

A National Oceanographic Partnership Program Award

A Renewal of the Ocean-Systems for Chemical, Optical, and Physical Experiments (O-SCOPE) Program

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<http://www.opl.ucsb.edu/oscope.html> and <http://www.pmel.noaa.gov/oscope/>

Long Term Goals

The overall goal of the National Ocean Partnership Program (NOPP) sponsored Ocean-Systems for Chemical, Optical, and Physical Experiments (O-SCOPE) project is to develop instrumentation to enable next-generation, autonomous, near real-time, nearly continuous, long-term, interdisciplinary, time-series measurements in critical regions of the world ocean.

Objectives

The program's general objective is 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. Basic NOPP O-SCOPE goals 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 deployed, 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, and 5) evaluate performances of new instrumentation and telemetry systems.

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. O-SCOPE is

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capitalizing on a variety of recent technological advances (e.g., pCO₂, dissolved oxygen, pH, and alkalinity sensors, nitrate analyzers, spectral optical sensors, and data telemetry) to accelerate the implementation of a plan to instrument (i.e., network) critical regions of the world ocean with long-term interdisciplinary moorings. Data obtained from a mooring network can be spatially extrapolated using remote sensing, complementary shipboard, drifter, float, and glider sampling, and models.

Work Completed

We have utilized ongoing testbed mooring programs near Bermuda (i.e., Bermuda Testbed Mooring; BTM) and in Monterey Bay, as well as existing measurement programs, capabilities, and facilities for biogeochemical, bio-optical, and physical sensor development, testing, and seatruthing. New instrumentation has also been deployed on a NOPP-NOAA Tsunami warning system mooring at Ocean Weather Station "P" (OWS "P") in the North Pacific Ocean; ship-based measurements have been conducted at the site for sensor groundtruthing and study of spatial variability in the vicinity of the mooring. It is important to emphasize that few ocean sites exist where long-term (more than 40 years) measurements are being done at present; the OWS "P" and Bermuda sites are two of these. The two sites are thought to be very important in terms of the CO₂ system. In particular, there are strong indications of increasing pCO₂, consistent with increasing atmospheric levels, at these sites and the Hawaii Ocean Time-series (HOT) site; thus, many biogeochemical modeling studies utilize data sets from these locations. Some of the key specific O-SCOPE results are summarized below.

Results

Nick Bates (BBSR) has focused on groundtruthing (e.g., verification) of chemical sensors deployed on the BTM. An important component was done in collaboration with Liliane Merlivat (University of Paris VI), specifically, the analysis of seawater pCO₂ data collected from an autonomous buoy system (i.e., Carbon Interface Ocean Atmosphere; CARIOCA), tethered to the BTM. Nearly co-located concurrent ship-based seawater pCO₂ data were also collected. The CARIOCA buoy pCO₂ data were determined to be accurate to within $\pm 3 \mu\text{atm}$ compared to shipboard measurements. The importance of high frequency sampling was highlighted by significant variability on hourly to 8-day time scales (e.g., inertial, diurnal, synoptic weather patterns, and mesoscale processes). Another collaborative effort was done with Mike DeGrandpre (University of Montana at Missoula) as DeGrandpre's Submersible Autonomous Moored Instrument (SAMI) pCO₂ system was deployed on the BTM. Comparisons of pCO₂ and ΔpCO_2 data collected by Gernot Friederich and YSI, respectively, with ship-based data are in progress and appear promising.

Bob Byrne (USF) has developed and tested an autonomous in situ spectrophotometer, Spectrophotometric Elemental Analysis System (SEAS), for measurement of seawater pH from ocean moorings. Observations of seawater pH allow quantification of the extent of anthropogenic CO₂ uptake in the surface ocean. SEAS was configured for measurements of the absorbance ratios of pH sensitive indicator dyes. 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 GOES system to shore-based facilities. Comparisons of the pH of seawater measured in the laboratory using both the SEAS in situ system and a conventional shipboard system indicated

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agreement to within approximately 0.008 pH units. The deployment of the SEAS pH sensor on the NOPP OWS "P" mooring was the first deployment of an autonomous spectrophotometric pH measurement system at sea. The USF work included determinations of instrument precision and accuracy in the laboratory, development of autonomous data acquisition and transmission capabilities, and demonstration of instrument durability during the OWS "P" mooring deployment.

Francisco Chavez and Gernot Friederich (MBARI) led the mooring program at MBARI. They have developed a pCO₂ measurement system, which has been tested on the O-SCOPE moorings. Major technical advances concerned the development of a new controller board, a new gas inlet system for the pCO₂ sensor, and data telemetry capability. Analyses of data collected with these systems have demonstrated their effectiveness under a variety of oceanic conditions. In particular, the most recent testing at the BTM site has led to results suggesting that the usual summertime sea surface CO₂ supersaturation was interrupted during most of July 2000 when pCO₂ returned to near atmospheric values. The pCO₂ decrease may have been coupled with a regional cooling event. In autumn, temperature and pCO₂ decreased concurrently. Studies at the MBARI M1 mooring site have demonstrated that a one-year service interval can be achieved for the ΔpCO₂ apparatus. A major advance by the MBARI group involves development of a prototype system for measuring absolute air and sea surface pCO₂ and dissolved oxygen along with a UV nitrate sensor (Ken Johnson, MBARI). The MBARI group also shared information concerning development of anti-biofouling mechanisms; this has expedited development of similar systems for other sensors and systems by UCSB and WET Labs partners. Some of the new MBARI instruments are now being utilized on NOAA Tropical Atmosphere-Ocean (TAO) moorings in the equatorial Pacific

Dick Feely (PMEL) led groundtruthing efforts, collecting background datasets for sensor verification and contextual interpretation, for the region around the NOPP OWS "P" mooring as well as coordinating the mooring program there. He has used a multi-parameter linear regression (MLR) analysis to estimate anthropogenic CO₂ increase in the North Pacific (between 30-50°N, and 140-180°W) from data collected between the first GEOSECS survey in the fall of 1973 and the most recent NOPP experiment in October of 1999. The MLR model was used to calculate the coefficients that describe the naturally occurring variations in oceanic CO₂. The statistical model used salinity, apparent oxygen utilization, silicate, and phosphate to construct a forward linear stepwise regression to predict DIC. Data from all cruises within the region were used where high quality DIC data, along with other hydrographic parameters, were available throughout the water column. A 2nd order polynomial equation for all parameters used in the MLR model for each cruise was then fitted against mid- to deep (>1250-3500m) data. The results of the MLR model show an estimated CO₂ uptake rate through the mixed layer of $1.6 \pm 0.21 \mu\text{mol DIC kg}^{-1} \text{ yr}^{-1}$ in the North Pacific. Dick and Cathy Cosca (PMEL) also developed a website for the O-SCOPE program, <http://www.pmel.noaa.gov/oscope/>, and a near real-time data telemetry, display, and distribution system.

Rik Wanninkhof (AOML) tested a new dissolved oxygen sensor and also obtained remote sensing data for the OWS "P" region for seatruthing activities. This study concerned the problem of measuring dissolved oxygen. These measurements are most effective when done at high sampling frequency; however, the problems of instrument drift and storage of calibration samples have long plagued researchers. A second-generation permeable membrane pulsed

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electrode dissolved oxygen system, built by Chris Langdon (LDEO), was utilized. Attributes of the new system enable longer term deployments in biologically productive waters. New probes were tested on the R/V Ron Brown and were subsequently deployed on the BTM and the R/V Weatherbird II. Results show excellent agreement between the BTM and ship-based data sets. A new sample storage scheme was developed with successful storage periods of up to 4 months. Rik has also tested an autonomous (36 samples) water sampler and evaluated the stability of CO₂, O₂, and nutrient samples.

Casey Moore (WET Labs) developed a modular sensor suite for bio-optical sampling for extended deployments. These include two new sensors: a chlorophyll fluorometer and a multi-angle scattering (volume scattering function, VSF) sensor. The instruments also featured new anti-fouling shutters for longer term deployments. The fluorometer allows the user to monitor chlorophyll concentration. The fluorometer uses two bright blue LEDs to provide the excitation source. The optical scattering sensor concurrently measures scattering from particles at 100, 125, and 140. Through interpolation, specific angles of scattering can then be matched to reflectance models used for remote sensing. The fluorometers and the scattering sensors collected data successfully during extended deployments with the UCSB bio-optical instrument suites. The most recent deployment was for 4 months from the BTM and results indicate high fidelity and little signal degradation due to biofouling. The WET Labs effort has led to a commercial line of products and served as the foundation for another NOPP project involving a Virtual Mooring Glider.

Tommy Dickey and the Ocean Physics Laboratory (OPL; UCSB) have developed new optical systems in collaboration with Satlantic (Marlon Lewis and Scott McLean) and WET Labs. New servo-controlled copper anti-biofouling shutters were engineered for the radiometers and successfully tested. A suite of sensors was deployed at the NOPP OWS "P" site in October 1999. A three-wavelength surface radiometer deployed at 7 m was sampled once per hour and a digital data stream was stored in memory. The radiometer system was cabled to the NOPP 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 the GOES satellite system. 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, OPL used systems to measure surface irradiance and radiance at 7m and 15m along with WET Labs fluorometers and three-wavelength backscatter sensors. OPL also coordinated the BTM testing and the O-SCOPE project.

Impact and Applications

Benefits and impacts of O-SCOPE include the development of technologies 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 biogeochemistry and ecology. Some of the new technologies developed under O-SCOPE have been utilized for other mobile autonomous platforms that will expand the spatial domains of observations as well as time ranges.

Economic Development

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The O-SCOPE program led to the commercialization of new optical instruments by WET Labs, which have already sold over 200 miniature optical sensors (for multi-angle scattering and fluorescence); their sales continue to grow annually. In addition, the UCSB anti-biofouling copper shutter design was adopted by Satlantic, Inc. for its BioShutter that is used with its OCR-500 radiometer line of instrumentation. These instruments are widely used for autonomous marine environmental observations and satellite ocean color validation applications.

Quality of Life

1. The O-SCOPE project developed, tested, and transitioned requisite next-generation technologies to the oceanographic community for long-term measurements and research of biogeochemical and bio-optical as well as physical processes. All of these are important for quality of life, public and ecosystem health, and coastal resource management.

2. In particular, the O-SCOPE project accelerated interdisciplinary ocean measurement technology capabilities by

- 1) increasing the variety of variables which can be measured autonomously,
- 2) improving the robustness and reliability of interdisciplinary sampling systems,
- 3) reducing adverse biofouling effects on chemical and optical systems, and
- 4) developing a system for near real-time telemetering and dissemination of data via the internet.

Science Education and Communication

A near real-time data telemetry and website facilitate was developed to enable public outreach and educational utilization of data collected during O-SCOPE.

Transitions

For the four NOPP evaluation factors below, please describe how the results (hardware, software, knowledge) are being utilized by others. Transition is taken to mean, “products which are being incorporated into more developmental (or operational) programs or have already been incorporated in other’s plans.”

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Consideration for Excellence in Partnering Award

Ocean Sector Diversity: Commercial (Casey Moore, WETLabs), Academic (Tommy Dickey, UCSB, and Bob Byrne, USF), Government Research Laboratories (Dick Feely, NOAA PMEL, and Rik Wanninkhof, NOAA AOML), and Private Research Laboratories (Francisco Chavez, MBARI, Nick Bates, Bermuda Biological Station for Research)

Partner Involvement: Nick Bates (BBSR) has focused on groundtruthing (e.g., verification) of chemical sensors deployed on the BTM. An important component was done in collaboration with Liliane Merlivat (University of Paris VI) on the analysis of seawater pCO₂ data collected from an autonomous buoy system (i.e., Carbon Interface Ocean Atmosphere; CARIOCA), tethered to the BTM. Nearly co-located concurrent ship-based seawater pCO₂ data were also collected. The CARIOCA buoy pCO₂ data were determined to be accurate to within $\pm 3 \mu\text{atm}$ compared to shipboard measurements. The importance of high frequency sampling was highlighted by significant variability on hourly to 8-day time scales (e.g., inertial, diurnal, synoptic weather patterns, and mesoscale processes). Another collaborative effort was done with Mike DeGrandpre (University of Montana at Missoula) as DeGrandpre's Submersible Autonomous Moored Instrument (SAMI) pCO₂ system was deployed on the BTM. Comparisons of pCO₂ and ΔpCO_2 data collected by Gernot Friederich and YSI, respectively, with ship-based data are in progress and appear promising.

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Dick Feely (PMEL) led groundtruthing efforts, collecting background datasets for sensor verification and contextual interpretation, for the region around the NOPP OWS "P" mooring as well as coordinating the mooring program there. Accomplishments included defining geochemical parameters for ship sampling and characterizing horizontal and vertical gradients in physical and biogeochemical variables near the site. Underway measurements included salinity, CO₂, DIC, temperature, pH, nutrients, chlorophyll, and oxygen. Water column measurements included salinity, CO₂, alkalinity, DIC, temperature, nutrients, and oxygen. Dick Feely and Cathy Cosca (PMEL) also developed a website for the O-SCOPE program, <http://www.pmel.noaa.gov/oscope/>, and a near real-time data telemetry, display, and distribution system.

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Matching Contributions: Moorings were shared by UCSB (Bermuda Testbed Mooring), PMEL (OWS P NOAA Tsunami mooring), and MBARI (OASIS Moorings)

Partner Long-Term Commitment: An excellent partnership created during O-SCOPE has led to the formation of the new NOPP MOSEAN partnership along with continued collaborations among all of the O-SCOPE investigators.

Success in Project Objectives: The program's general objectives were successfully met. These included: improvement of 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. Basic NOPP O-SCOPE goals achieved were: 1) identification of key variables to be measured, determine capabilities and limitations of available sensors, and define specifications for next-generation sensors, 2) design, development, and testing of integrated interdisciplinary systems for biogeochemical, bio-optical, and physical measurements (e.g., low-cost, easily deployed, reliable, robust), 3) design of a testbed mooring program (e.g., deployment scheduling, sampling rates, instrument placement depths, etc.), 4) deployment of next-generation

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interdisciplinary instrument suites on three moorings, and 5) evaluation of the performances of new instrumentation and telemetry systems. In addition, several important transitions to other NOPP projects, government laboratories, and the commercial sector were accomplished as detailed above.

Related Projects

Other NOPP projects have benefited from O-SCOPE through the development of sensors that have been transitioned as described above.

References (also see Publications below)

Dickey, T., N. Bates, R. Byrne, F. Chavez, R. Feely, C. Moore, and R. Wanninkhof, 2000, A Review of the NOPP Ocean-Systems for Chemical, Optical, and Physical Experiments (O-SCOPE) Project, Fifth Symposium on Integrated Observing Systems, Proc. Amer. Met. Soc.

Glenn, S.M., W. Boicourt, B. Parker, and T.D. Dickey, 2000, Operational observation networks for ports, a large estuary, and an open shelf, *Oceanography*, 13, 12-23.

Glenn, S.M., T.D. Dickey, B. Parker, and W. Boicourt, 2000, Long-term real-time coastal ocean observation networks, *Oceanography*, 13, 24-34.

Publications (2001-present)

Dickey, T., 2001, Emerging interdisciplinary sensors and systems for observing the world ocean, *Sea Tech.*, 42(12), 10-16.

Dickey, T., 2001, Sensors: inherent and apparent optical properties, *Encyclopedia of Ocean Science*, eds. J.H. Steele, S.A. Thorpe, and K.K. Turekian, Academic Press, London, 1313-1323.

Dickey, T., 2002, Future ocean observations for use in interdisciplinary data assimilation models, *J. Mar. Sys.*, in press.

Dickey, T., 2002, Instrumentation and new technologies, *Oceans 2020: Science for Future Needs*, eds. J.G. Field, G. Hempl, and C.P. Summerhayes, Island Press, Washington, DC, 211-255.

Dickey, T.D. and G.C. Chang, 2001, Recent advances and future visions: temporal variability of optical and bio-optical properties of the ocean, *Oceanography*, 14(3), 15-29.

Dickey, T. and P. Falkowski, 2002, Solar energy and its biological-physical interaction in the sea, eds. A.R. Robinson, J.J. McCarthy, and B.J. Rothschild, Chapter 10, *The Sea*, Vol. 12, John Wiley and Sons, New York, 401-440.

Dickey, T., S. Zedler, X. Yu, S.C. Doney, D. Frye, H. Jannasch, D. Manov, D. Sigurdson, J.D. McNeil, L. Dobeck, T. Gilboy, C. Bravo, D.A. Siegel, and N. Nelson, 2001, Physical and biogeochemical variability from hours to years at the Bermuda Testbed Mooring site: June 1994 – March 1998, *Deep-Sea Res. II*, 48 (8-9), 2105-2140.

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Dickey, T.D., 2001. New technologies and their roles in advancing biogeochemical research, *Oceanography*, 14(4), 108-120.

Griffiths, G., R. Davis, C. Eriksen, D. Frye, P. Marchand, T. Dickey, and R. Weller, 2001, Towards new platform technology for sustained observations, in *Observing the Oceans in the 21st Century*, eds. C.J. Koblinsky and N.R. Smith, Australian Bureau of Meteorology, 324-338.

Send, U., R. Weller, S. Cunningham, C. Eriksen, T. Dickey, M. Kawabe, R. Lukas, M. McCartney, and S. Osterhuis, 2001, Oceanographic time series observatories, *Observing the Ocean for Climate in the 21st Century*, eds. C.J. Koblinsky and N.R. Smith, Australian Bureau of Meteorology, 376-390.

Yu, X., T. Dickey, J. Bellingham, D. Manov, and K. Streilein, 2002, The application of autonomous underwater vehicles for interdisciplinary measurements in Massachusetts and Cape Cod Bays, *Cont. Shelf Res*, in press.

Zheng, X., T. Dickey, and G. Chang, 2002, Variability of the downwelling diffuse attenuation coefficient with consideration of inelastic scattering, *Appl. Optics*, in press.