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

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LONG-TERM GOALS

The Multi-disciplinary Ocean Sensors for Environmental Analyses and Networks (MOSEAN) project has the long-term goal of developing and testing new technologies that will lead to increased observations that are essential for solving a variety of interdisciplinary oceanographic problems of societal importance. These include: biogeochemical cycling, climate change effects, ocean pollution, harmful algal blooms (HABs), ocean ecology, and underwater visibility. The collective MOSEAN sensors will be able to sample key variables that are vital to solve problems in near shore to coastal to open ocean environments.

OBJECTIVES

The overall objective of MOSEAN is to produce new sensors that will be able to sample key variables that are vital to solve interdisciplinary oceanographic problems in virtually all ocean environments. To

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14. ABSTRACT
The Multi-disciplinary Ocean Sensors for Environmental Analyses and Networks (MOSEAN) project has the long-term goal of developing and testing new technologies that will lead to increased observations that are essential for solving a variety of interdisciplinary oceanographic problems of societal importance. These include: biogeochemical cycling, climate change effects, ocean pollution, harmful algal blooms (HABs), ocean ecology, and underwater visibility. The collective MOSEAN sensors will be able to sample key variables that are vital to solve problems in near shore to coastal to open ocean environments.

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accomplish this objective, the MOSEAN partnership is developing, interfacing, testing, and demonstrating new interdisciplinary sensor suites. Measurements with emerging biological, chemical, and optical sensors are the primary focus of the study. The sensors and systems are being designed for use with a variety of autonomous, unattended sampling platforms including both 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). The MOSEAN sensors and systems will be capable of measuring key chemical, biological, and optical variables to complement physical data suites 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 with capabilities of real-time and/or near real-time data telemetry.

APPROACH

Sensors measuring a host of interdisciplinary variables from moorings and other platforms can be configured to provide a continuous early warning system to global change in the ocean, changing ocean conditions (e.g., optical properties), and ocean pollution. 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. Data obtained from mooring platforms can be spatially extrapolated using remote sensing, complementary shipboard, drifter, float, and glider sampling, and models.

Casey Moore (WET Labs, Inc.) and Al Hanson (SubChem Systems) are working together to develop and test new, smaller, more capable sensors for understanding biogeochemical and bio-optical processes. Their goals include improvement of operational capabilities of our current generation of bio-optical and opto-chemical sensors for long-term mooring (and other autonomous sampling platforms) deployments, developing new capabilities, and validating performance.

1. WET Labs and SubChem will provide an array of sensors for the MOSEAN mooring installations that will provide a common denominator set of biogeochemical measurements. Sensors will be configured as turnkey packages that can operate and collect data independently on a not-to-interfere basis. Alternatively, they will be fully capable of interfacing to primary mooring logger and telemetry networks with a single multi-channel serial input. The sensor packages will consist of new, novel, miniaturized, bio-optical sensors developed by WET Labs and a new generation of self-contained, modular, autonomous, nutrient analyzers developed by both firms. The basic suite of measurements will include: a) Spectral optical backscattering (two-four wavelengths); b) Integrated scattering coefficient; c) Spectral fluorescence (two-three channel excitation); and d) Modular measurements for four nutrient components chosen from nitrite, nitrate, ammonium, phosphate, silicate, and iron. The bulk of the sensors will be product prototypes. There remain key developmental efforts. There is need to incorporate anti-fouling capabilities for compound optical sensors. Also, the modular nutrient analyzers derive from a real-time analysis system that incorporates continuous flow reagent mixing and reaction, and thus, the mooring-based systems will require optimization for their application. Modifications will include: a) Size and power reduction of the electro-fluidic component to match elecro-optical detectors; b) Extending reagent preservation and operation into multi-month capabilities; and c) Validating anti-fouling strategies for multi-month deployments. In addition to providing the biogeochemical sensor suites, WET Labs and SubChem will provide ongoing support including on-site initial installations, training of

mooring personal for normal practices and procedures, and a package swap-out program to coincide with prescribed regular mooring maintenance cycles.

2. WET Labs and SubChem are engaged in development of a new set of next-generation tools for obtaining bio-optical and chemical signatures. These include the development of a highly compact, low-power spectral fluorometer for biological classification; a UV based spectral excitation/emission fluorometer for detection and classification of hydrocarbons, and a multi-channel micro-nutrient sensor incorporating optical fluorescence. As these technologies come on line, they will be incorporated into selected moorings on a trial basis. Anti-fouling technologies and other related improvements derived from Item 1 efforts will be incorporated in the latter effort.

WORK COMPLETED

The NOPP MOSEAN Santa Barbara Channel CHAnnel Re-locatable Mooring (CHARM) was deployed on May 19, 2003 and will be recovered October 2, 2003. Data from the 4- and 22-m depth sensor packages were successfully telemetered for only a couple of days before the antenna on the mooring failed. All data were recorded on Compact Flash disks and will be recovered with the mooring October 2, 2003. A meteorological station was deployed on August 11, 2003, within 2 miles of the CHARM mooring. Meteorological data (air temperature, relative humidity, wind speed and direction, and solar radiation) are downloaded to an OPL database once per day.

During the first CHARM deployment, a harmful algal bloom of *Pseudo-nitzschia* (>80% of cells) was occurring in the Santa Barbara (SB) Channel as well as throughout much of coastal California. Domoic acid levels peaked in mid-May; levels reached 76 ppm in mussels (nearshore) and >100 ppm in lobsters at Anacapa Island, and dozens of dead sea lions and birds were found on the beach directly inshore of the CHARM mooring. *Pseudo-nitzschia* cell counts began to decrease in late-May and the bloom ceased by mid-June. In late August and early September 2003, a fall bloom occurred in the SB Channel. In the span of 10 days, the surface water color changed from blue-green to brown and finally to red. The red water mass exhibited bioluminescence; bottle sample analyses revealed that it was a red tide bloom of *Lingulodinium polyedrum*. The red tide advected offshore after a couple of days and became highly spatially and temporally patchy. In late-September, the red tide returned to the nearshore region, and was more intense than previously observed. The evolution of these and other phytoplankton blooms in the SB Channel can be optically characterized by use of hyperspectral radiance and irradiance; spectral absorption, attenuation and backscattering; and chlorophyll fluorescence data used in conjunction with ancillary data. Additionally, these data can be used to develop remote sensing algorithms to identify phytoplankton blooms by group.

Other WET Labs and SubChem efforts to date have included:
Nutrient analyzer development: Two assemblies are under development for integration into sensors. One sensor employs a spectrophotometric measurement and the other uses a dual channel fluorometric measurement (Figure 1). Coupled with a compact reagent delivery system, these sensors form the measurement core for a set of single channel nutrient analyzers designed for extended deployment. SubChem engaged in development of robust processes for these measurements and has completed the processes for phosphate, nitrate (spectrophotometric) and ammonia (fluorometric) (Figure 2). It is expected that the other primary nutrients and chemical analytes sought for development and use in the project can use these same components and primary sequences for reagent delivery, analyte reduction, and measurements. The optical cells are now completed and the companies are currently engaged in

the design of a monolithic manifold assembly for reagent mixing and delivery to the cells. The units will incorporate a modified electronics set from the WET Labs ECO line. Current goals are for integration of the first phosphate, nitrate and ammonia sensors on the next CHARM deployment in early 2004, for long-term testing and evaluation.

Development of a three-wavelength backscattering sensor and a three-channel fluorometer for long-term deployment: WET Labs designed and developed a three-wavelength optical backscattering sensor incorporating optical wiper technology designed for long-term deployment. The sensor incorporated the firm's ECO electronic and optical technologies in a slightly larger form factor in order to provide bio-fouling retardation capability on multi-parameter sensors. Wavelengths for the scattering sensor center at 450 nm, 530 nm, and 650 nm. Scattering occurs at an approximate 117 degree of intersection. The first prototype of these units was installed on the MOSEAN CHARM mooring for its inaugural May 2003 deployment. Analyses of the data await recovery of the mooring in October. In similar fashion the company also designed a three-channel fluorometer for monitoring biological variability in the water column. The fluorometer maintains the same size and form factor as the backscattering sensor and will include the wiper technology as well. The instrument can be configured for detection of CDOM, phycocyanin, phycoerythrin, and chlorophyll-a depending upon the specific wavelengths chosen. Efforts on this sensor have focused upon optimizing excitation-emission couplings for the chosen analytes. The first prototype configured for CDOM, chlorophyll-a, and phycoerythrin, is constructed and undergoing laboratory characterization in preparation for the next CHARM deployment. The new sensors incorporate a new wiper design optimized for inshore environments. Evolved from the company's non-contact shutter design, the new wiper was developed for environments plagued by high suspended sediment loads.

Data acquisition and telemetry system for moorings: WET Labs collaborated with the UCSB OPL group in developing and integrating a data collection and telemetry system for the CHARM installation. The initial system incorporated two nodes: one near surface and one in mid-water column. Each node controls and collects data from up to eight instruments. The surface node contains an additional master controller that manages system operation and will telemeter data to a shore location for real-time data transfer from the mooring. This system was integrated prior to the first CHARM deployment in May 2003 and was successfully tested subsequent to the deployment. Pending system modifications, it should function as an operational part of the system in the first 2004 deployment.

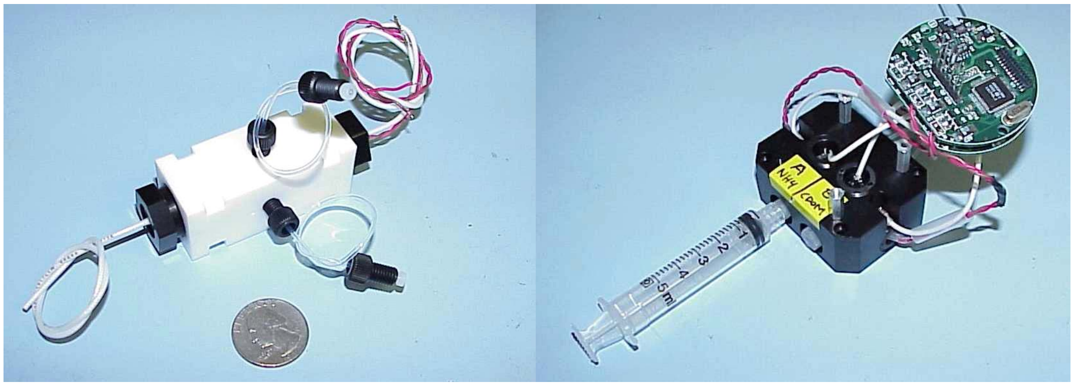

Figure 1. The spectrophotometric cell (left) and the dual channel fluorescence cell (right) form the optical core of the single channel nutrient analyzers under collaborative development.

Tommy Dickey (OPL; UCSB) has coordinated the MOSEAN project. OPL hosted investigators at the first MOSEAN Workshop at OPL in Santa Barbara. Discussions centered on new instrumentation designed for coastal applications and plans for the CHARM mooring (site selection, data telemetry, etc.). OPL worked with Woods Hole Oceanographic Institution (WHOI) to develop and construct a new surface buoy for the H-A mooring. This buoy is similar to the Bermuda Testbed Mooring (BTM) buoy, which was designed and engineered by OPL and WHOI. OPL also acquired a new acoustic Doppler current profiler (ADCP). OPL has also communicated with potential users of both the H-A and CHARM moorings.

Dave Karl (University of Hawaii) hosted the second MOSEAN workshop, which was attended by all MOSEAN principal investigators, held in Honolulu at the University of Hawaii February 3-5, 2003. During the meeting, we discussed the mooring hardware, instrumentation, and configuration, and sensors and systems that will be used on the mooring. Logistical matters included staging areas and facilities, ships to be used for the deployments, and ship scheduling. Potential users of the mooring and collaborating projects were discussed. Also, data management systems were considered (discussion led by Lance Fujieki, University of Hawaii) and it was decided that the present HOT data management system (called HOT-DOG) will be utilized for H-A mooring data sets. Fred Duennebier (University of Hawaii) also reviewed the status of his NSF project, which is intended to connect a communications/power cable to a node near the HOT and H-A site. It is our intent to link the H-A mooring to this cable in the future. Dave Karl has also worked with UCSB and WHOI to acquire requisite hardware for the H-A mooring and to communicate with users of the H-A.

IMPACT/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.

TRANSITIONS

MOSEAN has just begun, so there are no transitions yet. However, we anticipate that major transitions will occur in the form of commercialization of new sensors and telemetry systems and the utilization of these by governmental agencies and academic investigators. We expect that the MOSEAN project will accelerate 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.

RELATED PROJECTS

There are several projects taking place in the Santa Barbara Channel that relate to the CHARM component of MOSEAN. For example, spatial surface current data (using high frequency radar, CODAR) collected by Libe Washburn's UCSB group will be useful for characterizing major current features (e.g., like the Santa Barbara Channel Eddy) and passages of sub-mesoscale features and eddies; ship-based bio-optical data collected by the Plumes and Blooms Program (Dave Siegel, lead-PI; sediment plumes and phytoplankton blooms in Channel) will facilitate interpretation of the CHARM bio-optical data; ship-based data collected by the Santa Barbara Channel Long-Term Ecological Research (LTER; Dan Reed, lead-PI; with focus on land-ocean margin) program and the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO; Steve Gaines and Rob Warner, lead-PIs; nearshore ecosystems) program will be used for groundtruthing our suites of chemical and biological variables. Our harmful algal bloom (HAB) sensor work will complement and benefit from a recently funded ONR DURIP initiative, which is a major element of the planned Bioluminescence Prediction Network (BPN; spanning the coastline from Monterey to San Diego; lead-PI Jim Case) that includes work in the Santa Barbara Channel. There is also a newly funded (State of California) pier sampling program that will be valuable for some of our preliminary instrument testing. 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, JPL) 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 will be able to describe and quantify the three-dimensional evolution of several key water quality parameters on time scales of a day to the interannual. In addition, an interdisciplinary numerical model of the California Current, with high resolution in particular coastal regions including the Santa Barbara Channel, is being developed by collaborators led by Jim McWilliams (UCLA) and Yi Chao (JPL); this model will be important for synthesis and prediction. Van Holliday has done acoustic and physical measurements from a mooring placed near the CHARM mooring as a pilot experiment to investigate the formation and destruction of biological thin layers. OPL facilitated his near real-time data telemetry work.

Several investigators will be deploying sensors from the H-A mooring. These include Ed Boyle (MIT, trace metal sampler), Steve Emerson (University of Washington, gas tension chemical measurements), Ricardo Letelier (Oregon State University, spectral optical measurements), and Chris Sabine (Pacific Marine Environment Laboratory, carbon system). Similarly, several projects complement the HALE-ALOHA (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 is lead-PI) program, which collects a relatively complete suite of physical, chemical (including nutrients and CO_2), and biological data. There are plans to place an air-sea interaction/physics buoy near H-A by Bob Weller

(WHOI) and Roger Lukas (University of Hawaii) and a moored profiler is expected to also be placed near H-A by Bruce Howe (University of Washington), Roger Lukas (Univerity of Hawaii), and Emmanuel Boss (University of Maine). Also, remote sensing data are collected, and plans are in place for collection of interdisciplinary data from gliders (Charlie Eriksen and Steve Emerson, University of Washington). The HOT/H-A region is often used for other scientific studies that can be used to enhance our data sets and *vice versa*. Again, it should be noted that a cabled sampling node is planned in the vicinity of the HALE-ALOHA mooring site. Thus, it may possible in the future to obtain HALE-ALOHA broadband data in real-time via this advanced communication system. More information concerning the HOT and HALE-ALOHA programs may be found on the website: http://hahana.soest.hawaii.edu/hot/hot_jgofs.html.

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