Monterey Ocean Observing System (MOOS)

In 2004, the MOOS program will complete the development of one of the MOOS mooring configurations designed to support upper water column (UWC) studies. The UWC mooring will combine development efforts undertaken over the last three years by four of the MOOS projects, MOOS mooring, SIAM (Software Infrastructure and Application for MOOS), SSDS (Shore Side Data System) and the MOOS mooring controller (MMC). The MOOS mooring system will support a science deployment in the Santa Cruz bight and will be mainly funded by CIMT (Center for Integrated Marine Technology). New innovative features to be incorporated and tested include, plug and work instrumentation, automated mooring configuration, automated metadata generation and delivery with the data packets to the shore side archive, new power system and the new mooring controller based on the SideArm processor. Although the SIAM and SSDS developments are ongoing, this will be an excellent opportunity to test the systems end to end in support of science to evaluate how well we have met the requirements identified at the original MOOS workshop in 1999.

Developing OEM cables and moorings that will survive coastal environments for extended durations was identified as one of the key enabling technologies for ocean observing systems, both at our own MOOS workshop and at many community workshops. Designing such cables and moorings is proving to be every bit as challenging as first thought. The first test mooring deployed in December broke free after a storm where winds and significant wave heights approached 25 year storm levels. Since this event, the NSF has funded MBARI and WHOI (Frye et al) to develop these OEM (optical, electrical, mechanical) cable and mooring designs further (Oct 2003 through Oct 2005) as the technology is central to the DEOS element of the OOI (Ocean Observing Initiative) for global ocean buoys. The MBARI/WHOI program will establish cable designs, shore side cable test protocols, and mooring configurations that will be robust and verifiable (via shore side testing and analysis) for MOOS and DEOS deployments at low/mid latitude sites. This is an example where MBARI identified a technical challenge of importance to the oceanography community and funded the early development. Then, when the technology became of prime importance to a community effort (OOI), MBARI developed a collaboration with another Institution to further the development with supporting funds from outside agencies. Current plans call for two test moorings, and possibly a third, to be deployed in Monterey Bay in March 2003.

The OEM cable is a key element of the MOOS Science Experiment at Shepards Meander, originally planned for 2004. Due to the aforementioned setback at the end of last year, further work associated with preparing for the MOOS science experiment deployment has been placed on lower priority until the survivability of the OEM cable has been established.

Evaluation and testing of vertical profilers (VPs) (commercial and the MBARI buoyancy driven VP) will be undertaken in 2004. Initially, candidate VPs will be tested on a small test mooring that will be easy to deploy and recover in support of MBARI science programs, in particularly those of Haddock, Ryan, Scholin, and Paull. After these deployments we will be in a better position to understand the implications of incorporating these VP capabilities into the MOOS mooring system. This capability was raised at a recent DEOS meeting as being of prime importance to the DEOS mooring systems. The challenge will be incorporating VP capabilities into an OEM cable mooring. First indications are that this may be impossible, but the payoff is correspondingly large.

AUV docking will proceed with testing high risk elements of the system including sea testing of homing algorithms, and design and tank testing of the latching mechanism. The concept design review will be held at the end of the year.

In 2004 we will commission and test the Tiburon cable laying toolsled ready for laying cable in support of the Shepard Meander Science Experiment and design and test the new benthic node.

Cabled observatory efforts will increase in 2004. Most of the tasks are continuing and include supporting the NEPTUNE Systems Engineering Team, co-ordinating the design and test of the MARS sub-systems, much of which is being performed at partner Institutions, managing Alcatel and MariPro's tasks (our industrial partners for MARS) and pursuing permitting efforts (including multi-beam, sub-bottom profiling and biological surveying of the cable route). A new effort in 2004 will be to instigate a program to test the survival of cables crossing the mouth of the Canyon near Moss Landing. By the end of 2004 we aim to be integrating the sub systems into the MARS node at our shore integration site at MariPro, ready for installing the system in 2005.

MOOS Mooring and OEM Cable

Mark Chaffey

The MOOS mooring program has made progress toward the overall goal of creating a full OEM cable-to-the-sea-floor mooring system. However, one of the critical technical areas identified in the previous years proposal as high risk, "*The risk of premature failure of the riser cable due to environmental stress not predicted in the mooring design stage (requirements generation)…*" has turned out to be a serious problem. The initial field trial result was a break in the mooring riser cable near a cable float and a substantial weakening of the cable at other locations. Fortunately we have been able to recover nearly all of the test hardware and the cause of the failure has been clearly established to be the result of cable bending fatigue and poor float attachment design. The analysis of this cable failure and the great data set we collected during the severe storm conditions the test mooring experienced has resulted in a much better understanding of the bending environment of our mooring configuration and the design requirements for cables under these conditions. Based on these results, we have improved our bending stress prediction methods and are currently working with four potential cable suppliers and our collaborator, Walter Paul at WHOI to design a new OEM cable with substantially less bending sensitivity for the next test deployment. We are also focusing our attention on all areas where the cable sees repetitive bending stresses including the termination bending strain reliefs, the float attachment cable clamps and during manual and automatic (winch) handling operations.

In a more aggressive approach to solving the OEM cable mooring design problem we plan on deploying test moorings with the *two* most promising cable designs in March 2004 to validate the results of our cable design analysis and laboratory testing and a *third* cable design in November 2004. A major motivation for field-testing different cables is the emergence of a split in the design offerings between conventional outer strength member cables and more novel center strength member cables.

MBARI began working on OEM cabled moorings as a natural extension of our experience both with moored observatories such as OASIS as well as our extensive experience with ROV OEM umbilicals. The concept of a portable mooring system seafloor observatory has also attracted much interest in the larger oceanographic community as well and our work in this area has resulted in MBARI becoming a partner in the NSF Dynamics of Earth and Ocean Systems (DEOS) program. The MOOS Mooring concept design has been adopted as a portable observatory design for mid to low latitudes. Motivated by the desire to prove the concept of OEM cable moorings before the major proposed initiatives of DEOS are evaluated for funding in 2006 the MOOS mooring program project effort has received two years of NSF funding (2004/5) in collaboration with WHOI (MBARI portion $648,550) to improve buoy predictive modeling tools, develop cable verification test protocols and field test the best cable design (as part of the MOOS OEM mooring science experiment (MSE) deployment) to prove the feasibility of OEM cable moorings. The benefits of this funding are threefold, MBARI's internal capital expenditures for developing the OEM cable mooring for the MSE experiment are reduced significantly, the external funding will allow a greater effort be directed toward improving OEM cable survival predictive models and laboratory qualification tests than MBARI could have undertaken unilaterally and importantly, MBARI’s efforts are more likely to make a significant contribution to the larger community.

In a related effort we plan on deploying a single Benthic Instrument Node (BIN) using the RV Western Flyer in approximately 1200-1500 meters water depth in 2004 in association with the cable test moorings. We propose to then make a cable connection from the mooring to the BIN using ROV Ventana to gain experience with this important OEM mooring task before we attempt the operation further offshore for the "MSE mooring" deployment planned for 2005.

CIMT

Kent Headley, Francisco Chavez, Tom O’Reilly, John Graybeal, Mark Chaffey

The MOOS mooring program has made substantial progress toward the overall goal of creating a mooring-based observatory system that can support both upper water column and benthic observations. The low voltage power system, mooring controller and over-the-horizon communications systems have all completed initial engineering field trials. In addition, the mooring controller, software infrastructure and shore side data system were successfully deployed as part of the 2003 AOSN experiment.

The first major science field trial of the MOOS Mooring system has been focused on the upper water column. This will allow the completed MOOS subsystems to be field tested with a full science instrument payload without being directly dependent on the more technically risky EOM cable mooring development schedule (see MOOS Mooring Project for EOM cable details).

The proposed deployment, made in conjunction with the Center for Integrated Marine Technology (CIMT), provides externally visible science data return as well as field-testing the mooring system design: power and telemetry systems, MOOS mooring controller (MMC), software infrastructure and applications for MOOS (SIAM) and the shore-side data system (SSDS). This is consistent with the overall MOOS program goal of setting milestones for the engineering development of intermediate science deployments that provide real data products while verifying the design.

The science mission for the CIMT deployment will focus on bloom formation inside Monterey Bay; the mooring will be located where blooms potentially reach their maximum levels. Once water enters the bay, it slows and stratifies, leading to optimal conditions for phytoplankton growth. This stratification acts to select for taxonomic groups (pennate diatoms, dinoflagellates) that are capable of producing toxins that are harmful to humans. Collectively, an array of such moorings may allow Monterey Bay to serve as a useful microcosm for the California coastal upwelling system.

The MOOS-CIMT deployment provides an opportunity to temper and refine core functions and features developed to date:

<u>MOOS Mooring</u>
The MOOS buoy, bridle and tower provides compatibility with OASIS instrument mounts and flexibility to deploy with the EOM at a later date.

<u>Software Infrastructure and Applications for MOOS (SIAM)</u> On the mooring, SIAM components are responsible for instrument data acquisition, logging, and telemetry, as well as management of mooring power and communications subsystems. SIAM software and MBARI instrument pucks enable unique and extremely useful features such as automatic mooring reconfiguration ("plug and work"), as well as "self-identifying" instruments that log vital contextural information in addition to the sensor data.

SIAM also provides software that allows users to directly control and monitor the deployed mooring and its instruments, and shore-side "portal" software that retrieves and routes SIAM telemetry to shore-side processing and archival components (such as the MOOS SSDS).

The SIAM software has been designed to be very scalable and is applicable to systems consisting of a single mooring surface node as well as "moored networks" which include multiple benthic nodes. This is an important feature for operation and maintenance of networks of moorings and benthic nodes

The SIAM team has already implemented many of the features described above, and a SIAM mooring controller was deployed in June 2003 on the 'M1' mooring, collecting radiometric data in support of the Autonomous Ocean Sampling Network (AOSN) experiment.

In 2004, the SIAM project will implement, complete, and refine key system components that will be tested on the CIMT deployment.

The project will continue to utilize the "Extreme Programming" ("XP") development approach adopted by the team in 2003. XP is a disciplined development approach that stresses rapid prototyping and evaluation by a focused team of software developers and end-users (in SIAM's case the end-users are Operations Support Group and scientists). The SIAM team used the XP approach in 2003 to develop the robust, fully-featured system deployed as part of the AOSN experiment.

<u>Shore Side Data System</u>

The Shore Side Data System will provide data management for the CIMT system. Expanding on the basic framework introduced in 2003, the SSDS will be able to take advantage of features provided by the platform hardware and software (the MMC controller and SIAM software infrastructure) to accommodate all the instruments planned for the mooring. Through the iterative development process, developers will emphasize components and functions most critical for the deployments at hand, and will continually verify operational readiness in advance of the CIMT deployment itself.

Basic services provided by SSDS to date include properly archiving raw data from both streams and files, notifying users of data arrival, and providing basic access to the data and its corresponding metadata. These services will be integrated within the overall CIMT architecture. SIAM services will support additional SSDS features, including metadata archival, automatic generation of widely-accessible data sets from the raw data, and other advanced data services using the archived metadata.

The most visible SSDS services provided in 2004 will simplify initial metadata entry, and ease the users' access to archived data and metadata. SSDS- and SIAM-developed tools will make describing an instrument and adding it to a MOOS system as easy as possible. Downstream, SSDS will provide users varied ways to access their data. The SSDS will also reformat data per user requests for typical oceanographic visualization tools (such as Excel, Matlab, ODV, and Live Access Server). Simple quick-look plots will also be available for most of the data which has been properly described with metadata. Finally, the SSDS will provide interfaces to make post-processing the data sets more automated and maintainable.

MOOS Power System.
The large panel solar system provides 20 Watts of average power, supporting higher instrument sampling rates and a more capable controller.

MOOS Mooring Controller.
The MOOS-CIMT deployment will extensively test the complete controller system, including the instrument interfaces, fault detection/isolation and power management features.

With an emphasis on satisfying core requirements of operational and science users, the 2004 MOOS-CIMT deployment promises to flush out remaining technical issues and begin the transition of MOOS to operational status.

NEPTUNE/MARS

Keith Raybould, Gene Massion

MBARI's involvement in NEPTUNE in 2004 will be very much the same as in 2003. Marcia Mc Nutt and Jim Bellingham will be on the NEPTUNE Executive Team (ET) and Gene Massion will be on the NEPTUNE Systems Engineering Team (SET).

MARS efforts ramped up significantly during the second half of 2003 with the marine survey, biological survey, permit application to the State Lands Commission/MBNMC and the project Preliminary Design Review planned for late 2003/early 2004. Mid year we will hold the project Critical Design Review with system integration at Maripro in the last quarter of 2004. The MARS installation is currently scheduled for mid 2005.

Vertical Profiling

Andy Hamilton

A vertical profiling capability to make nearly simultaneous measurements of oceanographic variables throughout the water column has long been included as part of the MOOS plan and a feasibility study of the options for this capability began in 2003. In 2004, the vertical profiling efforts for MOOS aim to continue this study and complete the specific functional requirements for the MOOS profiling capability. Because significant work on profiling has been done at other institutions, it is important to understand the capabilities of the commercially available solutions so that MBARI's efforts can be concentrated on advancements of the technology. For instance, the commercially available solutions appear to be well suited to short-term deployments, but currently lack the data telemetry and in-situ battery recharging features that are required for long-term deployments. A future MBARI effort to develop these capabilities would add significantly to the state of the art in vertical profiling.

Also in 2004, two commercially available profiling solutions will be deployed as part of particular science experiments. A deep-water solution (McLane Moored Profiler) will be deployed as part of the MBARI Canyon Dynamics experiment and a near-surface solution (SeaHorse Profiler) will be deployed in conjunction with the MOOS-Lite/CIMT mooring deployment. The aim of these deployments is to evaluate the suitability of these units for integration into the MOOS architecture while simultaneously gathering significant science data. It is important to perform the evaluations within the context of the science experiments in order to evaluate the quality of the science data gathered. The SeaHorse profiler has already been deployed successfully by MBARI and additional work will be done in 2004 to incorporate real-time data telemetry into this unit. This will be the first step in making the SeaHorse profiler compatible with the MOOS data architecture.

Both the feasibility study and the deployments planned for 2004 will make contributions to the effort to define how to move forward beyond 2004 with MOOS profiling. The feasibility study will provide an understanding of potential scientific use cases and functional requirements. The deployment activities will contribute by providing a wealth of experience with the engineering challenges, the scientific possibilities, and the operational issues related to making profile measurements of the water column.

Shepard Meander Science Experiment

John Ryan

Plans for the next MOOS Science Experiment, the Shepard Meander Experiment (SME), have been carefully developed with broad science and engineering input. This plan includes novel science of great significance to better understanding carbon fluxes in this highly productive and dynamic eastern margin system and in a major ocean margin canyon system. The research spans the shallow California Current to 3500-meter depths of lower Monterey Canyon. SME is planned for 2005, and the primary goal for SME preparation during 2004 is to ensure that critical observing technologies required for SME are well understood, tested, and ready for operations in 2005. In addition to the MOOS mooring these critical observing technologies include deep ROV cable laying, connectable benthic nodes, and vertical profiling systems for shallow and deep observations.

Deep ROV cable laying: Testing of deep cable laying will begin with evaluation of three optional SME sites having different levels of scientific merit and operational difficulty. An existing cable segment will be deployed up the canyon wall and recovered at the optional sites to determine feasibility of operations and to choose the experiment site. Seafloor cable laying outside the canyon will also be tested.

Benthic Nodes: To prepare for successful operation of benthic instrument nodes (BINs) that can be connected to each other and to the MOOS mooring for power and communications, several tasks are required during 2004 in addition to cable laying. These include 1) design and construction of the BIN to enable reliable deployment, instrument addition, connection to the mooring, and ROV servicing, 2) accurate placement of BINs in the narrow central channel of the canyon, and 3) reliable turnaround of the BIN instrumentation. A next generation BIN design enhancing deployment, serviceability, and performance is being finalized during 2003. Construction of the BIN is scheduled to begin in January 2004, tank testing will follow, and deployment in the lower canyon is planned for late March 2004.

Vertical profiling: A commercially available system for deep profiling is being purchased this year, and it will be deployed in the lower canyon during 2004 concurrent with the next generation BIN deployment. This deployment will serve to evaluate the technology and gather environmental observations to aid experiment design. Evaluation of options for shallow profiling will continue during 2004. A commercially available system for upper water column profiling (SeaHorse) was tested as a rental during AOSN 2003, side-by-side with the MBARI vertical profiler (MVP). A SeaHorse will be purchased in 2004 for further testing performance and integration with MOOS. Both the MVP and the SeaHorse are currently limited to shallower than 200 m, but profiling deeper than 200 m is both a goal of SME and a functional requirement of MOOS. Both profilers would require modification to meet this requirement, and the key goal for 2004 is to evaluate which system to modify for application within the MOOS infrastructure during SME. This decision will be based on 1) refinement of the profiling functional requirements during 2004, 2) evaluation of the modifications required for each system to meet the functional requirements, and 3) further experience with both profilers in Monterey Bay during 2004.

<u>AUV Docking Abstract – 900393</u>

Mark Sibenac

The oceanic environment is unstructured, uncertain and dynamic in nature. Therefore, every system (robotic or non-robotic) faces various types of limitations when deployed in this complex environment. Limitations include poor mobility, poor spatial and temporal resolutions, susceptibility to weather condition, hazards in frequent deployment and recovery, incapability in long-term operation, poor event response, lack of flexibility and availability, and high operating cost, to mention some of them. Science missions such as mid-ocean ridge observations and event responses require both continuous monitoring and prompt deployment. To address this requirement and enhance the capabilities for exploration of the larger oceanic environment, the AUV Docking program plan avoids frequent deployment and recovery while also supporting the ability to respond to any event promptly. The MBARI AUV docking system will allow an AUV to home and transfer data and power, as required for long-term underwater operations which the science users have requested and is expected to be the best available tool for various scientific missions.

In 2004, we plan on working with the AUV to understand its reliability. Software modifications will be made to detect and isolate more faults and process them in a way to overcome them. Testing will be done in the test tank for long durations. Some long duration tests will also be done at sea. The AUV-CTD project will be collaborating on this aspect by running 24-hour AUV missions from M1 to M2 and back.

Homing will be the major development effort for 2004. After algorithms are developed, the system will be tested at sea using the RV Zephyr. Terminal guidance algorithms and methods will be worked on as well. If time and resources allow, a test frame will be constructed to test terminal guidance strategies.

By the end of 2004, we plan to hold a concept review for the actual docking system that will run on the MARS network. The MARS program is planning to install a cable on the Monterey Bay seafloor. The first MBARI docking system will be attached to this installation. The earliest feasible date of installing a dock would be late 2005 after the MARS node passes its initial check-outs.

Since a large development program such as AUV Docking can be resource intensive, outside funding is being pursued. Each of the docking subsystems are quite expensive, and help from a government resource would be a nice complement to Packard Foundation funding internally at MBARI. NSF's Division of Ocean Sciences would be a good starting point for submitting proposals for external grants.