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

U.S. JGOFS NEWS

Volume 10, Number 3 February 2000

The Effect Of El Niño Events On Variability Of CO_2 Fluxes In The Equatorial Pacific

by Richard A. Feely, Francisco P. Chavez, Gernot Friedrich, Michael J. McPhaden and Rik Wanninkhof

The equatorial ocean plays an important role in the global carbon cycle. Upwelling along the equator brings water rich in dissolved inorganic carbon to the surface, the source of roughly 0.6 to 1.5 petagrams of carbon (PgC) a year that is released into the atmosphere in the form of carbon dioxide (CO_2). Most of this flux emanates from the equatorial Pacific, which annually contributes four times more CO_2 to the atmosphere than the rest of the oceanic equatorial regions combined.


Scientists modify instruments on buoy in equatorial Pacific for real-time transmission of data to laboratories. R/V *Ka'imimoana*, a NOAA ship, is in the background.

photo by R. Feely

During non-El Niño years, the upwelling of waters enriched in nutrients and CO_2 extends from the coastal waters west of South America to approximately 160˚E; the size of the area in which upwelling takes place makes this region the largest oceanic source of CO_2 on Earth. Physical processes and biological productivity control the strength of this source from year to year.

Throughout the 1990s, investigators participating in the U.S. Joint Global Ocean Flux Study (U.S. JGOFS) conducted studies aimed at developing a quantitative understanding of carbon fluxes in the equatorial Pacific. One of their hypotheses was that variations in air-sea fluxes of CO_2 in the equatorial Pacific related to El Niño-Southern Oscillation (ENSO) cycles play a major role in the interannual variability of oceanic sinks and sources of CO_2.

With support from the National Oceanic and Atmospheric Administration, the National Science Foundation, the Department of Energy and the National Aeronautics and Space Administration, investigators measured the partial pressure of carbon dioxide (pCO_2) in the atmosphere and the surface waters of the central and eastern equatorial Pacific between 1992 and 1999. In 1996, sensors were deployed at two of the Tropical Atmosphere-Ocean moorings, located at 0˚, 155˚W and 2˚S, 170˚W, to measure temporal variations in pCO_2 and a number of biological parameters.

During normal or cold conditions in the equatorial Pacific, the trade winds drive upwelling along the equator from the coast of South America to the international date line. The source of this upwelled water is the Equatorial Undercurrent (EUC), which flows eastward across the basin. A strip of cold water near the equator called the "cold tongue" appears at the sea surface during these conditions. Every three to seven years, however, the central and eastern equatorial Pacific warms dramatically as an El Niño develops (Figure 1). The 1997-98 El Niño was, by some measures, the strongest of the 20th century, with major effects on global weather patterns.

During El Niños, the easterly trade winds in the western and central equatorial Pacific weaken and reverse, leading to the development of unusually warm sea-surface temperatures east of the international dateline. Collapse of the trade winds drives the western Pacific warm pool eastward with surface water temperatures greater than 28.5˚C. In the eastern Pacific, the equatorial cold tongue fails to develop in the summer and fall.

Reversal of the trade winds is typically punctuated by a series of westerly events of increasing intensity and eastward fetch along the equator. These westerly episodes are a manifestation of the Madden-Julian Oscillation, a 30- to 60-day wavelike disturbance in the atmosphere that originates over the Indian Ocean. It excites equatorial ocean Kelvin waves that propagate eastward across the basin over one to two months, de-

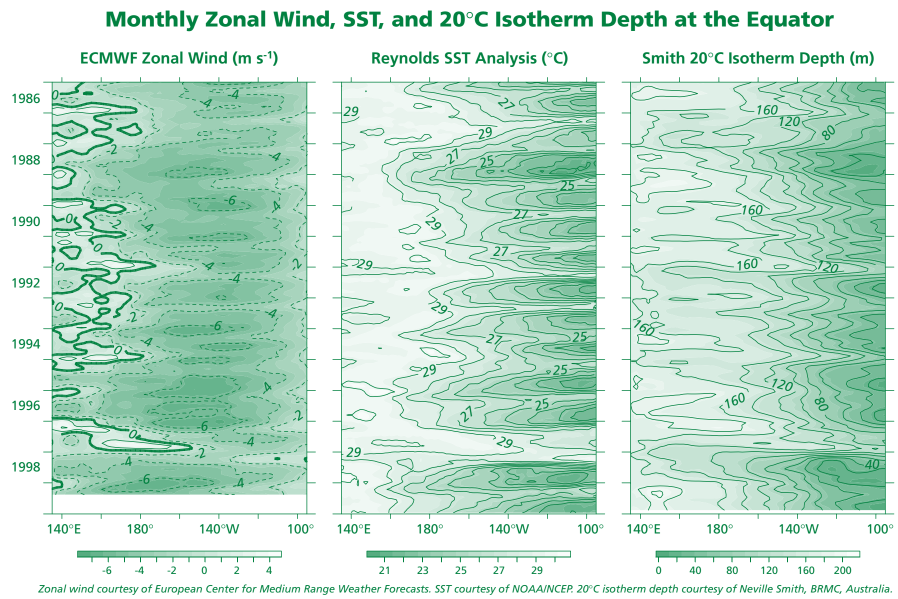

Figure 1: Monthly zonal wind speeds, sea-surface temperatures and 20˚C isotherm depths at the equator between 1986 and 1998 in the central equatorial Pacific. The analysis is based on monthly averages between 2˚S and 2˚N.

pressing the thermocline in the eastern Pacific and favoring development of warm surface temperatures. In the western Pacific, on the other hand, the thermocline shoals as a result of equatorial ocean Rossby waves generated by the weakened trade winds. The net result of these processes is to flatten the thermocline along the equator and reduce greatly the normal east-west sea-surface temperature gradient.

El Niños typically end in the spring with a return of normal easterly trade winds and resumption of equatorial upwelling. The ocean-atmosphere system often overshoots the mark, however, and a cold La Niña develops. A particularly striking switch from El Niño to La Niña conditions occurred in May and June 1998, when trade winds abruptly returned to near normal strength in the eastern Pacific, and surface temperatures in the equatorial cold tongue plummeted 8˚C in only 30 days.

Under normal conditions, some of the highest levels of surface-water pCO_2 in the entire equatorial ocean occur in the eastern Pacific (Figure 2). They are associated with the upward slope of the thermocline from west to east, which brings waters containing high levels of dissolved inorganic carbon closer to the surface in the east. In addition, the Peruvian upwelling system brings waters with pCO_2 levels greater than 700-1,000 microatmospheres (µatm) to the surface.

The northward flowing Peru Current carries this water into the South Equatorial Current (SEC) east of the Galapagos, and the SEC transports the high pCO_2 water westward. Further west, the high pCO_2 levels are augmented by upwelling at or near the equator. As this water diverges from the equator, various factors reduce pCO_2 levels. On the north, levels drop abruptly at the convergence between the SEC and the North Equatorial Counter Current (NECC) between 0˚ and 5˚N, which causes an asymmetry in the meridional trends of pCO_2 in the eastern equatorial Pacific (Figure 2).

To the south, pCO_2 levels drop sharply at the convergence between the SEC and the subtropical current system. A weakening of the NECC and a more northerly position of the convergence zone causes a more symmetrical distribution of pCO_2 around the equator in the central Pacific. Finally, high pCO_2 levels are cut off in the west by the edge of the warm pool.

The high pCO_2 levels associated with equatorial upwelling are controlled by the strength of the trade winds, which control both the upwelling rate and the depth of the thermocline, the latter by means of the large-scale Kelvin waves. Maximum upwelling occurs in the central basin because of higher winds. Surface-water pCO_2 levels are controlled both by the depth at which upwelling originates and by the position of the thermocline. As a result, two separate pCO_2 flux maxima often occur in the region, one near 140˚W and one near 110˚W with a slight depression in between (Figure 2).

The ENSO cycle exercises a controlling influence on surface-water pCO_2 levels in the eastern equatorial Pacific via three factors that regulate large-scale pCO_2 patterns: the depth of the thermocline, the strength of the upwelling, and the edge of the warm pool. The eastern edge of the warm pool moves from west of the dateline to as far east as 100˚W during strong El Niño periods. Reduced trade winds during these periods decrease the upwelling rate. Deepening of the thermocline further reduces surface pCO_2 levels.

As a result of El Niño conditions that persisted between 1991 and 1993, surface-water pCO_2 levels in March 1992 were well below normal in the region (Figure 3). By March 1993, the Southern Oscillation Index (SOI), a measure of atmospheric pressure differences between Darwin, Australia, and Tahiti, was less negative than in spring 1992, and pCO_2 levels were correspondingly higher.

The SOI was within its normal range in the springs of 1994 and 1996, and pCO_2 levels at 110˚W were within a range of 450 to 500 µatm (Figure 3). The lowest levels of the last decade were observed in the fall of 1997 and winter of 1998 during the century's most powerful El Niño. Maximum surface-water pCO_2 levels were about 30 µatm above equilibrium with the atmosphere in a region where normal levels are greater than 150 µatm above equilibrium. The region abruptly changed from El Niño

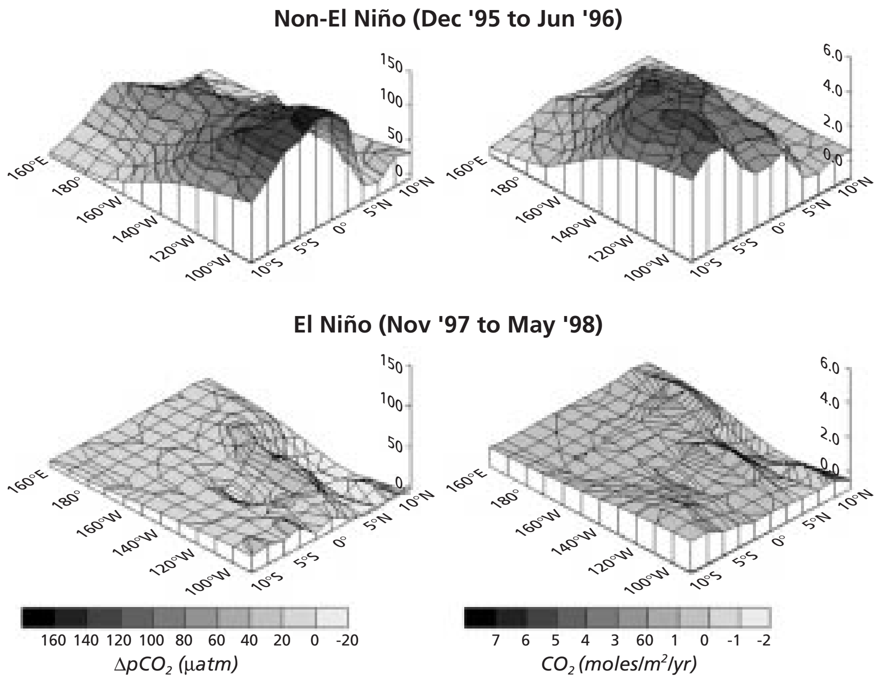

Figure 2: Distribution of ΔpCO_2 values (left) and CO_2 fluxes (right) in the equatorial Pacific from December 1995 to May 1998. Lower ΔpCO_2 values during the 1997-98 El Niño, combined with lower wind speeds, resulted in the lowest annual CO_2 flux from the ocean into the atmosphere since the 1982-83 El Niño.

to La Niña conditions in June 1998, and seawater pCO_2 values increased by more than 100 µatm in less than four months.

Data from the eastern equatorial Pacific during and after the 1997-98 El Niño suggest that variability in the difference between pCO_2 in the surface waters and the atmosphere (ΔpCO_2) is a product of the combined effects of the physical processes described above. The time-series record from the mooring at 0˚, 155˚W shows that, during the mature phase of the 1997-98 El Niño, surface-water pCO_2 was generally below atmospheric levels (Figure 4). Nitrate and chlorophyll concentrations were also at their lowest levels, 0.05 micromolar and 0.05 micrograms per liter (µg/l) respectively.

By June 1998 recovery from the El Niño had begun, and high surface-water pCO_2 was measured at 0˚, 155˚W. The recovery at the mooring at 2˚S, 170˚W occurred later; waters low in pCO_2 were found at this site in June 1998. Levels increased rapidly in July, followed by large excursions associated with the passage of tropical instability waves. Surface-water chlorophyll concentrations also increased dramatically during this period to levels in excess of 1 µg/l, among the highest ever measured in the equatorial Pacific.

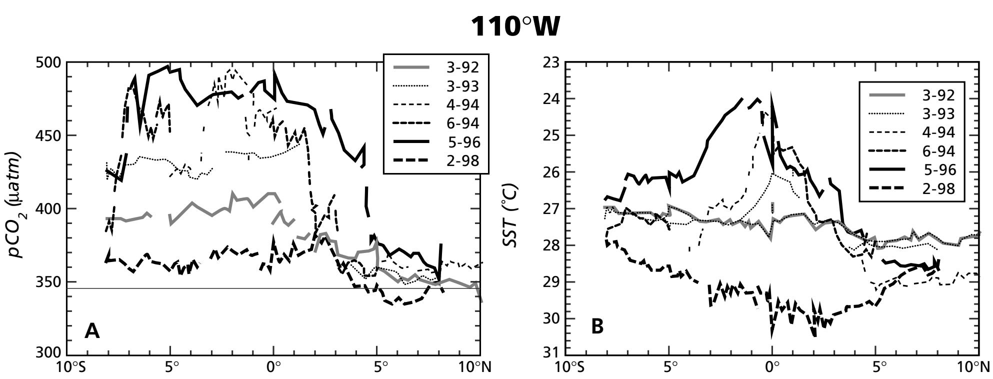

Figure 3: Surface-water pCO_2 levels and temperatures (SST) along 110˚W, measured on a series of cruises from March 1992 through February 1998. The solid line in panel A shows approximate level of pCO_2 in the atmosphere. Low pCO_2 levels occur during El Niño periods. SST is inversely correlated with pCO_2 in surface waters.

The flux of CO_2 across the air-sea interface is the product of the gas-transfer velocity, the solubility of CO_2 and the difference in pCO_2 between the ocean and atmosphere. CO_2 fluxes calculated from various shipboard surveys are presented in Figure 2. The data show the large interannual effects of El Niño on CO_2 exchange in the equatorial Pacific.

From the normal conditions of 1996 to the mature El Niño of 1997-98, average CO_2 fluxes decreased from approximately 2.0 to 0.3 moles of carbon per square meter per year (mol C/m^2/yr). The high CO_2 fluxes in 1996 were associated with increased surface-water pCO_2 levels and higher winds. The EUC was much closer to the surface in 1995-96 and brought water with higher pCO_2 levels to the surface. The lower fluxes during the 1997-98 El Niño were primarily the result of weaker winds and the movement of the warm pool into the central and eastern equatorial Pacific.

We estimate that approximately 0.9 +/-0.6 PgC was released as CO_2 into the atmosphere during 1996. In contrast, for the period from spring 1997 to spring 1998, the CO_2 flux into the atmosphere was approximately 0.2 +/-0.14 PgC over the same region. Thus the amount of CO_2 retained in the equatorial ocean during the 1997-98 El Niño (0.7 +/-0.4 PgC/yr) was similar to the amount retained during the severe El Niño of 1982-83 (about 0.6 PgC/yr). During the decade of the

Continued on page 4

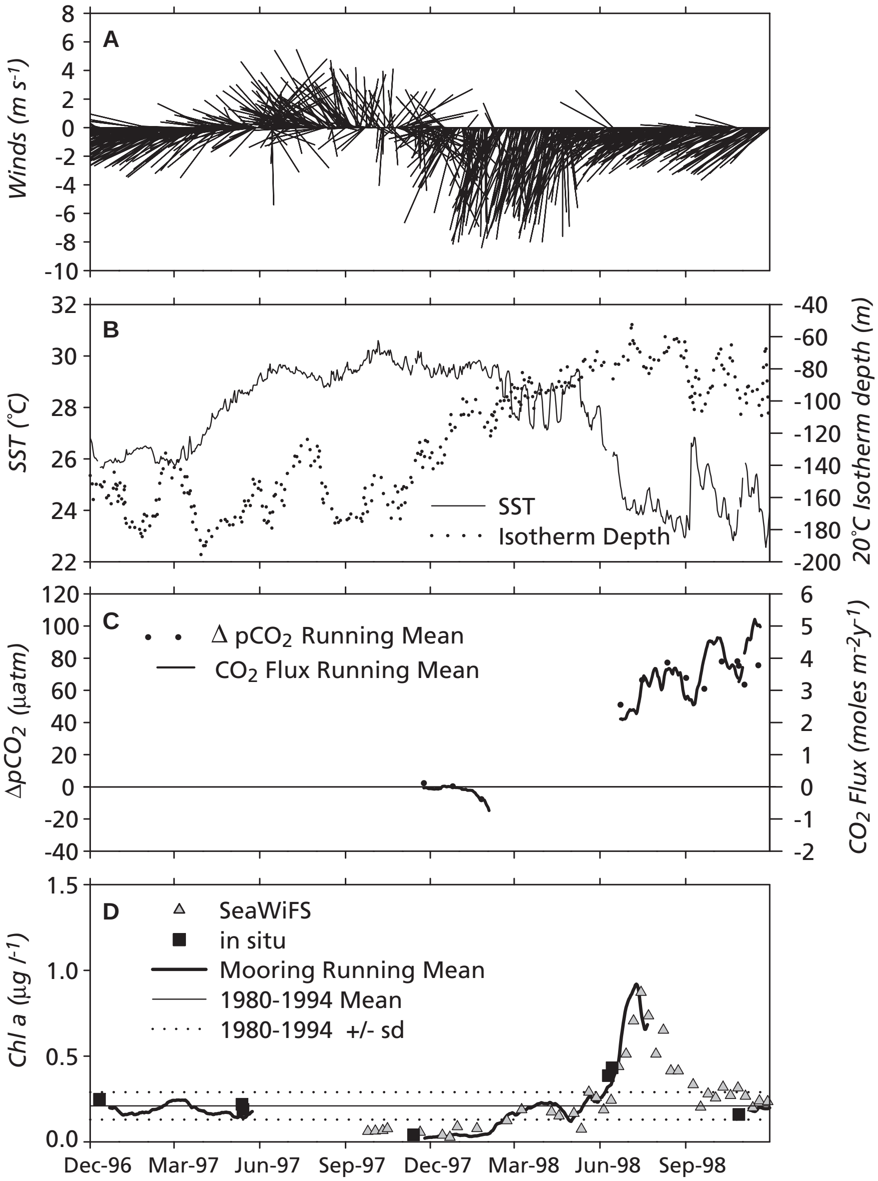

Figure 4: Wind speed and direction, sea-surface temperature and 20°C isotherm depth, ΔpCO_2 values and CO_2 flux, and chlorophyll measured by instruments on a mooring at 0°, 155°W from December 1996 to December 1998. Chlorophyll measured on shipboard and from the SeaWiFS satellite are also plotted in panel D. Strong eastward currents associated with the movement of the warm pool caused the mooring to be pulled under and the instruments to fail in February 1998. The problem was corrected in June 1998.

1990s, dominated by strong and prolonged El Niños, the equatorial ocean retained roughly 2 to 3 more petagrams of carbon in the form of CO_2 than it does during normal decades.

The overall CO_2 flux measured on the buoy at 0˚, 155˚W during the height of the 1997-98 El Niño averaged 0.25 mol C/m^2/yr from the atmosphere into the ocean (Figure 4). After the El Niño period was over, the overall flux was from the ocean into the atmosphere at a rate between 2 and 6 mol C/m^2/yr. The mooring data show large week-to-week variations in flux that the ship surveys missed. During cold periods, changes in wind speed can cause two- to threefold changes in CO_2 flux with little accompanying change in ΔpCO_2. From the mooring data, we estimate an average flux of 3.5 mol C/m^2/yr for the cold period following recovery from the 1997-98 El Niño.

We could not have determined the dramatic chemical and biological effects of the 1997-98 El Niño without the combination of *in-situ* sensors on moorings, regular shipboard measurements over the region and chlorophyll measurements from the SeaWiFS instrument. Future studies would benefit from additional moorings and drifters equipped with chemical and biological sensors.❖

(Editor's note: Dick Feely and Mike McPhaden are at the NOAA Pacific Marine Environmental Laboratory; Francisco Chavez and Gernot Friedrich are at the Monterey Bay Aquarium Research Institute, and Rik Wanninkhof is at the NOAA Atlantic Oceanographic and Meteorological Laboratory.)

Publications Available From The U.S. JGOFS Planning Office

Copies of a number of special issues of *Deep-Sea Research*, Part II on JGOFS programs are available from the U.S. JGOFS Planning Office (**mzawoysky@whoi.edu**). Issues and prices are:

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

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

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

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

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

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

Decade Of BATS Observations Offers Insight Into Links Between Ocean Biogeochemistry And Climate Patterns

by Nicholas R. Bates and Craig A. Carlson

One of the primary objectives of U.S. JGOFS is to assess the effects of carbon dioxide (CO_2) released into the atmosphere by human activity on biogeochemical variability in the ocean. Long-term observations at both the Bermuda Atlantic Time-series Study (BATS) site in the western North Atlantic and the Hawaii Ocean Time-series (HOT) site in the central North Pacific demonstrate a large degree of variability in both physical and biogeochemical phenomena on seasonal, interannual and decadal time scales.

Some of the physical and biogeochemical variablity observed at these sites over the last decade is linked to natural large-scale climate patterns such as the El Niño-Southern Oscillation (ENSO) or the North Atlantic Oscillation (NAO). The changes associated with ENSO and NAO cycles complicate our assessment of the rate of increase in oceanic concentrations of CO_2 in response to anthropogenic inputs. Establishing the underlying links between these large-scale climate patterns and ocean biogeochemistry will help oceanographers and climate scientists understand anthropogenic change in the context of natural variation.

Interannual variability

With more than a decade's worth of time-series data from the BATS sampling site, located 80 kilometers southeast of Bermuda, we can examine interannual trends by seeing how hydrographic and biogeochemical anomalies, or deviations from a mean state, vary over time. These anomalies are determined by statistical models. The output of these models yields positive and negative deviations from the mean in specific physical or biogeochemical parameters. Statistical analyses, such as cross-correlation coefficient analysis, can be used to determine whether there are significant correlations between biogeochemical anomalies at the BATS site and natural large-scale climate patterns such as ENSO or NAO.

These statistical analyses reveal that upper-ocean temperatures are inversely correlated with parameters such as mixed-layer depth, rates of integrated primary production and total carbon dioxide (TCO_2). Figure 1 shows physical and biogeochemical anomalies in the record from the BATS sampling site for the years 1988 to 1998. During negative (cooler) temperature anomaly periods over the decade, mixed-layer depths were deeper by up to 20 meters; rates of integrated primary production were higher by up to 200 milligrams of carbon per square meter per day (mg C/

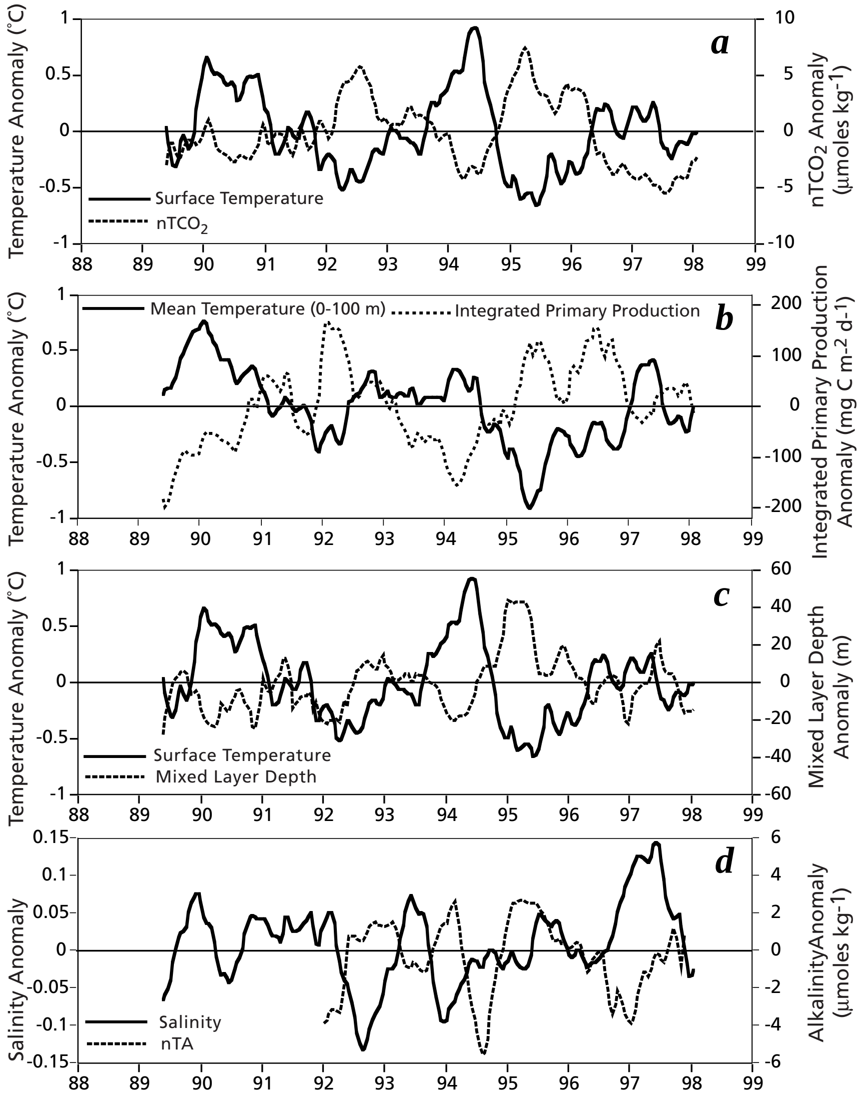

Figure 1: Time-series record of physical and biogeochemical anomalies at BATS sampling site from 1988 to 1998. The plotted anomalies represent a six-month runnning mean through bimonthly and monthly data. a) Surface temperature and total carbon dioxide normalized to salinity ($nTCO_2$). The $nTCO_2$ data are corrected for an interannual increase of 1.6 µmol/kg/yr. b) Mean temperature in the top 100 meters and integrated primary production. c) Surface temperature and mixed-layer depth. d) Surface salinity and alkalinity normalized to salinity (nTA).

m²/d), and TCO_2 concentrations were higher by up to 5 micromoles per kilogram (µmol/kg). During periods with positive (warmer) temperature anomalies, mixed-layer depths were shallower, and rates of primary production and TCO_2 concentrations were lower.

These analyses demonstrate that the year-to-year variability of biogeochemical parameters such as TCO_2 and primary production at the BATS site is significant compared to seasonal variability. The next step is to determine whether there are potential linkages between the observed interannual variability and larger scale climate variability.

The NAO connection

As Table 1 shows, anomalies of temperature, salinity, mixed-layer depth, primary production and TCO_2 are correlated with variation in the NAO, a periodic shift in the strengths and positions of sub-polar high and low pressure cells in the North Atlantic and the winds associated with them. The coefficients of variability range from 0.32 to 0.52. This correlation is surprisingly high, given the inherent mesoscale variability of the Sargasso Sea, described by Dennis McGillicuddy and colleagues in the February 1998 issue of *U.S. JGOFS News*, and our "apples and oranges" comparison between climate patterns and ocean indices.

The correlation between ocean temperature and salinity anomalies and the NAO in the Sargasso Sea is not a new finding. Many other research groups have found a connection between ocean temperatures and the state of the NAO in this region. During positive NAO periods, the westerlies that usually prevail in the region between Florida and Cape Hatteras west of the Azores High weaken, reducing wind stress and heat exchange and leading to warm ocean temperature anomalies. During negative NAO periods, storm tracks appear to shift southward, cooling surface waters and deepening mixed layers. It makes sense that ocean biogeochemistry is linked to these regional changes. Only now, with BATS observations continuing into a second decade, can the connections between ocean biogeochemistry and climate phenomena begin to be demonstrated.

The ENSO connection

The anomalies of salinity and alkalinity shown in Figure 1 are significantly correlated with each other. They are also correlated with variation in the Southern Oscillation, a periodic shift in winds and pressure areas in the Pacific that is associated with episodic El Niño and La Niña events. We found that periods of lower salinity and alkalinity followed El Niño events by approximately six months, while a positive (high) salinity anomaly followed the 1997 La Niña event. Other researchers have found a similar lag between ENSO events and salinity anomalies in the Caribbean Sea and tropical North Atlantic.

As Table 1 shows, TCO_2 and alkalinity normalized for salinity levels are inversely correlated with the Southern Oscillation Index (SOI). On BATS cruises along the 64˚W meridian between 25˚N and 36˚N, we have found that normalized TCO_2 and alkalinity decrease southwards across the Sargasso Sea. The correlations between normalized TCO_2, normalized alkalinity and the SOI suggest that water masses passing through the BATS area change with time. Furthermore, changes may occur in the circulation patterns of the subtropical gyre that contribute to the interplay between ocean biogeochemistry and climate variability.

Our analysis indicates that NAO and ENSO play a role in modulating interannual biogeochemical variability at BATS. This statistical exercise demonstrates, once again, the value of long-term data sets in providing insight into large-scale ocean variability. As HOT and BATS continue into the new decade, our understanding of how ocean biogeochemistry is influenced by climate variability will continue to improve.❖

(Editor's note: Nick Bates, Craig Carlson and Debbie Steinberg of the Bermuda Biological Station for Research are co-principal investigators for BATS. Together with program manager Rod Johnson, they are responsible for the monthly sampling cruises and other activities of the decade-long time-series program.)

	SOI[2]	NAO	SST	Temp. (0-100m)	Salinity	TCO_2	$nTCO_2$	TA	nTA	ML	PP
SO Index[1,2]	—	—	—	—	—	—	—	—	—	—	—
NAO Index[1]	-0.43	—	—	—	—	—	—	—	—	—	—
Surface Temperature (SST)[1]	0.28[2]	0.40	—	—	—	—	—	—	—	—	—
Temperature (0-100m)[1]	0.35[2]	0.42	-0.66	—	—	—	—	—	—	—	—
Salinity[1]	0.52[2]	-0.48			—	—	—	—	—	—	—
TCO_2		-0.46	-0.54	-0.38	-0.44	—	—	—	—	—	—
$nTCO_2$[1]	-0.53[2]		-0.65	-0.45	-0.39	0.64	—	—	—	—	—
Alkalinity (TA)[1]	0.34	-0.52			0.69	0.25		—	—	—	—
nTA[1]	-0.41				-0.37	-0.39	0.38		—	—	—
Mixed Layer (ML)[1]	0.35[2]	-0.32	-0.56	-0.45		0.40	0.49			—	—
Primary Production (PP)[1]	-0.21[2]	-0.33	-0.51	-0.64		0.35	0.32			0.20	—

[1]6-month running mean of anomaly
[2]A lag of 6 months to the SOI gives the best correlations between SOI, hydrographic and biogeochemical parameters.

Table 1: Correlation coefficients for hydrographic and biogeochemical anomalies at the BATS sampling site (1988-1998) and large-scale climate patterns, represented by the Southern Oscillation Index (SOI) and the North Atlantic Oscillation (NAO) Index. Coefficients of less than 0.2 were not reported.

Commentary: The Legacy Of JGOFS

by Mark R. Abbott

Sixteen years ago, I received a letter from Kenneth Bruland of the University of California at Santa Cruz inviting me to a workshop in Woods Hole to discuss ocean biogeochemistry and a new program called the Global Ocean Flux Study (GOFS). Ken asked if I would co-chair a working group on Satellite/Surface Productivity with James McCarthy of Harvard University. At that time, the Coastal Zone Color Scanner (CZCS) radiometer on the National Aeronautics and Space Administration's Nimbus-7 research satellite was nearing the end of its useful life, and there were no firm plans for a successor. I thought that GOFS might provide impetus for such a mission, much as the World Ocean Circulation Experiment (WOCE) was providing a rationale for the TOPEX/POSEIDON (Ocean Topography Experiment) altimeter.

At the conclusion of the workshop on Sept. 14, 1984, the participants agreed on a goal for GOFS:

> *To identify and quantify the physical, chemical and biological processes controlling biogeochemical cycling in the ocean and their interaction with the global atmosphere. The goal is to understand the processes governing the production and fate of biogenic materials in the sea well enough to predict their influences on, and responses to, global-scale perturbations.*

Although my memories are somewhat blurred, I recall that we spent several long evenings at the National Academy of Sciences study center in Woods Hole, wordsmithing this goal and eight supporting objectives. The initial GOFS goal was not focused on carbon exclusively, but it did envision an interdisciplinary approach to biogeochemical cycling on a global scale with a focus on global-scale changes in the Earth system.

GOFS became U.S. JGOFS as the international, multidisciplinary program got underway. Although we have not met all of the original GOFS objectives, we have made significant progress and identified new objectives and new opportunities along the way. Estimates of amounts and distribution of anthropogenic carbon dioxide (CO_2) in ocean regions are greatly improved as a result of the global CO_2 survey. We have more confidence in our estimates of the flux of organic carbon from the surface waters to the depths and the sea floor.

Furthermore, results emerging from JGOFS studies have changed many of our basic concepts of ocean biogeochemistry. Data from the U.S. JGOFS time-series programs near Hawaii and Bermuda have shown that fluxes often vary in their elemental ratios from the Redfieldian standard for long periods of time. Episodic variability is an important component of ocean ecosystems and their biogeochemistry. These revisions in our thinking are especially important as we begin to predict the role of a changing ocean in a changing world.

A decade of process studies and time-series programs in various ocean basins in addition to the global survey of CO_2, carried out on WOCE Hydrographic Programme sections around the world, has produced an impressive array of scientific publications. Results from a number of national and international JGOFS studies have been published in a steady stream of Deep-Sea Research II special issues. The concept of ocean biogeochemistry as a discipline has begun to blossom.

When Hugh Ducklow of Virginia Institute of Marine Sciences (VIMS) assumed the chairmanship of the U.S. JGOFS Scientific Steering Committee in 1995, the Arabian Sea process study was coming to an end. The Antarctic Environment and Southern Ocean Process Study (AESOPS), last process study of the U.S. program, was about to get underway. Robert Anderson of Lamont-Doherty Earth Observatory and Walker Smith of VIMS coordinated the two-year study, overseeing field work in both the Ross Sea and the Antarctic Polar Frontal Zone. Although the AESOPS cruises were carried out, for the most part, under extremely difficult conditions, results presented at the ASLO/AGU Ocean Sciences meeting last month in San Antonio, Texas, have greatly advanced our understanding of this vast region of the world ocean.

From their earliest discussions, planners stressed the importance of data synthesis and the development of numerical models as critical components of the JGOFS legacy. As I begin my term as chairman, the focus of U.S. JGOFS has shifted to the Synthesis and Modeling Project (SMP), the final component of our national program. Scott Doney of the National Center for Atmospheric Research (NCAR) and Jorge Sarmiento of Princeton University are leading the SMP, which was launched in early 1998 to integrate the observational data sets through modeling and data analysis. Initial SMP results are expected to appear in a special issue of *Deep-Sea Research II* next year.

We are also discussing ways of enhancing the U.S. JGOFS data management system, which has provided outstanding service during the field program, to meet the particular needs of the SMP. Many SMP analyses, for example, need access to measurements organized by data type rather than by cruise. SMP coordinators and project scientist Joanie Kleypas of NCAR are working with Christine Hammond and David Schneider of the data management office to define these new requirements.

As JGOFS moves through its final stage, the global carbon cycle is continuing to receive considerable attention. In the U.S., the Carbon and Climate Working Group, co-chaired by Sarmiento and Steven Wofsy of Harvard University, recently released the U.S. Carbon Cycle Science Plan (CCSP), which strongly supports a continuing program of atmosphere, ocean and land

Cont. on page 9

U.S. JGOFS SMP Sponsors Workshop On Modeling Dynamics Of Equatorial Pacific Ecosystem

by Eileen Hofmann, Charles McClain and Fei Chai

As part of its effort to facilitate synthesis of the data sets obtained during JGOFS field studies, the U.S. JGOFS Synthesis and Modeling Program (SMP) is supporting small workshops that bring together investigators with common research interests. One such workshop was held in early November at Old Dominion University's Center for Coastal Physical Oceanography in Norfolk, Virginia. Its purposes were to discuss the current understanding of the physical and biological interactions that contribute to the structuring of the lower trophic levels of the equatorial Pacific Ocean ecosystem and to make recommendations for future studies. Some 23 researchers and graduate students participated in the two-day meeting.

The workshop began with overviews of current SMP studies of the equatorial Pacific. The first group of presentations focused on new production studies, carbon cycling, silicate dynamics, bacterial and zooplankton dynamics, optical studies, remote sensing of *Trichodesmium* species and large-scale patterns in phytoplankton distributions in the equatorial Pacific as determined from ocean color measurements made by the satellite-mounted SeaWiFS instrument.

These presentations were followed by talks on efforts to model aspects of the equatorial Pacific. The projects included simulation of La Niña dynamics, three-dimensional basin-scale ecosystem simulations and biological data assimilation. Other presentations focused on setting parameters for assessing iron limitation and an assessment of the feasibility of seasonal and interannual prediction of El Niño-Southern Oscillation (ENSO) patterns. The latter presentations showed that considerable progress has been made in modeling the physics and biology of the equatorial Pacific since the U.S. JGOFS Equatorial Pacific Process Study (EqPac) in 1992.

The original plan for the workshop was to break into working groups that would focus on specific topics: producing common data sets, especially of rate measurements, from field programs; identifying the benefits and limitations of using one-dimensional models, and coordinating potential comparisons of three-dimensional model structures and results, both physical and biological. Once the plenary discussion of workshop topics began, however, it became apparent that participants preferred to stay together to work on conclusions and recommendations as a group.

An initial task was to define a basic "background state" for the lower trophic levels of the equatorial Pacific Ocean. The consensus was that the background state for this region consists of a balanced system, in which gains equal losses, that is dominated by microzooplankton and picoplankton. The description of this system with data from various sampling methods and its simulation with mathematical models are high priorities. This comprehensive approach is a prerequisite for describing and understanding perturbations of this state.

Workshop participants recognized the need to understand the biological and physical mechanisms and interactions that support and sustain the background state. We also acknowledged, however, that the background state of the circulation of the equatorial Pacific is not known (or perhaps does not exist). Thus we do not know how biological-physical interactions sustain the background ecosystem.

As part of the effort to advance our understanding of the basic background state, participants listed several key biological processes and mechanisms that require further study. These include grazing behavior of micro- and mesozooplankton, the sinking rate of phytoplankton as a function of their nutritional state, iron and silicate interactions, switching in the feeding behavior of grazers and delays in the response of the zooplankton to changes in food supply.

We were all impressed by the advances that have been made in modeling the circulation of the equatorial Pacific. The circulation models are well able to describe ENSO patterns of the past and are now being used to predict future events. While the circulation models are adequate for these applications, however, improvements are still needed if they are to be coupled with biological models.

Many of the initial ecosystem modeling efforts for the equatorial Pacific use one-dimensional models with physical parameters derived from the output of circulation models. Ecosystem modelers particularly need simulated time-series of vertical velocity, convective adjustment, vertical mixing and vertical diffusion coefficients from circulation modeling results. However, the physical dynamics that produce these motions are not always well represented in the circulation models. Areas in which circulation models need improvement include simulation of the vertical velocity structure, entrainment velocity, heat content of the surface layer, mixed layer dynamics, the diel cycle of mixing, sea surface temperature, and the resolution of tropical instability waves and higher frequency motions.

Participants recognized the role of modeling and the many advances made in coupling circulation and biological models for the equatorial Pacific. Continued advances in this area, however, require the input of data sets, especially as data assimilation becomes a routine component of biological modeling. We need to acquire long-term monitoring data sets for biological variables like the ones that are available for physical observations from the Tropical Atmosphere Ocean (TAO) array, for example. Routine measurements that would be particularly useful and feasible to collect with instruments mounted on moorings include the partial pressure of carbon dioxide (pCO_2), optical properties and nutrient concentrations.

The data analysis and modeling studies that have taken place since the U.S. JGOFS EqPac field program have highlighted the need for other types of data that were not part of that study. These include iron profiles, rate measurements that take into account size and taxa of organisms, and measurements to elucidate silicate cycling. Workshop participants felt that these measurements should be a part of any future multidisciplinary field programs planned for the equatorial Pacific Ocean.

We also identified topics that need attention now in order to make the best use of the existing EqPac data sets. They include the synthesis of existing zooplankton grazing parameters and biomass estimates, beam attenuation/particulate organic carbon calibration, calcification rates, and dissolved organic matter production and consumption rates. The availability of these results would greatly enhance current modeling and analysis efforts.

The final workshop discussions focused on defining group efforts that could facilitate synthesis of the ongoing equatorial Pacific modeling efforts. Workshop participants who have coupled physical-biological models agreed to compare the output of their models at 140˚W and 165˚E for the periods of March 1992 and October 1992.

The comparisons will be made using simulations from the models currently being run by groups at the University of Maine, Old Dominion University, the University of Washington and the National Aeronautics and Space Administration's Goddard Space Flight Center. Comparisons will be made in terms of state variables such as nutrients and chlorophyll, as well as derived quantities such as f-ratio, the export flux of carbon, nitrogen and silicate from the euphotic zone (top 120 meters), and primary and secondary production. Jim Christian of Goddard Space Flight Center agreed to lead this effort.

The results of this comparison exercise will help us to highlight differences and similarities among the models, to make recommendations for model improvements and modifications and to indicate areas where additional data are needed.❖

(Editor's note: Eileen Hofmann of Old Dominion University, Fei Chai of the University of Maine and Charles McClain of Goddard Space Flight Center were co-conveners of the SMP equatorial Pacific workshop.)

Legacy – (Cont. from page 7)

studies of carbon cycling. Goal 2 of the CCSP is to understand the ocean carbon sink, including its uptake of anthropogenic CO_2, interannual variability and spatial patterns. Within this broad goal, the CCSP identifies several specific scientific and technical objectives based on field observations, direct manipulation experiments and modeling. It is worth noting that the CCSP stresses the importance of integrated studies of the complete Earth system.

With the renewed interest in carbon cycling, three program concepts are emerging. A proposed Surface Ocean Lower Atmosphere Study (SOLAS) is being formulated with strong international participation. SOLAS has the following goals:

- To formulate and test hypotheses for key interactions between the marine biogeochemical system, the atmosphere and climate;
- To quantify cause and effect in those interactions;
- To incorporate this new understanding into models.

The second plan, Ecological Determinants of Ocean Carbon Cycling (EDOCC), emerged last year at the AGU/ASLO Aquatic Sciences meeting in Santa Fe. It asks:

- How do environmental and biotic factors determine the distributions and activities of key species or functional groups important to biogeochemical cycles in space and time?
- What are the important interactions among marine biota, global climate and biogeochemistry?

The third plan is Ocean Carbon Transport, Exchanges and Transformations (OCTET). The central goal of OCTET is:

- To better characterize physical, geochemical and biological controls that govern regional and vertical partitioning of inorganic and organic carbon pools within the ocean, and, therefore, the spatial and temporal variations in the partial pressure of CO_2 in the mixed layer.

Although carbon cycling is a common theme in all three, each program has a different focus. With increasing societal interest in the interactions between the global climate system and biogeo-chemistry, we feel a special urgency to reduce our uncertainties about future changes in the Earth system. Each program is actively soliciting input from the oceanographic community. As they develop and mature, we should all contribute our insights.

Big questions are being asked regarding the interfaces between land and ocean, between the atmosphere and ocean, between the coastal ocean and the open ocean. Answers will require interdisciplinary approaches as well as a mix of large-scale programs and individual science projects.

We have learned many scientific lessons over the 16 years since GOFS was launched. We have also learned that open access to data, an open management process and interdisciplinary teams are essential for programs that tackle complex scientific questions. I hope that this legacy of JGOFS will be remembered.

(Editor's note: Mark Abbott, professor of biological oceanography at Oregon State University, was elected chairman of the U.S. JGOFS SSC in October 1999.)

How The Deep Arabian Sea Reflects The Productivity Of Surface Waters

by Karin Lochte and Olaf Pfannkuche

The deep ocean and sea floor receive the crumbs that fall down from the feast in the surface waters. It seems, at first sight, obvious that the productivity of the benthic regions should present an impoverished image of the riches above. However, this picture is more often than not altered, sometimes beyond recognition, by bottom topography, deep sea currents and transport down shelf slopes, as well as by the inability of current methods to measure true deep-sea rates of productivity. In many cases, strong productivity gradients occur in upwelling regions along continental margins where the sea floor slopes down more than 1,000 meters, making comparable measurements futile.

The Arabian Sea is a very interesting study area in this respect, as the monsoon winds establish a distinct productivity gradient from the eutrophic upwelling areas in the west and north to the oligotrophic southeastern parts. Long-term sediment trap studies at three stations document the high sedimentation rates in the western and northern regions of the Arabian Sea, among the highest recorded in the world's ocean. Water depth varies only from roughly 3,000 meters to 4,400 meters; the region thus offers sites well suited to a comparative study of the influence of different sedimentation regimes on deep-sea biogeochemical processes.

We investigated the coupling between monsoon-driven productivity cycles and benthic processes in the Arabian Sea in a study titled Biogeochemical Transports of Energy and Matter in the Deep Sea (BIGSET), which is part of the German national deep-sea research programme. We expected that the spatial trophic gradient would leave its imprint on the biogeochemistry of the deep sea, and we also supposed that the distinct biannual monsoon patterns could be detected.

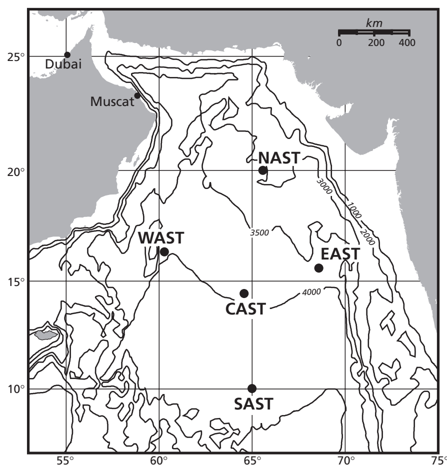

Figure 1: Map of the study area showing the main sampling stations.

We conducted an intensive study with different types of benthic landers, benthic observation systems and video-controlled baited traps at five main stations on four cruises (R/V *Meteor* 31-3, R/V *Meteor* 33-1, R/V *Sonne* 118, R/V *Sonne* 129) from 1995 to 1998 at different times of the monsoon cycle (Figure 1). The stations are located at the long-term sediment trap sites of the Indian/German sediment trap programme of the National Institution of Oceanography in Goa, India, and the University of Hamburg, Germany. Our study also benefited from access to the results from the U.S. JGOFS sediment trap arrays, which covered the deep basin from the southern station (SAST) northwest to the Oman upwelling area.

We found a spatial gradient, similar to the gradient in surface-water productivity estimated from satellite images, for a variety of benthic element concentrations, turnover rates and biochemical parameters (Figure 2). We used these values to rank the stations according to the level of benthic activity we found at each: WAST, NAST, CAST/EAST, SAST. It is remarkable that the stations fell into the same or a similar ranking with regard to processes with time scales differing by orders of magnitude, like respiration rates at the sediment-water interface or shifts in the proportions of elements in deep sediment cores. These results show that differences in surface-water productivity leave a distinct mark on sea-floor biological and biogeochemical phenomena.

Our observations at the station situated in the western Arabian Sea (WAST) closest to the upwelling region off Oman show that this area is clearly the most eutrophic of the region. The high rates of particulate organic carbon (POC) rain measured here by sediment traps are reflected in the high concentrations of chlorophyll *a* and total pigment inventories in the sediments. We observed significantly higher biomass of macrofauna, meiofauna (nematodes), living foraminifera and bacteria at this station in comparison with the other stations.

Our benthic landers, shown in the accompanying photograph, measured overall benthic remineralisation rates at station WAST that are comparable to the high rates found on upper continental slopes. High bacterial production rates and activities of extracellular enzymes give further evidence of unusually high turnover rates. Benthic carbon consumption estimated from respiration measurements by benthic landers and from bacterial production are higher than the POC flux determined by the sediment traps (Figure 2). The evidence from these and a number of other measurements suggests that lateral input from the continental shelf increases the amount of organic matter consumed and deposited at this location. We measured substantial sulfate reduction rates here at a sediment depth of 12 centimeters, which is a new observation for abyssal sites.

At the northernmost station (NAST), we found elevated values for many of the parameters that we measured, but most were significantly lower than at WAST. Values found at the stations in the central (CAST) and eastern (EAST) Arabian Sea were intermediate and fairly similar. The southern station (SAST) is located in the most oligotrophic region of the area investigated, but it still bears some signs of monsoonal influences. Here some parameters showed higher values than at other abyssal sites, such as the BIOTRANS site in the northeast Atlantic, which is influenced by mass sedimentation events after the spring phytoplankton bloom (Figure 2).

photo by O. Pfannkuche

Benthic lander system of the GEOMAR research centre features three benthic chambers equipped with oxygen electrodes and syringe arrays for collecting water samples.

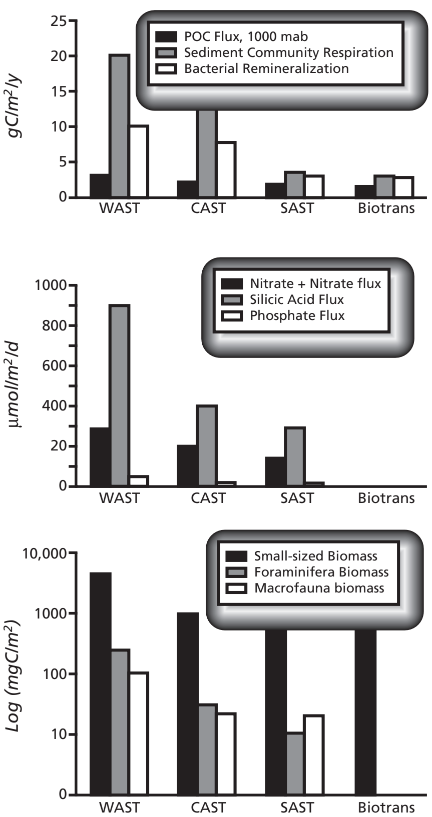

Figure 2: Measurements made at Arabian Sea stations WAST, CAST and SAST and at a deep-sea site (BIOTRANS) in the northeast Atlantic at 47.30°N, 20°W. Top panel shows POC flux, sediment community respiration and bacterial remineralization rates. Middle panel shows nutrient fluxes at the sediment-water interface estimated from concentration profiles. Bottom panel shows the biomass of groups of benthic organisms. Small-sized organisms were determined from concentrations of phospholipids.

Despite clear regional trends, only microbial activity and biomass showed significant linear correlations with the vertical flux of POC; macrofaunal and meiofaunal biomass did not show a similar correlation. Instead we observed some distinct behavioural differences. At the more eutrophic stations, macrofauna and meiofauna were found deeper in the sediment, whereas they only occupied the upper sediment layers at the oligotrophic station SAST. Despite this shallow distribution, surprisingly high bioturbation rates were found at SAST. They were probably caused by an abundant community of benthic worms called echiurids, which produce feeding traces that look like the spokes of a wheel.

Baited traps showed that the main consumers of large food falls were ophidiid fish, which consumed the bait faster at SAST than at WAST. One could speculate that a richer food supply slows down the hunt for carrion at the eutrophic sites. With a deep-sea video, we made the unexpected observation at WAST and CAST that masses of swimming crabs had died and sunk to the sea floor. These crabs had been found previously in sediment traps and were discarded as unwanted "swimmers." Perhaps they should have been included in the POC flux estimates. Although the extent of this event and its causes remain unknown, this large food fall contributed significantly to the input of organic matter to the deep sea.

Although pronounced seasonal fluctuations in particle fluxes are found in the Arabian Sea, we could detect only a few significant temporal changes in benthic processes that can be linked to the monsoon cycle. This is due in part to the high variability in the benthic data but also, perhaps, to the timing of the expeditions. Apparently our investigations in autumn 1995 did not hit the peak particle pulse of the southwest (summer) monsoon, which was more than a month later than average.

We were surprised to find that most parameters describing biomass, metabolic activity or degradation rates showed an increase after the northeast (winter) monsoon. The effect was more pronounced at NAST and CAST and less distinct at WAST and EAST. It indicates that the impact of the northeast monsoon on the carbon cycling in the Arabian Sea has been greatly underestimated so far.

The results of our investigations have been submitted for publication in a *Deep-Sea Research II* special issue titled "Biogeochemistry of the deep Arabian Sea." More information is available at our World Wide Web site (**http://www.geomar.de/sci_dpmt/umwelt/u_special.html**).

(Editor's note: Karin Lochte is a senior scientist at the Baltic Sea Research Institute of Warnemünde, Rostock, Germany. Olaf Pfannkuche is a senior scientist at the GEOMAR Research Center, Kiel, Germany.)

Commentary: Ocean Biogeochemistry In The Post-Kyoto World

by Hugh W. Ducklow

As we and the societies that we have created enter the post-Kyoto world, we are still adding carbon to the atmosphere at unprecedented rates. During 1996 alone, human activities released some 6.5 petagrams (6.5 billion metric tonnes) of carbon. The carbon dioxide (CO_2) content of the atmosphere is still increasing at rates possibly not achieved over the last 25 million years. Because of strong La Niña conditions in the Pacific, the year 1999 was only the sixth warmest in the instrumental record, but 1998 was the warmest year yet measured.

Hugh Ducklow

The Kyoto Protocol to the United Nations Framework Convention on Climate Change, signed in Japan in December 1997, obligates participating countries to reduce their aggregate CO_2 emissions to 5% below 1990 levels. In response, national governments, corporations and individuals are now energetically pursuing means of exchanging carbon credits and sequestering carbon, including a plethora of ocean storage options such as nutrient enrichment to enhance the intensity and efficiency of the biological pump.

Where does JGOFS, with its principal focus on the ocean carbon pumps, fit in?

Last autumn, in preparation for succeeding Michael Fasham as chairman of the JGOFS Scientific Steering Committee (SSC) in January, I asked members of our community for their suggestions on what issues mattered to them, to JGOFS, to *U.S. JGOFS News* readers. Although I received quite a few thoughtful responses, one in particular stood out. Trevor Platt, chairman of the JGOFS SSC from January 1991 to January 94, wrote: "In my view, the most pressing issue for JGOFS right now is planning future programs in ocean biogeochemistry; how to retain the initiative for the next round. By this, I imply that the synthesis is in good hands." The great accomplishment of Trevor's term in office was placing the issue of global synthesis squarely before JGOFS scientists and funding agencies. So while it was reassuring to hear that he is confident that the synthesis effort is on track, the other implication of Trevor's message is more serious.

JGOFS will end in less than 4 years. It doesn't have all the answers, and it won't get them all during its synthesis phase. The achievements of JGOFS include the creation of a comprehensive and accessible database and management system, establishment of time-series observatories, a global survey of CO_2 in the ocean, five major process studies, effective use of ocean color data from satellite-mounted instruments and an ongoing synthesis and modeling effort. These achievements and the goals of the synthesis program have been reported and discussed elsewhere. Is there a need for another global-scale research program in ocean biogeochemistry? If so, what are the prospects for it?

To predict the future operation of the ocean carbon system, we need to observe and understand the way it works now. JGOFS made a start. But no matter what the course of fossil fuel-based emissions in the coming decades and whether or not emission controls or carbon storage measures are adopted widely, we need to monitor not only atmospheric CO_2 but also the major carbon sinks and sources on land and in the oceans. The efficiency and intensity of these sinks and sources vary from year to year and decade to decade. We cannot say with much certainty how carbon fluxes will change in response to carbon cycle management or climate change. Will we know if ocean productivity begins to change or the formation of deep water slows or stops?

Responsible and intelligent implementation of the Kyoto Protocol and purposeful carbon sequestration measures demand, first, a monitoring strategy that will enable us to detect interannual variability and any changes that may occur in the ocean carbon cycle. The international Global Ocean Observing System (GOOS) is just beginning to consider carbon observations that will, if implemented, address the problem of ocean monitoring. But other key uncertainties remain that cannot yet be resolved with operational observations alone.

Some of these uncertainties and key questions are laid out in a recent U.S. report titled "A U.S. Carbon Cycle Science Plan" (**http://geochange.er.usgs.gov/usgcrp/ccsp/planning.html**). CCSP is a new scientific research initiative designed to extend across U.S. national funding agencies to address carbon cycling within the terrestrial biosphere, the ocean biogeochemical system and the atmosphere in an integrated way. In his editorial in this issue, U.S. JGOFS chairman Mark Abbott has described Ocean Carbon Transport, Exchanges and Transformations (OCTET) and Ecological Determinants of Ocean Carbon Cycling (EDOCC), two planning initiatives that have emerged in the U.S. in response to the CCSP.

Other pertinent research needs are being assessed by the international SOLAS (Surface Ocean Lower Atmosphere Study) planning group under sponsorship of the International Geosphere-Biosphere Programme (IGBP) and the Scientific Committee on Oceanic Research (SCOR). The focus of SOLAS is on key interactions between the atmosphere, climate and marine bio-

Cont. on page 15

PICES Group Focuses on Quality Of CO_2 Measurements In North Pacific

by Andrew G. Dickson

As investigators in the synthesis and modeling phase of JGOFS work with results from the program's field studies to build global and regional estimates of the sinks and sources of carbon dioxide (CO_2) in the ocean, the need remains for continuing high-quality measurements of ocean carbonate system parameters. Recognizing this need, the North Pacific Marine Science Organization (PICES) has taken steps to ensure the quality of such measurements in the North Pacific Ocean.

The Physical Oceanography and Climate Committee of PICES, an intergovernmental organization comprising Canada, China, Japan, Russia and the United States, established a working group on CO_2 in the North Pacific in 1998. Chaired by Richard Feely of the National Oceanic and Atmospheric Agency's Pacific Marine Environmental Laboratory in the U.S. and Yukihiro Nojiri of the National Institute for Environmental Studies in Japan, PICES Working Group 13 is responsible for reviewing the current understanding of processes controlling CO_2 in this region and for encouraging future efforts.

At its first meeting in Fairbanks, Alaska, in October 1998, the working group decided that its highest priority was to initiate detailed technical exchange regarding measurement techniques and data quality among the scientists involved in studying CO_2 in the North Pacific. The strategy we chose was to conduct an inter-laboratory comparison, followed by a technical workshop. For our initial study, we decided to focus on the measurement of total dissolved inorganic carbon and total alkalinity in sea water.

Preparations for this exercise began right after the Fairbanks meeting. Four samples were prepared for distribution:

- A certified reference material (CRM Batch 45) prepared at Scripps Institution of Oceanography;
- A surface seawater sample prepared at Scripps;
- A surface seawater sample prepared at the University of Hokkaido in Japan;
- A deep (3000 meter) seawater sample prepared on board R/V *Mirai* and supplied by the Japan Marine Science and Technology Center (JAMSTEC).

Samples were distributed to participating laboratories early in 1999. In all, 13 laboratories were involved: seven from Japan, three from the United States, and one from each from Canada, Korea and Taiwan (Table 1). All participants returned their results promptly.

The technical workshop was held April 20-22, 1999 in Tsukuba, Japan, at the National Institute for Resources and Environment (NIRE). It was organized by Yukihiro Nojiri of the National Institute for Environmental Studies (NIES) and Koh Harada of NIRE and supported jointly by PICES, JAMSTEC and the Kansai Environment Engineering Center (KEEC).

The 31 workshop participants, including Galina Pavlova of the Pacific Oceanological Institute in Vladivostock, Russia, as an observer, enjoyed a detailed discussion of the analytical techniques used by their laboratories for the measurement of total dissolved inorganic carbon and total alkalinity. The instruments from a number of the participating groups were set up in a laboratory next to the meeting room.

The results of the actual intercomparison, discussed in detail at the workshop, were relatively encouraging. For total dissolved inorganic carbon, the results from a number of laboratories clearly reflected the effects of calibration problems. Once the various values had been adjusted to a common calibration scale using

Table 1: CO_2 Technical Workshop Participants

W. Keith Johnson, Institute of Ocean Sciences, Sidney, Canada
Kiminori Shitashima, Central Research Institute of Electric Power Industry, Abiko, Japan
Shuichi Watanabe, Hokkaido University, Sapporo, Japan
Akihibo Murata, Japan Marine Science and Technology Center, Yokosuka, Japan
Nobuo Tsurushima, Japan Science and Technology Corporation & Hokkaido University, Sapporo, Japan
Takeshi Egashiri & Fujio Shimano, Japan Science and Technology Corporation & National Institute for Environmental Studies, Tsukuba, Japan
Koichi Goto, Takashi Harimoto, Kazunori Isheda, Takashi Kitao, Hidekazu Ohta & Hiroyuki Tsubota, Kansai Environment Engineering Center Ltd., Osaka, Japan
Jun Imai & Hideki Yamamoto, Marine Works Japan Ltd., Yokohama, Japan
Hisayuki Inoue & Masao Ishii, Meteorological Research Institute, Tsukuba, Japan
Yukihiro Nojiri, National Institute for Environmental Studies, Tsukuba, Japan
Koh Harada & Yutaka Y. Watanabe, National Institute for Resources and Environment, Tsukuba, Japan
Tsuneo Ono, National Research Institute of Fisheries Science, Yokohama, Japan
Takashi Kimoto, Research Institute of Oceano-Chemistry, Osaka, Japan
Mino Aoki, Tokyo University of Fisheries, Tokyo, Japan
Dong-Jin Kang, Seoul National University, Seoul, Korea
Galina Pavlova, Pacific Oceanological Institute, Vladivostock, Russia
Richard Feely and Marilyn Roberts, NOAA Pacific Marine Environmental Laboratory, U.S.
Justine Afghan, George Anderson and Andrew Dickson, Scripps Institution of Oceanography, San Diego, U.S.
Chris Carillo and Dale Hebel, University of Hawaii, Honolulu, U.S.

The laboratories of Chen-Tung Arthur Chen at National Sun-Yat Sen University, Taiwan, and Rik Wanninkhof of the NOAA Atlantic Oceanographic and Meteorological Laboratory, U.S., participated in the measurement exercise but not in the workshop.

the measurements made on the certified reference materials, however, agreement between the various laboratories was excellent (+/- 2 micromoles per kilogram).

For total alkalinity, the results were more disappointing. Although adjustment to a common calibration scale helped to reduce the extent of the disagreement, there were still major differences among results from different laboratories (+/- 12 micromoles per kilogram).

Both the technical workshop, which all found stimulating and informative, and the wonderful hospitality of our hosts made the visit to Tsukuba extremely enjoyable. A detailed report describing the interlaboratory comparison and the subsequent workshop is in preparation and will be published by NIES in both Japanese and English.

Working Group 13 met again at the PICES conference in Vladivostock last October and decided that this activity should continue, focusing primarily on improving the measurement of total alkalinity. The approach will be similar to that of the last exercise. A sample exchange in March will provide the basis for another comparison of measurement techniques. To ensure comparability of the results from the various laboratories, a calibrated acid sample will also be distributed for use in this exercise.

A second technical workshop will follow to discuss the results. Planned for October 2000 in Tsukuba, Japan, it will be held in conjunction with a symposium on North Pacific CO_2 data synthesis cosponsored by PICES and the Japan Science and Technology Agency. Our hope is that significant progress will have been made towards our goal - that measurements made at different times, by different investigators, from different laboratories be comparable and correct.❖

(*Editor's note: Andrew Dickson, an associate professor at Scripps Institution of Oceanography, is a member of PICES Working Group 13. His laboratory was responsible for producing certified reference materials for measurements of ocean carbonate system parameters during the JGOFS field studies*).

New Deputy Director Sought For IGBP

Neil Swanberg, deputy executive director of the International Geosphere-Biosphere Programme (IGBP), is leaving in March to take a new position at the U.S. National Science Foundation. During his years in Stockholm, Neil oversaw the operations of the oceanic core projects of IGBP, including Global Ocean Ecosystems Dynamics (GLOBEC) and Land-Ocean Interactions in the Coastal Zone (LOICZ) as well as JGOFS. Both GLOBEC and LOICZ were adopted as IGBP core projects under Swanberg's direction, and JGOFS completed most of its field work and entered its synthesis phase.

Swanberg received his doctorate from the Woods Hole Oceanographic Institution-Massachusetts Institute of Technology joint program in oceanography and worked at Lamont-Doherty Earth Observatory and the University of Bergen before joining the IGBP Secretariat in October 1993. Over the next few months JGOFS will be assisting in the search for Swanberg's successor at IGBP.

Conference Will Focus On JGOFS Synthesis

JGOFS investigators will present their latest results at the upcoming second open science conference, to be held April 13 to 17 in Bergen, Norway. Titled "Ocean Biogeochemistry: A New Paradigm," the conference will focus on the synthesis of JGOFS data from a decade of international and multidisciplinary field studies.

In 10 keynote talks, speakers will address a number of biogeochemical themes in studies of the ocean carbon cycle. These themes include biogeochemical regimes, primary production and export, temporal variability, community structure, exchange with continental margins, feeback processes and ocean carbon modelling. Conference organizers are also expecting 58 oral presentations and more than 100 posters.

The conference will provide a venue for summarizing JGOFS scientific accomplishments and progress toward achieving both a global view of ocean biogeochemical processes and a better understanding of the role of the ocean in climate change. The future of ocean biogeochemical research will be the topic of joint sessions on each of the last two days of the conference.

More information about the open science conference is available from the JGOFs International Project Office in Bergen or on line via the JGOFS home page at **http://ads.smr.uib.no/jgofs/conference.htm** . Information about registration, accommodations and fees is available at **http://www.plus-convention/no/**.

JGOFS Publications

A new report titled **JGOFS Publications 1988-1999** is now available from the JGOFS International Project Office (IPO) in Bergen, Norway. The report, number 30 in the JGOFS series, is available on line via **http://ads.smr.uib.no/jgofs/publications/on-line/JGOFS30.pdf** . Scientists are encouraged to check their publications in this report and to send updates to Beatriz Baliño, assistant scientist in the IPO.

Final Phase Of CANIGO Begins With Conference In Spain

by Gregorio Parrilla and Gerold Wefer

The final phase of the Canary Island, Azores, Gibraltar Observation (CANIGO) project was launched with a conference, "The Marine System in the Canary-Azores-Gibraltar Region," which took place in Las Palmas de Gran Canaria, Spain, in September 1999.

CANIGO is the second-largest project funded by the European Programme of Marine Science and Technology (MAST) III. Employing comprehensive interdisciplinary basin-scale studies, its primary goal is to understand the functions and processes of the marine system in the Canary-Azores-Gibraltar region as well as system links with the Mediterranean Sea. The project is a collaboration of 45 partner institutions from 10 European Union countries plus Switzerland and Israel.

The project began in August 1996. It has included, to date, some 50 cruises, more than 700 days of shiptime and around 1,700 stations, plus XBT lines, RAFOS deployments and 40 moorings. CANIGO also includes a significant modelling effort.

Synthesising the data into a consistent representation of the ocean system in this region and comparing them to model results is the aim of the final phase of CANIGO. The synthesis has already begun with several sub-project workshops. The goals of the conference were:

- to review the present knowledge of physical, chemical and biological processes in the Canary-Azores-Gibraltar region;
- to present recent results from CANIGO and from other related studies in this region;
- to discuss seasonal and interannual changes in circulation, water mass and material distributions;
- to discuss sediment properties, geological processes and the corresponding variability on long time scales, and
- to relate regional variability to global climate change.

The conference was attended by more than 200 scientists; 58 oral presentations were given, and 80 posters were presented in the four non-parallel sessions. The topics discussed covered a wide range of themes and interests, reflecting the interdisciplinary character of the CANIGO project.

The data gathered in CANIGO, covering almost the entire gamut of oceanographic observations, are being stored in a common project database. They will be in the public domain, according to the MAST code for data management, through national and international centres. The scientific community will also be informed about access to CANIGO remote-sensing imagery and about the availability of model codes and results.❖

(Editor's note: Gregorio Parrilla of the Instituto Español de Oceanografía Madrid is coordinator of CANIGO. Gerold Wefer of the Universität Bremen is chairman of the Particle Flux and Paleoceanography sub-project.)

Commentary: (Cont. from page 12)

geochemical processes. The IGBP has also initiated a Carbon Working Group, which has mostly addressed questions in the terrestrial realm so far. There are no international plans as yet for a more comprehensive, top-to-bottom study of ocean carbon biogeochemistry.

As a result, the hiatus in large-scale ocean biogeochemical research that dates from the end of most of the JGOFS field programs in 1998-99 is likely to continue for several more years. It seems critical to regain momentum, to establish a reliable ocean baseline at the beginning of the post-Kyoto era.

Narrowing uncertainty in the future evolution of the ocean's physical and biological carbon pumps is the most critical need in order to achieve more accurate predictions of ocean carbon storage and a solid scientific basis from which to develop carbon management strategies. Most geochemists assume tacitly that the biological pump is in steady state on the time scale of the anthropogenic perturbation. Some biologists disagree. JGOFS observations at the Hawaii Ocean Time-series (HOT) site suggest that a fundamental, decadal-scale shift from nitrogen to phosphorus limitation is underway in the North Central Pacific Gyre, the largest biome on Earth. The ocean is likely to warm by 2° to 3° C during the next century, with a consequent reduction in the solubility of CO_2, a diminution in the thermohaline circulation, and thus a weakening of the physical carbon pump.

Models also suggest reductions in ocean biological productivity and weakening of the biological pump as the ocean changes. How certain are these qualitative projections of climate-induced changes in the ocean carbon system, and at what rates will they proceed? What new surprises lie waiting for us to find? How will these "passive" changes interact with active modifications of the carbon cycle from iron addition and CO_2 injection? How will ocean biology respond to changes in circulation? What is driving the decade-scale changes observed off Hawaii?

We need a new consensus to plan and implement the next generation of ocean biogeochemical observations, experiments and models. The JGOFS community, the group of scientists best equipped to provide the answers, has an invaluable role to play in designing a new attack on the global carbon cycle.❖

• U.S. JGOFS Calendar 2000 •

11-12 April: JGOFS Scientific Steering Committee meeting, Bergen, Norway. Contact: Roger Hanson, JGOFS International Project Office, University of Bergen.

13-17 April: Second JGOFS Open Science Conference, Bergen, Norway. Contact: Roger Hanson, JGOFS International Project Office, University of Bergen.

20-22 June: U.S. JGOFS Scientific Steering Committee meeting, Washington, DC. Contact: Ken Buesseler, U.S. JGOFS Planning Office, Woods Hole Oceanographic Institution, Woods Hole, MA.

28-30 June: Antarctic Polar Frontal Zone workshop, Oregon State University, Corvallis. Contact: Robert Anderson, Lamont-Doherty Earth Observatory or Walker Smith, Virginia Institute of Marine Sciences.

9-13 July: The Southern Ocean: Climatic Changes and the Cycle of Carbon, Brest, France. Contact: Paul Tréguer, Institut Universitaire Européen de la Mer, Brest.

10-14 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.

18-21 September: Biogeochemical Cycles: German Contribution to JGOFS, Bremen, Germany. Contact: Gerold Wefer, Bremen University.

Getting Access to U.S. JGOFS Data and Information

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

http://usjgofs.whoi.edu/

Inquiries may be addressed to the U.S. JGOFS data management office via electronic mail to **dmomail@dataone.whoi.edu** or by phone to David Schneider (508-289-2873).
Data from U.S. JGOFS process study cruises are available through the U.S. JGOFS data management system at the Web site above.
Data from the U.S. JGOFS time-series programs are also available via the World Wide Web at the following sites:
HOT **http://hahana.soest.hawaii.edu/hot/hot-dogs/interface.html**
BATS **http://www.bbsr.edu/ctd**
Data from the Survey of Carbon Dioxide in the Oceans are available from the Carbon Dioxide Information Analysis Center at
http://cdiac.esd.ornl.gov/oceans/home.html

U.S. JGOFS News

Published quarterly by the U.S. JGOFS Scientific Steering Committee
Editor: Margaret C. Bowles
Designer: Jeannine M. Pires

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

We welcome your comments and contributions for publication.

To obtain a free subscription, write to:

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

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

Address service requested

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