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 nearshore to coastal to open ocean environments.

OBJECTIVES

The overall objective of MOSEAN is to produce and test new sensors that will be able to sample key variables that are vital to solve interdisciplinary oceanographic problems in virtually all ocean environments. To 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 and tested 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 and tested with capabilities of real-time and/or near real-time data telemetry.

APPROACH AND WORK PLAN

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 (three to nine wavelengths); b) Hyperspectral absorption, scattering, and attenuation coefficient (90-100 wavelengths); c) Spectral fluorescence (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.

3. UCSB and UH are supplying newly engineered mooring platforms for the implementation and testing of the WET Labs, Inc., SubChem Systems, and other sensors and systems. Complementary mooring sensors and systems are provided by UCSB and UH including: newly designed and developed buoy (by UCSB and WHOI 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. is providing a profiling package equipped with state-of-the-art optical sensors for calibration/validation of mooring measurements. Real-time data telemetry systems are being developed, deployed, and tested at both sites.

WORK COMPLETED

CHARM:

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 and the fourth and fifth CHARM deployments were February 2, 2005 – April 22, 2005; May 1, 2005 – September 28, 2005. In addition to NOPP MOSEAN sensors, a newly developed bioluminescence sensor (James Case, UCSB, under funding by NOPP with WET Labs, Inc.) was also tested on the CHARM at 10 m water depth. 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.

1. Nutrient sensor development In conjunction with SubChem Systems, WET Labs is engaged in development and implementation of nutrient sensors for extended deployment. This past year's efforts focused upon developing operational capabilities for a mooring based Phosphate sensor. The initial development and testing of this sensor occurred over the past two years.

Results from the initial CHARM mooring deployment indicated that the sensor effectively tracked a major upwelling event in the Santa Barbara channel. The sensor demonstrated effective performance over a six week period during this deployment (Egli et al). Subsequent test in Narragansett Rhode Island showed good agreement with concurrently acquired water samples. Based upon these results we proceeded to build five additional units. Our goals were to assess manufacture readiness, sensor to sensor repeatability, and ultimately to deploy in differing conditions Construction and characterization of these units led us to conclude that while the current design provided promising results, the sensor was not yet at a truly operational stage. It lacked stability, it suffered in unit to unit conformal performance, it was difficult to prepare for deployment, it was limited in configuration, and it was cumbersome to effectively manufacture and calibrate.

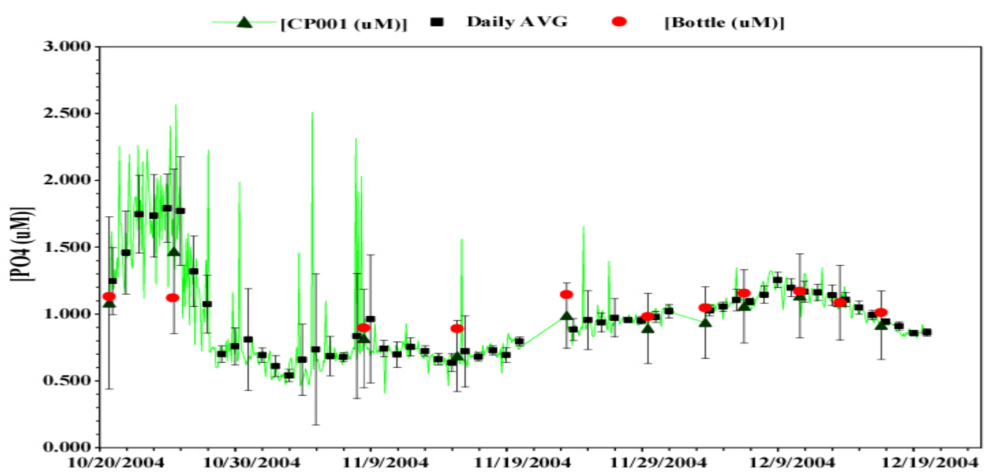

Figure 1. Phosphate sensor deployed over 8 week period in Narragansett, RI showed good agreement with discreet samples. (Data collected by Peter Egli, University of Rhode Island)

These limitations resulted substantial redesign efforts. Redesign included implementation of a new more powerful controller, and several new mixing assemblies. The new controller provide a more flexible configuration interface that allowed us to more effectively control the four micro pumps in the fluidics chamber. This in turn allowed greater control of our reagent mixing. We also began a series of incremental improvements in our mixing chamber. Testing on the five test units led us to conclude that effective mixing, or lack thereof was the dominating factor in maintaining instrument stability and measurement repeatability. These efforts have led to a novel implementation currently in testing, that provides a four to one volumetric reduction in total reagent per sample required, a substantial decrease in reaction time, and readings over time consistent to approximately 50 nanomolar concentrations. While these results are preliminary they do indicate that we better understand the dynamics of the fluidics mixing.

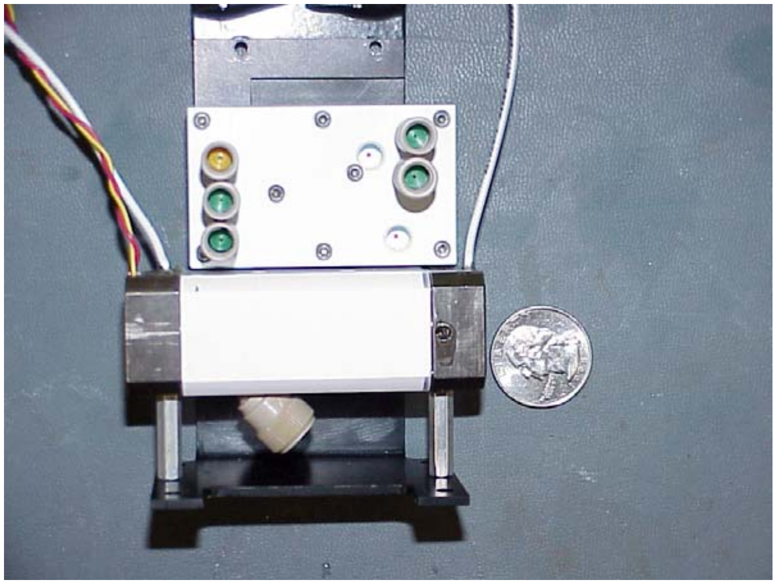

Figure 2. Current embodiment of the optical cell and integrated mixing assembly in testing.

2. In addition to testing the phosphate sensor methodology, SubChem Systems initiated an investigation to adapt this instrumental technology for the measurement of other nutrients (nitrate, nitrite, ammonia, and silicate) of interest. Initial laboratory tests have been completed for nitrate and nitrite, with promising results. As part of this effort a multi-month "reagent longevity" experiment was conducted in the laboratory. The experiment was designed to develop and test our ability to prepare and preserve reagents and standards so they would remain "analytically effective" for extended time periods (i.e. while deployed on a mooring). Reagent and standard formulations and procedures were successfully developed that enabled the prepared chemical solutions to remain analytically effective for up to three months, without refrigeration.*Support for the CHARM and HA moorings* – WET Labs provided substantial support for the two MOSEANS mooring installations. This support included providing servicing and refurbishment for over 40 instruments and power systems for f the CHARM and Hale Aloha deployments, and also interim calibration and servicing of the equipment.

3. *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. *We provided 6 six sensors slated for eventual MOSEANs delivery. to the Alliance of Coastal Technologies (ACT).* The NOAA sponsored ACT conducted a comprehensive verification process on fluorometers during summer, 2005. The goal of the tests were to test and assess manufacturers' products in extended coastal deployment conditions. Participating as one of 7 manufacturers in these trials 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, 2005. Sensors used in these tests will be supplied to our NOPP partners at the University of California Santa Barbara, for deployment on the CHARM and HA moorings.

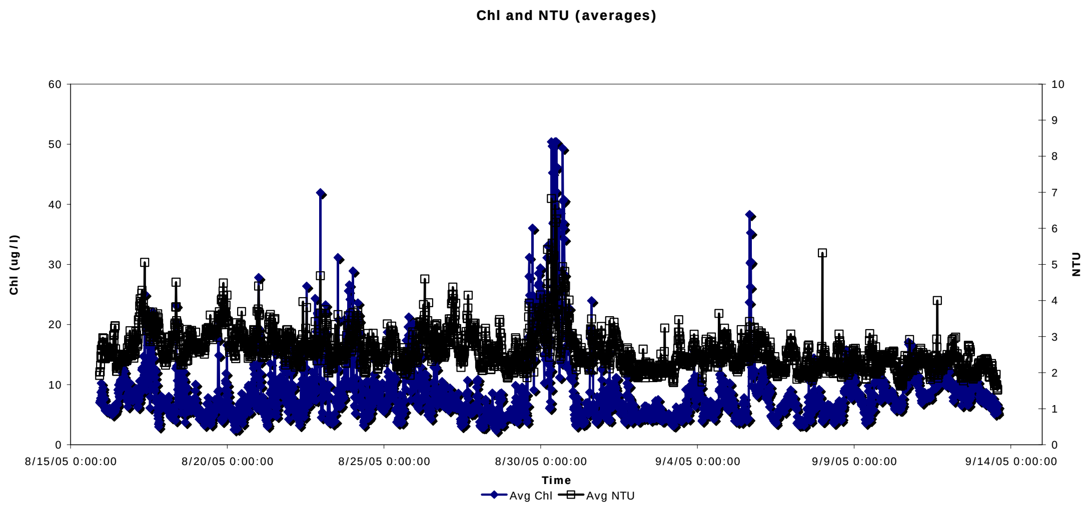

Figure 3. ACT Data from Chesapeake Bay shows chlorophyll and turbidity values from a WET Labs combination fluorescence- scattering meter for a 28 day period. It shows clear diel variation and a stable baseline –consistent qualities of a fouling free deployment. (Data collected by Chesapeake Bay Laboratory)

b. *We implemented a integral copper faceplate into our flat face sensors to further enhance fouling retardation.* In heavy fouling regimes we have found that our copper shutter technologies eventually fail due to gradual encroachment of organisms around the face of the detector. In these situations the shutter often becomes encumbered and ultimately ceases to open and close. Figures 4 and 5 demonstrate this type of fouling in a situation in which the package was pulled before the package failed. The copper faceplate increases the effective area over which the copper is effective. Initial tests show this to be very effective. As a result the company will transition the improvement into its commercial designs.

Figure 4. Heavy biofouling encroaches upon anti-fouling shutters, sometimes causing eventual failure of the shutter assembly. In this situation the shutter was still operating when it was pulled from the water. (Photo by Derek Manov)

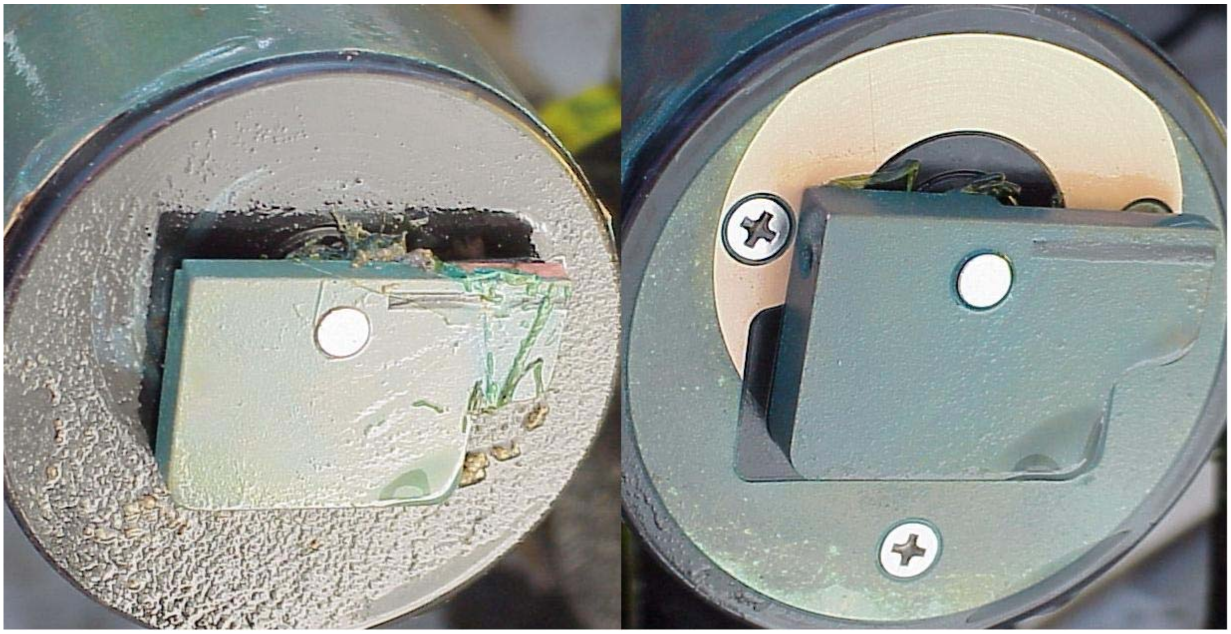

Figure 5. New faceplate on flat faced sensors (on right) after side-by-side deployment with sensor without faceplate.

c. *We tested an air-purge system for flow-through instrumentation* - This proof-of–principle test involved implementing an electronic valve flow-through system for periodic sampling of chlorophyll fluorescence. Between samples the flow through path was evacuated with oxygen. The system was used over a four week period with a control fluorometer and a fluorometer with internal copper sleeves running concurrently. After a summer of collecting results we say no clear advantage in the air system. We currently plan some minor modifications on the assembly and then to repeat tests in early spring of 2006.

HALE-ALOHA Mooring

The NOPP MOSEAN H-A mooring was first deployed on August 11, 2004 and recovered November 24, 2004. There have since been two other successful deployments of H-A: December 19, 2004 to May 22, 2005 and May 29, 2005 to February 8, 2006 (scheduled). 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 NOPP 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 anticipating the NSF ORION and other agency sponsored observatory initiatives.

Remote Access Samplers (RAS) are designed to collect in-situ water samples in support of oceanographic research projects and environmental monitoring programs. The RAS 3-48-500 used in the MOSEAN deployments collects ambient water and suspended material in tedlar bags, isolating the samples for subsequent laboratory analysis. RAS systems can be fitted with in-line pre-filters, and the HCl acid cleaning cycles used throughout the deployment remove bio-fouling and other contaminants to keep samples pure.

The RAS can collect up to 48- 500ml samples, autonomously following a user defined sampling schedule. For the MOSEAN deployments the intervals of sampling were spaced out evenly throughout the sampling period, averaging 1 sample taken every three days. The operator has control over sampling schedules, sample volumes, time limits, and other sampling parameters. During the deployments, the system logs data such as electrical parameters, sample timing, volume, rate and flow. This data is offloaded after the RAS is recovered. All of the RAS-500 components are mounted inside a 316 stainless steel frame.

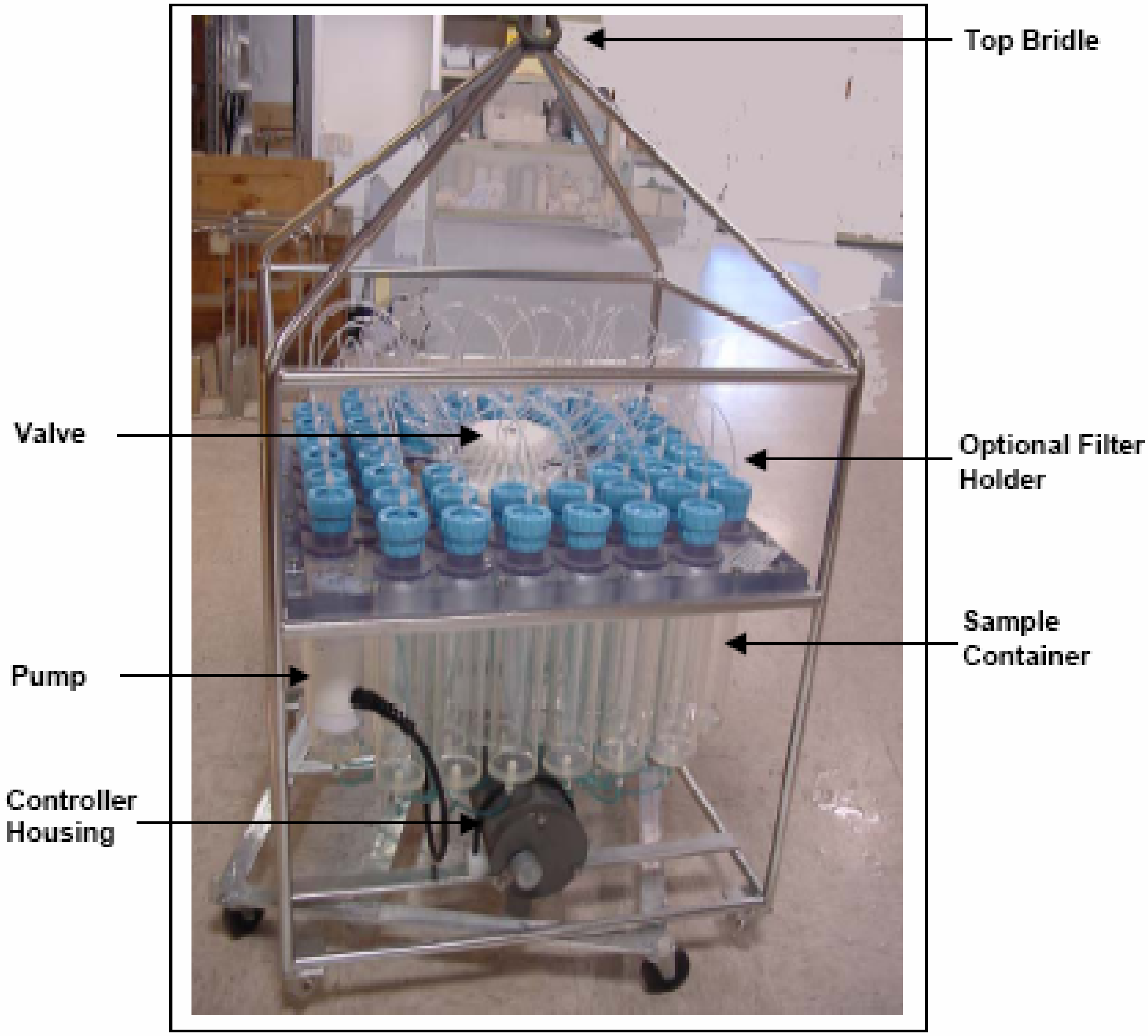

Figure 2-1: RAS-500 Full View

Figure 6. Pictures of the RAS before, with some of the major components - and after the deployment, a bit fuzzy with biofouling after three months exposure.

The RAS deployed on MOSEAN moorings 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

Tommy Dickey (OPL; UCSB) has coordinated the MOSEAN project. The third MOSEAN workshop was held in Honolulu, HI in February 2004. 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.).

RESULTS

CHARM:

Data from the 4-m depth sensor packages were successfully telemetered via radio frequency telemetry over the entire time periods for the second and fifth 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 recorded on Compact Flash disks and recovered with each mooring.

We investigated relationships and variability of bio-optical properties to elucidate processes affecting reflectance in the Santa Barbara Channel. Optical proxies were used to distinguish between particle types (e.g., backscattering ratio, beam c vs. chlorophyll fluorescence, etc.; Figure 7).

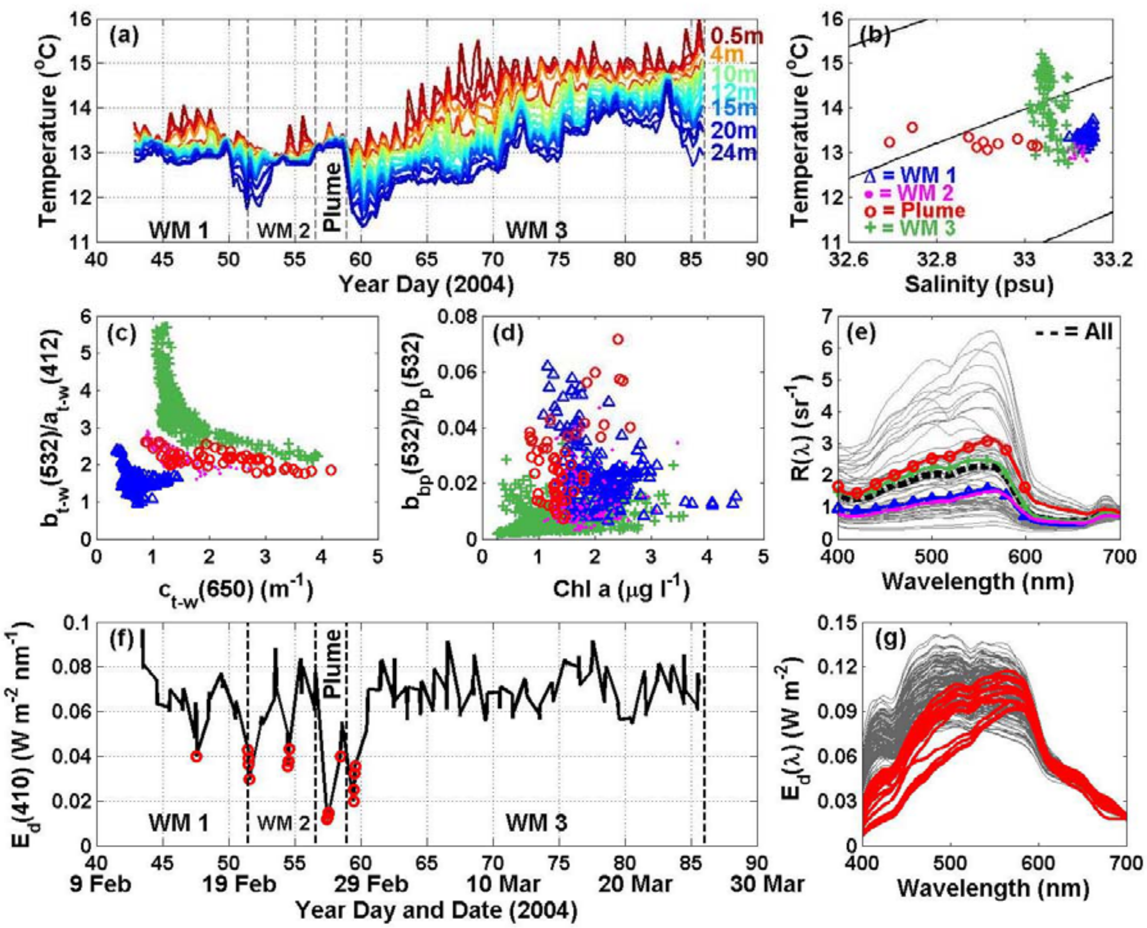

Figure 7. Data from CHARM. (a) Time series of temperature at every meter from surface to 24 m.

Time periods of different optical water types are delineated and labeled. (b) Temperature-Salinity plot showing the different water masses present at CHARM. (c) Optical proxy: ratio of scattering to absorption coefficient versus attenuation coefficient to show presence of different optical water types. (d) Optical proxy: backscattering ratio versus chlorophyll concentration, indicating particle type (organic vs. inorganic). (e) Daily noon hyperspectral reflectance spectra for different optical water types (legend in (b)). (f) Time series of downwelling irradiance. Red circles indicate plume conditions isolated using the Spectral Angle Mapper technique. (g) Hyperspectral downwelling irradiance spectra. Red spectra are plume conditions, isolated from the rest of the time series by use of the Spectral Angle Mapper method.

Results showed the presence of four water masses with distinct optical characteristics at the CHARM site in a two-month period. The first was relatively clear and dominated by high index of refraction, chlorophyll-containing particles. The second optical water mass was more turbid and consisted of mostly inorganic particles with a small component of phytoplankton. An intense winter storm resulted in advection of Ventura River plume waters and high concentrations of inorganic particles. The last was characterized by residual inorganic particles from the storm plume and then shifted to high nutrient concentrations and phytoplankton-dominated waters. CHARM reflectance spectra changed from coastal-like signatures in early winter to more estuarine for plume waters, to more coastal conditions toward springtime. We demonstrated the utilization of *in situ* optical proxies for the characterization of these optical water masses and showed that traditional global empirical algorithms to identify relationships between ratios of reflectance to bio-optical properties are not applicable in such a complex, optically dynamic coastal region. The Spectral Angle Mapper technique was employed to successfully classify optical signatures, which has important implications for coastal management operations (e.g., contaminant and particle detection and tracking, harmful algal bloom identification, and monitoring of storm-induced beach erosion and runoff).

HALE-ALOHA:

OPL, in collaboration with Woods Hole Oceanographic Institution (WHOI), developed and constructed a new surface buoy for the H-A mooring. This specially designed buoy allows interfacing of a wide variety of interdisciplinary instrumentation, e.g., real-time (through ARGOS) meteorological packages; real-time (through iridium) pCO_2 sensor, Chris Sabine, PMEL; spectral radiometer, Ricardo Letelier, OSU. This buoy has been successfully deployed at the H-A site for the past 1.5 years. The NOPP sponsored H-A mooring has been deployed three 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.

The HALE-ALOHA (H-A) mooring is providing the oceanographic community with a critical resource for scientific and technological studies, namely a deep-ocean mooring platform with core interdisciplinary measurements. This aspect of MOSEAN was originally motivated by the need to develop and demonstrate autonomous interdisciplinary oceanographic sampling capabilities. This objective has been achieved and in fact many of the current ocean observatories and the nascent NSF ORION program and many others have already benefited from the H-A activity. Areas of advancement based on our previous NOPP O-SCOPE and the present MOSEAN projects have included the testing and modification of several sensors and systems, development and commercialization of anti-biofouling techniques, the design, engineering, and testing of a new user-friendly interdisciplinary surface buoy, and the development and testing of underwater and satellite-based data telemetry systems. In addition, the H-A was intended to provide high temporal interdisciplinary data sets to complement the NSF sponsored Joint Global Ocean Flux Study (JGOFS) Hawaii Ocean Time-series (HOT) for quantifying and modeling temporal variability of the biogeochemistry and ecology of the ocean, particularly as they affect and are affected by global climate change in the oligotrophic North Pacific off Oahu. These efforts have been effectively used to make exciting scientific discoveries, to increase our knowledge and understanding of a variety of ocean processes, and to develop and test models. Importantly, ship-based observation cannot capture important phenomena with characteristic time scales from minutes to weeks and thus scientific understanding and effective modeling were being hampered. Several research efforts that have utilized the HALE-ALOHA mooring (very near the HOT site) to clearly demonstrate that processes in this temporal spectral domain are important for ocean biogeochemical and ecological processes and episodic events to long-term climate change. Key processes that require high resolution mooring time series data include: mesoscale eddies, storms, dust deposition events, rapid shoaling of the mixed layer, phytoplankton bloom events, inertial oscillations, diel and shorter time scale variability in phytoplankton and bio-optical properties, and internal gravity waves. For example, unique H-A observations including passages of mesoscale features with high nutrient and phytoplankton concentrations, and dust events, have led to paradigm shifts. H-A data are constantly being used by the international research community. Importantly, H-A results have stimulated many more exciting questions and hypotheses which remain to be addressed.

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 will be 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 PCO2 sensor on the H-A mooring and this activity is becoming part of a global pCO2 and carbon measurement program with real-time data telemetry. Also, the development, testing, and commercialization of a WETLabs 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, spatial surface current data (using high frequency radar, CODAR) collected by Libe Washburn's UCSB group are being used to characterize major current features (e.g., like the Santa Barbara Channel Eddy) and passages of sub-mesoscale features and eddies; ship-based bio-optical data are being collected by the Plumes and Blooms Program (Dave Siegel, lead-PI; sediment plumes and phytoplankton blooms in Channel) and 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 are being used for groundtruthing our suites of chemical and biological variables. Our harmful algal bloom (HAB) sensor work complements and benefit from an 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 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. 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. 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 test-bed mooring to demonstrate and validate envisioned system stability over longer time periods (3 months).

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. 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 NOPP MOSEAN cruise activity. The HOT/H-A region is often used for other scientific studies that can be used to enhance our data sets and *vice versa*. 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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