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.

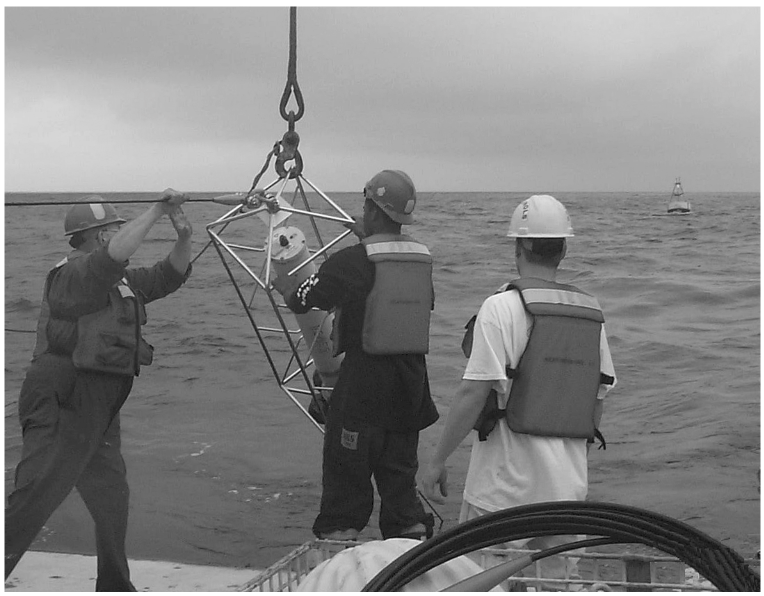

photo by T. Dickey

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)

Advances–from page 9

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**).