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A REVIEW OF THE NOPP OCEAN-SYSTEMS FOR CHEMICAL, OPTICAL, AND PHYSICAL EXPERIMENTS (O-SCOPE) PROJECT

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1. INTRODUCTION

The National Ocean Partnership Program (NOPP) sponsored Ocean-Systems for Chemical, Optical, and Physical Experiments (O-SCOPE) program addresses the need for next-generation, autonomous, near real-time, nearly continuous, long-term, time-series measurements in critical regions of the world ocean. The program has an overarching objective to improve the variety, quantity, quality, and cost-effectiveness of observations in anticipation of a global ocean observing network of strategically placed moorings and other ocean platforms. Benefits of O-SCOPE concern the development of technologies, which can be used to quantify seasonal, interannual, and decadal changes in upper ocean biogeochemical, bio-optical, and physical, variables. These variables bear on understanding and predicting global climate change and its impacts on ocean chemistry and ecology.

2. OBJECTIVES

Basic NOPP O-SCOPE objectives are to:

1. Identify key variables to be measured, determine capabilities and limitations of available sensors, and define specifications for next-generation sensors
2. Design, develop, and test integrated interdisciplinary systems for biogeochemical, bio-optical, and physical measurements (e.g., low-cost, easily deployable, reliable, robust)
3. Design a testbed mooring program (e.g., deployment scheduling, sampling rates, instrument placement depths, etc.)
4. Deploy next-generation interdisciplinary instrument suites on three moorings
5. Evaluate performances of new instrumentation and telemetry systems.

3. APPROACH

Sensors measuring a host of interdisciplinary variables from moorings can be configured to provide a continuous early warning system to global change in the ocean (e.g., Global Ocean Observing System (GOOS) concept; Dickey, 1991). O-SCOPE is capitalizing on a variety of recent technological advances (e.g., pCO_2, pH, and alkalinity sensors, nitrate analyzers, spectral optical sensors, and data telemetry; see Blain et al., 2000; DeGrandpre et al., 2000; Varney, 2000; Tokar and Dickey, 2000) to accelerate the implementation of a plan to instrument (i.e., network) critical regions of the ocean (e.g., North and South Atlantic Oceans, North and South Pacific Oceans, Southern Ocean) with long-term interdisciplinary moorings. Data obtained from a mooring network of time-series observations can be extrapolated using remote sensing and models. A vision for the future is to develop an integrated system for enabling near real-time data distribution to the oceanographic community (for education as well as research) via the internet. We are utilizing ongoing testbed mooring programs near Bermuda (i.e., Bermuda Testbed Mooring; BTM; see Dickey et al., 1997, 1998, 2000) and in Monterey Bay (MOOS mooring; see Chavez et al., 1997), as well as existing measurement programs, capabilities, and facilities (e.g., Bermuda Atlantic Time-Series Study (BATS) at the Bermuda Biological Station for Research (BBSR); Monterey Bay Research Institute (MBARI)) for biogeochemical, bio-

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optical, and physical sensor development, testing, and seatruthing. New instrumentation has also been deployed at Ocean Weather Station "P" (OWS "P") in the North Pacific Ocean.

4. RESULTS

Nick Bates (BBSR) has completed work with Liliane Merlivat (University of Paris VI) on the analysis of seawater pCO_2 data collected from an autonomous buoy system (i.e., Carbon Interface Ocean Atmosphere; CARIOCA), tethered to the BTM; nearly co-located concurrent BATS ship-based seawater pCO_2 data were also collected. The CARIOCA buoy pCO_2 data were determined to be accurate to within ± 3 μatm compared to shipboard measurements (Bates et al., 2000). Bates has also been working with Mike DeGrandpre (University of Montana at Missoula) toward the deployment of the DeGrandpre Submersible Autonomous Moored Instrument (SAMI) pCO_2 system from the BTM (DeGrandpre et al., 2000).

Bob Byrne (USF) has developed the Spectrophotometric Elemental Analysis System (SEAS), which has been configured for measurements of the absorbance ratios of pH sensitive indicator dyes (Hopkins et al., 2000; Kaltenbacher et al., 2000). The system autonomously mixes seawater and indicator dye, records absorbances at three wavelengths within the liquid core waveguide spectrophotometer cell, and communicates with external electronics for data transmission via the Geostationary Observational Environmental Satellite (GOES) to shore-based facilities. Comparisons of the pH of seawater obtained in the laboratory using both the SEAS *in-situ* system and a conventional shipboard system indicated agreement within approximately 0.008 pH units. The deployment of the SEAS pH sensor on the NOPP mooring was the first deployment of an autonomous spectrophotometric pH measurement system at sea.

Francisco Chavez, Gernot Friedrich, and Hans Jannasch (MBARI) have developed nitrate and pCO_2 measurement systems (e.g., see Jannasch et al., 1994; Friedrich et al., 1995; Blain et al. 2000), which have been tested on the O-SCOPE moorings.

Dick Feely (PMEL) has led groundtruthing efforts for the region around the NOPP OWS "P" mooring. Goals have included defining geochemical parameters for ship sampling. Underway measurements included salinity, CO_2, DIC, temperature, pH, nutrients, chlorophyll, and oxygen. Water column measurements included salinity, CO_2, alkalinity, DIC, temperature, nutrients, and oxygen. Dick Feely and Cathy Cosca (PMEL) have developed a new website for the O-SCOPE program: http://www.pmel.noaa.gov/oscope/.

Rik Wanninkhof (AOML) has been working on a dissolved oxygen sensor and a water sampler. Wanninkhof has also taken the lead in obtaining remote sensing data for OWS "P" region for seatruthing activity.

Casey Moore of WETLabs has developed a modular sensor suite for bio-optical sampling of natural water through extended deployments. These include two new sensors: a chlorophyll fluorometer and a multi-angle scattering sensor. Both instruments utilize a common electronics and housing design and incorporate monolithic potted optical assemblies. While the sensors span two different types of instruments, multiple wavelength capabilities sought in the volume scattering function (VSF) sensors resulted in the development of four unique optical heads within the scope of this project. The instruments also featured new anti-fouling shutters for longer term deployments. The WETLabs fluorometer allows the user to monitor chlorophyll concentration by directly measuring the amount of chlorophyll-*a* fluorescence emission from a given sample volume of water. The fluorometer uses two bright blue LEDs (centered at 455 nm and modulated at 1 kHz) to provide the excitation source. The blue light from the sources enters the water volume at an angle of approximately 55–60 degrees with respect to the end face of the unit. Fluoresced light is received by a detector positioned where the acceptance angle forms a 140 degree intersection with the source beam. The optical scattering sensor measures scattering from particles at 100, 125, and 140 degrees concurrently. By incorporating the multi-angle measurements, one can determine the shape of the volume scattering function throughout the angular range of the sensor. Through interpolation, specific angles of scattering can then be matched to reflectance models used in remote sensing. By extrapolation and integration, the backscattering coefficient can also be determined with accuracies to within 2 percent. Both the fluorometers and the scattering sensors collected data successfully during extended deployments with the UCSB bio-optical instrument suites described in the following paragraph.

Tommy Dickey and the Ocean Physics Laboratory (OPL; UCSB) have developed new optical systems (e.g., Manov et al., 1999; Dickey, 2000) in collaboration with Satlantic (Marlon Lewis and Scott McLain). A suite of sensors was deployed by the UCSB OPL at the NOPP "P" site in October 1999. A three-wavelength surface radiometer at 7 m was sampled once per hour and a digital data stream was stored in memory. The radiometer system was cabled to the PMEL buoy's data logger. Once per day the radiometer sensor system was successfully interrogated by the PMEL surface data telemetry system for subsequent transmission by GOES satellite. A near real-time data archive was then generated for the O-SCOPE website. An identical sensor suite and logging system was deployed at 15 meters. Using the BTM, the OPL has used systems to measure surface irradiance and radiance at 7m and 15m along with WETLabs fluorometers and three-wavelength backscatter sensors.

5. SUMMARY

O-SCOPE has capitalized on recent technological advances to develop new interdisciplinary sensors and systems, which can be deployed from moorings and, in principal, other oceanographic platforms. Ultimately, these instruments can become critical elements of a continuous early warning system to global change in the ocean and can accelerate the implementation of a plan to instrument (i.e., network) critical regions of the ocean with long-term interdisciplinary moorings. We have also developed an integrated system of near real-time data distribution to the oceanographic community (for education as well as research) via the internet. We have capitalized on two ongoing testbed mooring programs (near Bermuda and Monterey Bay) and complementary ongoing shipboard sampling for groundtruthing the new instrumentation. Importantly, we have transitioned next-generation technologies to the Tsunami Warning Mooring located at Ocean Weather Station "P" in the Pacific. The O-SCOPE project has enabled us to apply our partnership's expertise to develop, test, and transition requisite next generation technologies to the oceanographic community (e.g., national agencies such as NOAA) for long-term monitoring and research of biogeochemical as well as physical processes. Several new chemical and optical systems for mooring (and potentially other platforms) have been developed and laboratory tested as described above. We have completed the field testing phase with deployments of the various systems from the three mooring sites: Bermuda (BTM), Monterey Bay (MBARI), and OWS "P" in the North Pacific. It is worth noting that some data sets were telemetered from OWS "P."

A program introduction and workshop reports (Dickey et al., 1998, 1999) may be found at http://www.pmel.noaa.gov/oscope/ as well as at http://www.opl.ucsb.edu/oscope.html.

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