly, however, from that given by estimates of export derived from maps of primary productivity based on remote-sensing measurements and algorithms relating export and primary production.

Which set of maps is correct? As each is derived from and shows fidelity to one or more of the largest global biogeochemical data sets, they are both "right". The reasons why they do not agree are not obvious.

J G F S SYNTHESIS

Phase 1 (1998-2001)	Phase 2 (1998-2003)	Phase 3 (2001-03)
Regional/Disciplinary syntheses	**Program-wide synthesis**	**Global Synthesis**
NASG (DSR-II volume)	Southampton Workshop	DMTT IOCCG
EPSG (DSR-II volume)	Bergen OSC	
IOSG (Book)	Springer Book	
SOSG (Book, DSR-II)	Brochures	***GSWG***
NPSG	Contributions to IGBP Synthesis	
CO2 Panel		
CMTT (Book)	Washington OSC	
PJTT		JGTT OCMIP

The JGOFS executive committee asked Schlitzer to chair a new Global Synthesis Working Group (GSWG), whose initial charge would be to explore the problem of export in various global models. The newly constituted group will meet in July in connection with the IGBP Open Science Conference "Challenges of a Changing Earth" in Amsterdam, The Netherlands.

GSWG members, in addition to Schlitzer, are Andreas Oschlies, Institut für Meereskunde, 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; Richard Jahnke, Skidaway Institute of Oceanography, U.S.; Richard Matear, Commonwealth Science and Industrial Research Organization, Australia, and Yasuhiro Yamanaka, Institute for Global Change Research, Japan.

The GSWG will also work with the JGOFS Data Management Task Team (DMTT), which is responsible for amassing JGOFS data sets in national repositories and facilitating access to them and with the International Ocean Colour Coordinating Group (IOCCG). Another new task team has been formed jointly between JGOFS and another IGBP program element, the Global Analysis, Integration and Modeling (GAIM) initiative, to support global synthesis efforts on ocean carbon modeling. The JGOFS-GAIM Task Team (JGTT) oversees the ongoing effort of the Ocean Carbon-cycle Model Intercomparison Project (OCMIP), which focuses on advancing the development of ocean biogeochemical models.

As I write this, I am sailing into the northeast Atlantic on the British ship RRS *Discovery* to carry out a study of the transport of dissolved organic carbon and nitrogen with co-investigator Dennis Hansell of the Univer-

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The Good, The Bad And The Ugly: How Good Are My DOC Results?

by Dennis A. Hansell

All good analytical chemistry requires an agreed-upon means of judging the accuracy of results. Without such a means, experimental findings cannot be easily compared or transferred among laboratories or disciplines and remain of value only to the investigators who generated them.

For most analyses, certified reference materials are available from chemical supply houses in the private sector. For amino acid determination by high pressure liquid chromatography, for example, a standard material is readily available. There are many environmental analyses, however, for which standards are not available. Until recently, the analysis of organic carbon dissolved in natural waters has been among them.

Marine dissolved organic matter contains roughly the same amount of the Earth's carbon as is present in the atmosphere in the form of carbon dioxide (CO_2). Ocean scientists from many countries are studying the production, consumption and distribution of this large pool of carbon with the aim of understanding its role in the marine carbon cycle.

Determining the concentration of dissolved organic carbon (DOC) is the most basic requirement for conducting these studies. As increasing numbers of laboratories measured DOC in the early 1990s, it quickly became obvious that poor agreement existed among the various results.

Our problem was the lack of a commonly available seawater standard that could be used for direct comparisons of methods and results. Through the mid to late 1990s, Jonathan Sharp of the University of Delaware and a DOC steering committee, comprising John Hedges of the University of Washington, Cindy Lee of the State University of New York at Stony Brook, Charles Hopkinson of the Marine Biological Laboratory and Anthony Knap of the Bermuda Biological Station for Research (BBSR), inaugurated a series of inter-comparison exercises in which many DOC investigators participated.

During those exercises a common substance, notably deep ocean water, was sent to participating laboratories for analysis. The exercises reminded us of the value of inter-comparisons and led to increasing but still incomplete analytical confidence.

In 1998, the National Science Foundation (NSF) awarded a grant to BBSR to support development of a reference material program for DOC analyses. Marine DOC measurements are made at more than 100 laboratories in the United States and at an even greater number of facilities in other countries. Before the establishment of this program, analyses made in various laboratories lacked a common reference material; researchers could not assume that their results were comparable.

Two forms of reference material have been developed for DOC analysis. One is deep ocean water, collected at a depth of 2,600 meters in the Sargasso Sea and containing biologically refractory DOC. The other is low carbon water, containing DOC at a level of roughly 2 micromolar (µM). Both materials are certified for specific DOC concentrations through the consensus efforts of a group of independent laboratories.

Some 45 laboratories in 18 nations have received 13,000 ampoules of these materials to date (Table 1). Although the analytical protocols they use may vary greatly, these laboratories are now able to achieve accurate and comparable results, a great step forward for the concerted study of the ocean carbon cycle.

Both low carbon water and deep Sargasso Sea water (43-45 µM DOC and roughly 21.5 µM total nitrogen) are available to the scientific community in 10 mL ampoules. The water is acidified with phosphoric acid and is thought to be stable for at least one year.

The reference waters have been certified for DOC concentrations by the laboratories of James Bauer of Virginia Institute for Marine Science, Ronald Benner of the University of South Carolina, Yngve Børsheim of the Norwegian Institute of Science and Technology, Gus Cauwet of the Laboratoire Arago, France, Robert Chen of the University of Massachusetts, Boston, Dennis Hansell and Wenhao Chen of the University of Miami, Charles Hopkinson, MBL, Ken Mopper and Jianguo Qian of Old Dominion University, and Hiroshi Ogawa of the University of Tokyo. The Hansell and Ogawa laboratories performed the total nitrogen analyses. In all laboratories, DOC and total nitrogen were determined by high-temperature combustion.

The DOC certified reference materials should be used when an analyst wishes to reference results against those of other DOC analysts. Ideally, this would be the case for each analysis made. Several thousand ampoules of each reference are available, so their use is encouraged on each day an analysis is performed.

The DOC reference material program supported by NSF will run through 2001. Subsequent funding will depend on the success of the program, as demonstrated by the commitment of laboratories making DOC measurements to the use of cerfified reference materials.

These reference materials are available without charge; participating laboratories are only required to pay for shipping. Those interested in obtaining materials should contact Dr. Wenhao Chen at the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences (wenchen@rsmas.miami.edu) to place orders and make arrangements for shipping.

A table of participants in the DOC certified reference materials program is on opposite page.

Table 1: Participants in DOC CRM Program

Brooks Avery	Univ. of North Carolina at Wilmington, USA
Jim Bauer	College of William and Mary, USA
Ronald Benner	University of South Carolina, USA
Yngve Børsheim	Norwegian University of Science and Technology, Norway
Stephen Boswell	Southampton Oceanography Centre, UK
Charlotte Braungardt	University of Plymouth, UK
David Burdige	Old Dominion University, USA
Gus Cauwet	Laboratoire Arago, France
Robert Chen	University of Massachusetts, Boston, USA
Jennifer Cherrier	Florida A & M University, USA
Minhan Dai	Xiamen University, China
Mike Dalva	McGill University, Canada
Lucy Dimitrakopoulos	University of Cardiff, UK
Marylo Doval	Instituto de Investigaciones Marinas (CSIC), Spain
Cristina Esquíroz	Instituto Mediterráneo de Estudios Avanzados (CSIC-UIB), Spain
Nicolas Gonzalez	Instituto Espagnol de Oceanografia, Spain
Signe Foverskov	National Environmental Research Institute, Denmark
Dennis Hansell	University of Miami, USA
John Hedges	University of Washington, USA
Huasheng Hong	Xiamen University, China
Charles Hopkinson	Marine Biological Laboratory, USA
Jia-Jang Hung	National Sun Yat-Sen University, Taiwan
David M. Karl	University of Hawaii, USA
Marieke Van Kooten	National Institute of Water & Atmospheric Research, New Zealand
Lois Lane	University of Maryland, USA
Ron Lauck	Rutgers University, USA
Anna Luchetta	Istituto Talassografico di Trieste, Italy
Erik Lundberg	Umeå University, Sweden
Valter Maurino	Università di Torino, Italy
Axel Miller	University of the Highlands & Islands Project, UK
Mercedes Miranda	Centro de Control da Calidade do Medio Mariño, Spain
Ken Mopper	Old Dominion University, USA
Mary Ann Moran	University of Georgia, USA
Ester Murru	IMC - Centro Marino Internazionale, Italy
Hiroshi Ogawa	University of Tokyo, Japan
Emma Rochelle-Newall	Observatoire Oceanologique, Station Zoologique, France
Sybil Seitzinger	Rutgers University, USA
Richard Sempere	LMM, CNRS EP 2032, France
Alfredo Seritti	Istituto di Biofisica, Italy
Jonathan Sharp	University of Delaware, USA
Georgina Spyres	CCMS - Plymouth Marine Laboratory, UK
Henrik Stahl	Dept. of Analytical and Marine Chemistry, Sweden
Yoshimi Suzuki	Shizuoka University, Japan
Tom Trull	University of Tasmania, Australia
Christina Zeri	National Centre for Marine Research, Greece
Chen Zhiqiang	The Hongkong University of Science & Technology, China
Natalya Zolotova	Washington University in St. Louis, USA

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sity of Miami. The goal of the cruise is to conduct a high-resolution study of the circulation and hydrography of the Iceland-Faroes-Shetland region.

Although this is in some senses a physical oceanography cruise, it includes substantial ecological and biogeochemical components. This sort of multidisciplinary cruise was not really possible before JGOFS. In its synthesis of physical, biological and chemical oceanography into ocean biogeochemistry, JGOFS has made its most enduring contribution to ocean science.

(Editor's note: Hugh Ducklow, chairman of the JGOFS SSC, sent this report on May 6 from 54°N, 12°W.)

New Officer at JGOFS IPO

French scientist Bernard Avril joined the JGOFS International Project Office (IPO) in Bergen, Norway, in April as assistant executive officer. He replaces Beatriz Baliño who accepted a position earlier this year as program coordinator at the University of Bergen's Bjerknes Center for Climate Research.

Avril received his doctorate in ocean biogeochemistry from the Université Pierre et Marie Curie in Paris in 1995. A student of Gérard Copin-Montégut, with whom he published a number of articles, Avril conducted his doctoral research on dissolved organic carbon in seawater. He also participated in the development of a database for the Dynamic Flux of Matter in the Mediterranean (DYFAMED) time-series programme, a component of JGOFS-France.

After completing his degree, Avril took a post-doctoral position at the University of South Florida, where he worked with Paula Coble from 1995 to 1997. His work there extended his expertise in marine organic biogeochemistry to bio-optics. Coble and Avril published an article on the distribution and optical properties of dissolved organic matter in a special issue of *Deep-Sea Research II* on the U.S. JGOFS Arabian Sea process study.

Following his post-doctoral training, Avril took a position as assistant project manager for the Ocean Margin Exchange (OMEX), working with Roland Wollast and Lei Chou at the Université Libre de Bruxelles in Belgium. His responsibilities in this position were similar to those of the IPO assistant executive officer: scientific steering committee administration, ocean data management and web site maintenance. He worked with partners in 10 countries and 40 institutions, organizing project symposia, making presentations at international scientific conferences, preparing reports and brochures and supporting data management efforts.

• U.S. JGOFS Calendar 2001 •

7-8 July: JGOFS Scientific Steering Committee Meeting, Amsterdam, The Netherlands. Contact: Roger Hanson, JGOFS International Project Office, Universitet Bergen, Norway (**Roger.Hanson@jgofs.uib.no**).

10-13 July: IGBP Open Science Conference, "Challenges of a Changing Earth," Amsterdam, The Netherlands. Contact: CONGREX HOLLAND BV, Amsterdam, The Netherlands (**igbp@congrex.nl**).

16-20 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**).

8-13 October: Second International Conference on the Oceanography of the Ross Sea, Naples, Italy. Contact: Walker Smith, Virginia Institute of Marine Science (**wos@vims.edu**).

16-18 October: U.S. JGOFS Scientific Steering Committee meeting, Woods Hole Oceanographic Institution (WHOI), Woods Hole, MA. Contact: Ken Buesseler, U.S. JGOFS Planning Office, WHOI (**kbuesseler@whoi.edu**).

21-28 October: JGOFS session at the Joint IAPSO-IABO Assembly: *2001 An Ocean Odyssey*, Mar del Plata, Argentina. Contact: Hugh Ducklow, Virginia Institute of Marine Science, Gloucester Point, VA (**duck@vims.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

U.S. JGOFS News

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