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 the coastal and open oceans.

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.

(2) To develop, interface, test, and demonstrate new interdisciplinary sensor suites for use with a variety of autonomous, unattended sampling platforms, including stationary-type and mobile-type.

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 real-time 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 mooring platforms for the implementation and testing of WET Labs, SubChem, and other sensors and systems. Platforms and sensor systems 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). WET Labs, Inc. has also provided a ship-based profiling package equipped with state-of-the-art optical sensors for 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).

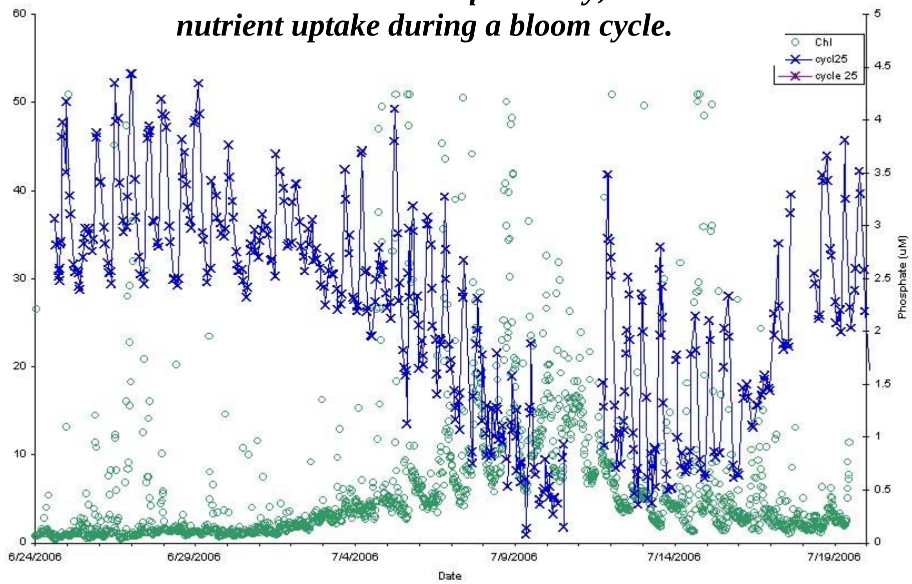
WORK COMPLETED

Sensor Development

(1) Efforts focused on developing operational capabilities for nutrient sensors (WET Labs and SubChem Systems).
    a. *Robust design* - 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 for the phosphate sensor.
    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. *Testing* - A total of four sensors were deployed for weeks to months in diverse sites including Yaquina Bay, OR (6-weeks; Fig. 1), Great Bay, NH, Narragansett Bay, RI, and Monterey Bay, CA. Tests have continued on an ongoing basis and culminated with participation in a NOAA Alliance of Coastal Technologies demonstration and evaluation. In these tests the prototype Phosphate sensor was deployed in 3 sites (Chesapeake Bay, MD; Seward, Alaska; Lake Michigan tributary, Michigan), for a period of four weeks. Preliminary results from Chesapeake Bay and Alaska show positive performance in both tests (ACT has not released reference values at time of publication). The tests in Michigan are underway at time of publication;
    d. *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. 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 environmental factors.

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



(3) WET Labs provided 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) 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.

   a. *Six sensors were provided to the Alliance of Coastal Technologies (ACT).* WET Labs supplied a set of combination fluorometer - scattering sensors with incorporated anti-fouling shutters to the NOAA sponsored ACT during summer 2006. The units were deployed in seven unique locations for 28-day durations. The ACT results will be published in January 2007.

   b. *Implementation of a miniaturized pumped chlorine sensor for flow through system bio-fouling retardation.* The chlorine dispensing unit promises to dramatically prolong deployments of many flow through devices subject to internal bio-fouling. Tests are soon to be applied to flow through optical devices such as the ac-9.

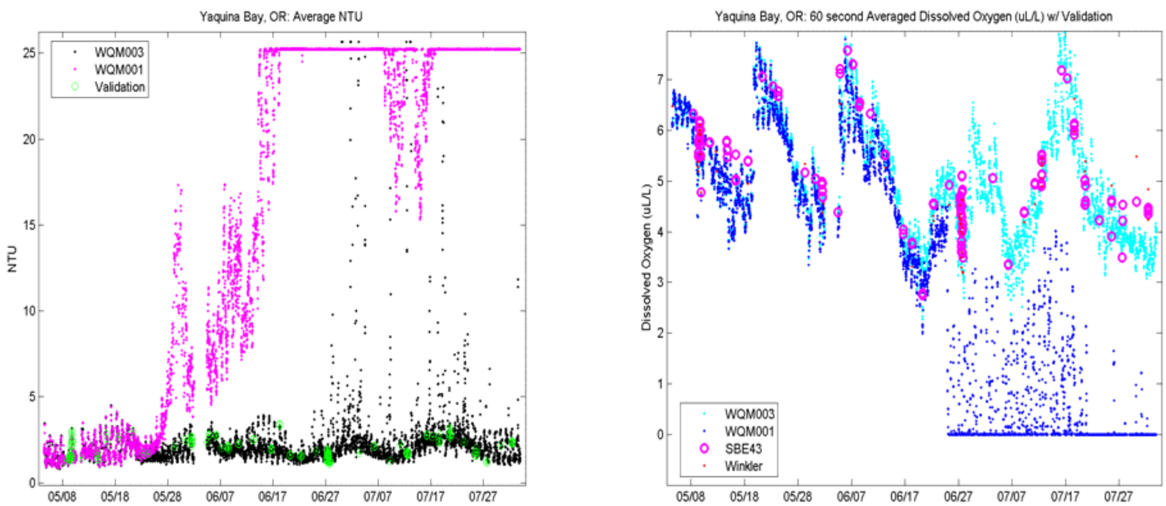
   c. *Completion of three years of testing with our advanced shutter system for multi-parameter optical sensors.* The shuttered "triplet" configuration, which entailed three independent optical measurements on a single flat face sensor, have operated through three years of coastal deployments on the CHARM and have successfully demonstrated their anti-fouling capabilities during that time. Sensors were configured as multi-wavelength backscattering devices and as a spectral fluorometer with three independent excitation-emission pairs.

(5) In 2006 WET Labs teamed with Seabird Electronics to develop a next generation multi-parameter oceanographic sensor for extended deployments. The new sensor provides 2-5 month capability for determination of temperature, salinity, dissolved oxygen, chlorophyll fluorescence, and turbidity (Fig. 2). The multi-level anti-fouling strategy employed a variety of technologies and methods many of which were developed under the auspices of the MOSEAN effort. This product (released in early 2007) represents a significant research to application transition from this NOPP.

<u>CHARM</u>

The seventh and eighth deployments of the NOPP MOSEAN Santa Barbara CHAnnel Re-locatable Mooring (CHARM) were completed May 4 - October 5, 2006 and January 18 - May 11, 2007. Data were telemetered in real-time during the course of these deployments. Jim Case, UCSB continued testing his bioluminescence sensor using the CHARM mooring.

Fig. 2 – A comparison test (Yaquina Bay, OR) between a fouling-protected multiple parameter probe and a non-protected unit. The test demonstrated the efficacy of the MOSEAN developed anti-fouling technologies. (Orrico et al, 2007)



HALE-ALOHA

The NOPP MOSEAN H-A mooring was successfully deployed from June 18 - December 14, 2006 and from January 27 - July 30, 2007. Many other investigators utilized the MOSEAN H-A mooring for the testing of sensors, systems, and platforms: 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). 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 4 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

Real-time mooring data at 4-m depth 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 made freely available on the OPL/UCSB website.

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, third, fourth, and fifth deployments. Radiative transfer modeling and statistical analyses were employed to investigate sources of variability of *in situ* remote sensing reflectance [$r_{rs}(\lambda, 4\text{ m})$] and the f/Q ratio. It was found that the variability of IOPs and the slope of the particle size distribution (ξ) were strongly related to the variability of $r_{rs}(\lambda, 4\text{ m})$. The variability of f/Q was strongly affected by particle type characteristics. A semi-analytical radiative transfer model was applied and effects of variable particle characteristics on optical closure were evaluated. Closure was best achieved in waters composed of a mixture of biogenic and minerogenic particles (Chang et al., 2007).

HALE-ALOHA

One of the interesting aspects of the H-A data sets includes the passage of a major mesoscale eddy that is clearly evident in both our H-A mooring data (physics and bio-optics) and in remote sensing data. We will be further analyzing these data and preparing a collaborative paper.

During the MOSEAN project, several new sensors and systems have been tested by U.S. and international groups: pCO_2, DO, nitrate, N_2, gas tension (with and without oxygen), ratios of $^{13}C/^{12}C$, dissolved organic carbon (DIC) [the latter two are used to estimate the rate of carbon export from the mixed layer], trace elements, several spectral inherent and apparent optical properties, ^{14}C for primary production, and currents.

An important aspect of the MOSEAN H-A program involves the development of multi-platform sampling strategies to obtain 4-dimensional data sets. Charlie Eriksen, Steve Emerson, and Charles Stump (UW) have deployed gliders at the H-A site as part of the H-A MOSEAN mooring cruise operations to obtain spatial data describing spatial variability of the physics and biogeochemistry in the vicinity of the H-A mooring.

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, e.g., the WQM (see above for description).

Economic Development
The sensors and systems developed and tested during MOSEAN are being commercialized and made available to the broad scientific community. Please see below.

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 using some of the NOPP results for a textbook (Chamberlin and Dickey, 2007).

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. 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. MOSEAN efforts contributed to a host of next generation products for operational biogeochemical measurements. The aforementioned WQM will prove an important contribution to observation systems and will greatly reduce OMM costs for IOOS and other permanent monitoring efforts. The nutrient sensor efforts thorough MOSEAN will culminate with an entire suite of products that will fill a big gap in high-priority required observing technologies. 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.

RELATED PROJECTS

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 collected by Libe Washburn's group are used to characterize major current features and passages of sub-mesoscale features and eddies. Ship-based and satellite bio-optical data are collected by the Plumes and Blooms Program and facilitate interpretation of the CHARM bio-optical data and *vice versa*. SubChem Systems, Inc. and WET Labs, Inc. are 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". The project partners plan to utilize the MOSEAN project to demonstrate and validate envisioned system stability over longer time periods (3 months).

The centerpiece program that complements the H-A mooring activity is the NSF Hawaii Ocean Time-series (HOT) program, which collects a suite of physical, chemical and biological data. Gliders with chemical and biological sensors (Charlie Eriksen and Steve Emerson) 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).

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