Multi-disciplinary Ocean Sensors for Environmental Analyses and Networks (MOSEAN)

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LONG-TERM GOALS

The long-term goal of the Multi-disciplinary Ocean Sensors for Environmental Analyses and Networks (MOSEAN) project is to develop and test new technologies that are essential for solving a variety of interdisciplinary oceanographic problems of societal importance in coastal and open ocean environments. Problems of relevance to MOSEAN include: biogeochemical cycling, climate change effects, ocean pollution, harmful algal blooms (HABs), ocean ecology, and underwater visibility.

OBJECTIVES

The primary objectives of MOSEAN are:

(1) To produce and test new sensors that will be capable of sampling key biological, chemical, and optical variables on time scales as short as minutes and space scales down to a meter for periods on order of months and horizontal space scales on order of 100's of kilometers. The sensors are being designed and tested with capabilities of real-time and/or near real-time data telemetry.

(2) To develop, interface, test, and demonstrate new interdisciplinary sensor suites for use with a variety of autonomous, unattended sampling platforms, including stationary-type (e.g., moorings, offshore platforms, and towers) and mobile-type (e.g., moored profilers, autonomous underwater vehicles (AUVs), gliders, drifters, and profiling floats).

APPROACH AND WORK PLAN

MOSEAN is building upon a variety of recent technological advances to accelerate the implementation of a plan to instrument and network critical regions of the world ocean with long-term interdisciplinary moorings as well as other platforms.

(1) WET Labs and SubChem have provided a suite of novel, miniaturized, bio-optical sensors (WET Labs) and a new generation of self-contained, modular, autonomous, nutrient analyzers (both firms) for the MOSEAN mooring installations. Sensors have been configured as turnkey packages that operate and collect data independently. Alternatively, they are being developed to allow for ease in interfacing of the sensor suites with mooring loggers and telemetry networks with multi-channel serial inputs. The basic suite of measurements include: a) Spectral optical backscattering; b) Hyperspectral absorption, scattering, and attenuation coefficient (90-100 wavelengths); c) Spectral fluorescence (for biological classification and classification of hydrocarbons); and d) Modular measurements for four nutrient components chosen from nitrite, nitrate, ammonium, phosphate, silicate, and iron. Anti-fouling technologies and other related improvements have been incorporated for optical sensors and will be for chemical applications.

(2) UCSB and UH have supplied newly engineered mooring platforms for the implementation and testing of WET Labs, SubChem, and other sensors and systems. Complementary mooring sensors and systems have been provided by UCSB and UH. These include: a modular buoy (deployed at H-A), ADCP and hydrographic sensors (at both locations), meteorological packages (at both locations), fluorometers (at both locations), hyperspectral radiometers (at CHARM), a dissolved oxygen sensor (at CHARM), and a remote automatic sampler (RAS; H-A). In addition, pCO_2 sensors (Chris Sabine, NOAA PMEL), gas tension and oxygen sensors (Steve Emerson, UW), trace element sensors (Ed Boyle, MIT), and spectral radiometers (Ricardo Letelier, OSU) have been deployed from the H-A mooring. A new bioluminescence sensor (Jim Case, UCSB) was tested using the CHARM mooring. WET Labs, Inc. has also provided a ship-based profiling package equipped with state-of-the-art optical sensors for calibration/validation of mooring measurements at the H-A and CHARM mooring sites. Real-time data telemetry systems have been developed, deployed, and tested at both sites (RF at CHARM and Argos and Iridium at H-A).

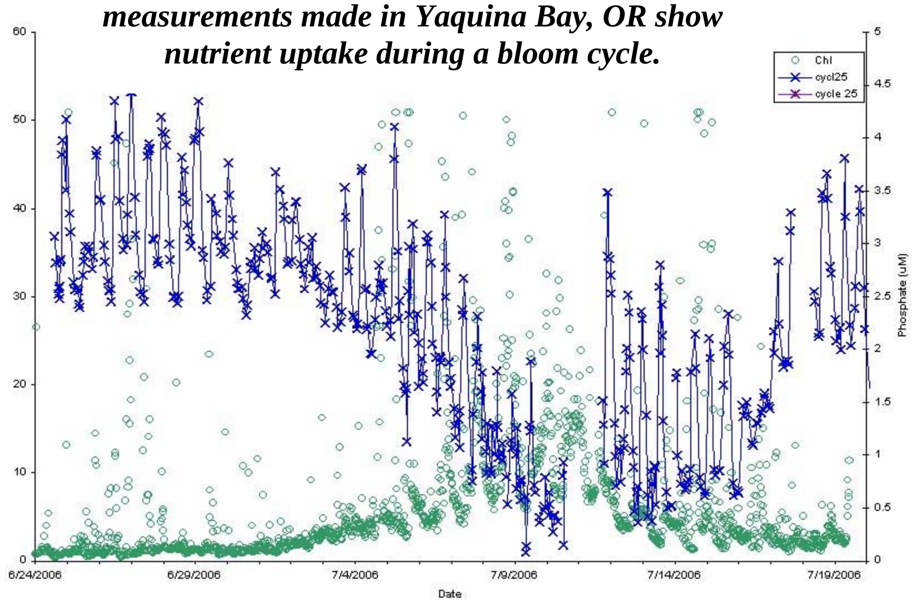
WORK COMPLETED

<u>CHARM</u>

The NOPP MOSEAN Santa Barbara CHAnnel Re-locatable Mooring (CHARM) was first deployed on May 19, 2003 and was recovered October 2, 2003. The second and third deployments of CHARM were conducted February 10, 2004 – May 5, 2004; May 15, 2004 – September 21, 2004, the fourth and fifth CHARM deployments were February 2, 2005 – April 22, 2005; May 1, 2005 – October 5, 2005. The sixth and seventh deployments were February 1 – April 25 and May 5 – October 5, 2006. Data have been telemetered during the course of the several deployments.

(1) *Nutrient sensor development.* In conjunction with SubChem Systems, WET Labs engaged in development and implementation of nutrient sensors for extended deployment. This past year's efforts focused on developing operational capabilities for these sensors. Specific work included:
   a. *Development of a more robust design for the phosphate sensor* - New design components included integrated pump manifold and fluidics housings, more bubble robust fluidics assembly, a more compact housing assembly and new, more robust electronics and software;

Fig. 1. Phosphate (blue) and chlorophyll (green) measurements made in Yaquina Bay, OR show nutrient uptake during a bloom cycle.



b. *Enhancing operation* – Efforts focused upon developing stable operational algorithms and validating basic performance parameters. Current phosphate measurements now fall well within 50 nanomolar RMS precision.

c. *Extensive testing of phosphate sensors* - A total of four sensors were deployed in diverse sites including Yaquina Bay, OR (Fig. 1), Great Bay, NH, Narragansett Bay, RI, and Monterey Bay, CA. Time series ranging from weeks to months were collected at these various sites.

d. *Development of moored Nitrate and Nitrate measurement capabilities* – SubChem scientists and engineers developed and tested moored NO_3 and NO_2 capabilities in Narragansett Bay, RI.

(2) Efforts continued towards developing new nutrient methods for the moored nutrient sensors. In addition to the above-mentioned NO_3 and NO_2 measurements, investigations began in adapting the new sensors to the NH_4 fluorometric method for a moored NH_4 analyzer. Tests also continued on extending reagent and standards lifetimes as well as testing for interferences from salinity, temperature, turbidity and other environmental factors.

(3) *Support for the CHARM and H-A moorings* – WET Labs provided support for the two MOSEAN mooring installations. This support included providing servicing and refurbishment for over 40 instruments and power systems for the CHARM and H-A deployments, and also interim calibration and servicing of the equipment.

(4) *Biofouling reduction tests.* Integral to the WET Labs MOSEAN involvement is an underlying effort to improve biofouling resistance on bio-optical sensors. These efforts include both active and passive systems and we have focused on both flat-face sensors and flow through sensors. Central action items included in this year's efforts were:

a. *Six sensors were provided to the Alliance of Coastal Technologies (ACT).* The NOAA sponsored ACT conducted a comprehensive verification process on turbidity meters and scattering sensors during summer 2006. The goal of the tests was to test and assess manufacturers' products in extended coastal deployment conditions. WET Labs supplied a set of combination fluorometer – scattering sensors with incorporated anti-fouling shutters. The units were deployed in seven unique locations for 28-day durations. Locations included, Gulf of Maine Lake Michigan, Monterrey Bay Chesapeake Bay, Tampa Bay, Coastal Georgia, and in the Coconut Island Lagoon in Hawaii. The ACT results will be published in January 2007.

b. *We implemented a miniaturized pumped chlorine sensor for flow through system bio-fouling retardation.* Initially trialed with Seabird dO sensors, the chlorine dispensing unit promises to dramatically prolong deployments of many flow through devices subject to internal bio-fouling. Initial tests with the dO sensors saw agreement in measurements with standards to within 3% of nominal value for periods of over two months. These tests are soon to be applied to flow through optical devices such as the ac-9.
c. *We successfully completed three years of testing with our advanced shutter system for multiparameter optical sensors.* During the first year of this NOPP effort we deployed a shuttered "triplet" configuration, which entailed three independent optical measurements on a single flat face sensor. One sensor was configured as a multi-wavelength backscattering device and the other was configured as a spectral fluorometer with three independent excitation-emission pairs. These sensors have operated through three years of coastal deployments on the CHARM and have successfully demonstrated their anti-fouling capabilities during that time.

HALE-ALOHA

The NOPP MOSEAN H-A mooring was first deployed on August 11, 2004 and recovered November 24, 2004. There have since been four more successful deployments of H-A: December 19, 2004 to May 22, 2005; May 29, 2005 to February 10, 2006; February 19-June 8, 2006; and June 18 – December 14, 2006. Many other investigators, e.g., Steve Emerson (gas tension and oxygen sensor, U WA), Ricardo Letelier (spectral radiometers, OSU), Charles Eriksen (gliders, University of Washington), Chris Sabine (pCO_2 sensor, PMEL), and Ed Boyle (trace element sensor, MIT), have utilized the MOSEAN H-A mooring for the testing of sensors, systems, and platforms. The addition of Eriksen's Seaglider has expanded the spatial coverage in the vicinity of the H-A mooring and serves as a model for future integrated sampling systems and agency sponsored observatory initiatives (e.g., ORION).

The Remote Access Sampler (RAS) deployed on the MOSEAN mooring has been employed for high frequency temporal resolution of upper ocean (14 m) inorganic and organic nutrient dynamics at Station ALOHA. The RAS has been deployed 3 times, with each deployment ranging in duration from 90 to 180 days. The RAS is preprogrammed prior to deployment to collect a 500 ml sample about every 3 days; the liquid seawater samples are preserved in situ with 10 ml of a 2M HCl solution. Upon retrieval, samples are analyzed for high sensitivity determinations of nitrate+nitrite (using a chemiluminescence technique) and orthophosphate (using the magnesium induced co-precipitation technique) concentrations. In addition, high frequency dynamics in total dissolved nitrogen and total dissolved phosphorus concentrations are determined to evaluate short-term variability in inorganic and organic nitrogen and phosphorus availability and stoichiometric ratios.

Coordination

OPL / UCSB has coordinated the MOSEAN project. The fourth MOSEAN workshop was held in Kona, HI in June 2006. Discussions centered on new instrumentation designed for coastal and open ocean applications and plans for the CHARM and H-A mooring (site selection, data telemetry, etc.). Also, recent results were shared and discussed and publications were outlined.

RESULTS

CHARM

Data from the 4-m depth sensor packages were successfully telemetered via radio frequency telemetry during the second, fifth, sixth, and seventh deployments. The data telemetry was successful for only a few weeks during the third and fourth deployments before the antenna on the mooring failed. Real-time mooring data have been automatically displayed graphically with complementary near real-time satellite data (SST, ocean color, winds, and altimetry) on our OPL/UCSB website (http://www.opl.ucsb.edu/mosean.html). All mooring data were also archived and recovered.

Data analyses conducted over the past year using CHARM data include assessment of optical closure between the measured inherent and apparent optical properties (IOPs and AOPs) from the second, fourth, and fifth deployments. The closure relationships were evaluated to investigate sources of variability for the immeasurable quantities f/Q. Results from statistical analyses (linear regression, coherence, and EOF) suggest that the variability of IOPs and reflectance [R(λ, 4m)] was strong; changes in optical properties were likely driven by advective events, e.g., plumes, upwelling (Chang et al., 2006b). The slope of the particle size distribution most heavily influenced IOP and R(λ, 4m) variability, whereas properties related to particle type were only weakly variable and not related to R(λ, 4m) variability. The variability of f/Q was strongly affected by particle type characteristics rather than the slope of the particle size distribution. The spectral shape of f/Q was only dependent on the variability of backscattering properties. Chl had virtually no bearing on the variability of the AOPs.

These insights into optical influences on closure between the IOPs and AOPs are important for the development of IOP-centered algorithms and inversion techniques for the derivation of biogeochemical properties from satellite ocean color data. Large-scale, synoptic monitoring of biogeochemistry, particularly in the coastal ocean, is essential for the management of regions of the world's oceans that are most heavily influenced by the presence of humans.

HALE-ALOHA

The NOPP sponsored H-A mooring has been deployed five times since August 2004 and mooring deployments are ongoing. Meteorological, physical (ADCP currents, temperature, and salinity), bio-optical, and chemical (including trace elements with Ed Boyle's MITESS sampler and Dave Karl's RAS) time series data have been collected. A warm-core eddy passed over the H-A site in summer 2005. H-A interdisciplinary time series are currently being analyzed to resolve the biogeochemical effects of the passage of this eddy.

IMPACT AND APPLICATIONS

Benefits and impacts of MOSEAN include the development of technologies to quantify episodic, event-scale, 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 as well as operational problems involving naval operations and public warnings due to red tides, and ocean pollution. The MOSEAN project is contributing to the development of new sensors and systems that can be easily transitioned to a variety of platforms that will be used for various observing system programs such as the NSF Ocean Observatories (OOI), the Ocean.US Integrated Ocean Observational System (IOOS), and international Global Ocean Observing System (GOOS) programs.

Economic Development

The sensors and systems developed and tested during MOSEAN are being commercialized and made available to the scientific community (academia, research laboratories, and government laboratories).

Science Education and Communication

The results of this project are being used in the education of undergraduate and graduate students and postdoctoral fellows at UCSB and the University of Hawaii. Professor Dickey is using some of the NOPP results for textbooks that he is currently writing (Exploring the World Ocean to be published in early 2007 by McGraw-Hill with co-author Sean Chamberlin and Bio-optical Oceanography to be published in 2008 by Elsevier with co-author Emmanuel Boss).

TRANSITIONS

The MOSEAN project has 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, and 3) reducing adverse biofouling effects on chemical and optical systems. The MOSEAN project is contributing to the development of new sensors and systems that can be easily transitioned to a variety of platforms that will be used for various observing system programs such as the NSF Ocean Observatories (OOI), the Ocean.US Integrated Ocean Observational System (IOOS), the Global Earth Observing System of Systems (GEOSS), and international Global Ocean Observing System (GOOS) programs. For example, Chris Sabine of NOAA's PMEL has already deployed a pCO_2 sensor on the H-A mooring and this activity is becoming part of a global pCO_2 and carbon measurement program with real-time data telemetry. Also, the development, testing, and commercialization of a WET Labs bioluminescence sensor has been facilitated by MOSEAN and can be transitioned to various government agencies including the Navy.

RELATED PROJECTS

As mentioned above in the WORK COMPLETED section, several investigators are utilizing the H-A and CHARM platforms for the development and testing of sensors and systems as well as for fundamental research. There are also several projects taking place in the Santa Barbara Channel that benefit from CHARM component of MOSEAN. For example, the Southern California Coastal Ocean Observing System (SCCOOS) maintains a mooring directly offshore of CHARM. CHARM provides necessary nearshore data for resolution of cross-shelf processes. Spatial surface current data (high frequency radar) collected by Libe Washburn's UCSB group are being used to characterize major current features and passages of sub-mesoscale features and eddies and ship-based bio-optical data are being collected by the Plumes and Blooms Program (Dave Siegel) and facilitate interpretation of the CHARM bio-optical data. Satellite sea surface temperature and ocean color data are being collected by Dave Siegel's group and Ben Holt and Paul DiGiacomo (Jet Propulsion Laboratory) have been collecting synthetic aperture radar (SAR) data. These remote sensing data sets along with others provide spatial context. By combining and synthesizing these data sets with ours, we now have the capability to describe and quantify the three-dimensional evolution of several key water quality parameters on time scales of a day to the interannual. SubChem Systems, Inc. and WET Labs, Inc. are also partners in a related NOPP project (FY05-FY08) entitled "Transitioning Submersible Chemical Analyzer Technologies for Sustained, Autonomous Observations from Profiling Moorings, Gliders and other AUVs". In addition to developing low-power submersible chemical analyzers for sustained deployment on moving platforms, the project partners plan to utilize the CHARM to demonstrate and validate envisioned system stability over longer time periods (3 months).

Several projects complement the H-A mooring activity off the Hawaiian Islands. The centerpiece program is the ongoing NSF Hawaii Ocean Time-series (HOT; formerly JGOFS-funded ; Dave Karl) program, which collects a suite of physical, chemical and biological data. Gliders with chemical and biological sensors (Charlie Eriksen and Steve Emerson, University of Washington) have been deployed and recovered near the H-A mooring site as part of our MOSEAN cruise activity. The HOT/H-A region is often used for other scientific studies that can be used to enhance MOSEAN datasets and *vice versa* (http://hahana.soest.hawaii.edu/hot/hot_jgofs.html).

REFERENCES (Please see publications below)

PUBLICATIONS (2005-present)

Benson, B., G. Chang, D. Manov, B. Graham, and R. Kastner, 2006, Design of a low-cost acoustic modem for moored oceanographic applications, Proceedings of The First ACM International Workshop on UnderWater Networks (WUWNet), ACM Press, Los Angeles, CA.

Chang, G.C. and T.D. Dickey, 2006, Interdisciplinary sampling strategies for detection and characterization of harmful algal blooms, Workshop on Real-Time Systems for Observing Coastal Ecosystem Dynamics and Harmful Algal Blooms, (HABWATCH), eds. M. Babin, C. Roesler, and J. Cullen, UNESCO Publishing, in press.

Chang, G.C., Dickey, T., and M. Lewis, 2006a, Toward a global ocean system for measurements of optical properties using remote sensing and in situ observations, In: Remote Sensing of the Marine Environmment: Manual of Remote Sensing, Vol. 6, Ch. 9, edited by J. Gower, pp. 285-326.

Chang, G.C., A.H. Barnard, S. McLean, P.J. Egli, C. Moore, J.R V. Zaneveld, T.D. Dickey, and A. Hanson, 2006b, In situ optical variability and relationships in the Santa Barbara Channel: implications for remote sensing, Appl. Opt., 45(15), 3593-3604.

Chang, G., A. Barnard, J.R.V. Zaneveld, T. Dickey, and C. Moore, Closure in an optically complex coastal environment, in prep. for Optics Express.

Dickey, T.D. and R.R. Bidigare, 2005, Interdisciplinary Oceanographic observations: the wave of the future, Scientia Marina, 69(Suppl. 1), 23-42.

Dickey, T., M. Lewis, and G. Chang, 2006, Bio-optical oceanography: Recent advances and future directions using global remote sensing and in situ observations, Rev. Geophys., 44, RG1001, doi:10.1029/2003RG000148.

Dickey, T., G. Chang, C. Moore, A. Hanson, D. Karl, D. Manov, F. Spada, D. Peters, J. Kemp, O. Schofield, and S. Glenn, 2006, The Bermuda Testbed Mooring and HALE-ALOHA Mooring Programs: Innovative Deep-Sea Global Observatories, Proceedings of MTS/IEEE Oceans’06, Edited by V. Premus and A. J. Williams, III, Boston, MA.

Egli, P.J., Hanson, A.K., Moore, C., Dickey, T.D. Chang, G.C., 2005, In situ phosphate measurements aboard the Santa Barbara Channel CHARM mooring, ASLO Abstract, Salt Lake City, Utah.