Annual Report – FY2007
SENSORS: Collaborative Research:
ALOHA Mooring Sensor Network and Adaptive Sampling

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Summary

The primary objective of the project is to demonstrate a prototype cabled mooring sensor system with profiling capability, an essential element of NSF's ORION program and the associated Ocean Observatories Initiative (OOI). The seafloor portion of the system has been working at a shallow water test site in Puget Sound (including the 1700 m electro-optical seafloor cable, electrical-optical media converters, seafloor secondary node, and instrument package with CTD, oxygen and optical backscatter/fluorometer). Testing will continue through autumn 2007 before deployment on the MARS Observatory in spring 2008 for six months. A variety of factors (e.g., technical challenges and scheduling delays) have raised the cost and duration of the project. A request for supplemental funding has been approved covering FY2008 costs.

Introduction

The original goal of the project was to deploy a first-of-its-kind cabled mooring sensor network, including a profiler with inductive battery charging, on the ALOHA Cabled Observatory (ACO) at the HOT site north of Oahu. This sensor network would enable scientific adaptive sampling within the framework of the (now) 19-year HOT time series. The project started October 2003 and was planned to run three years. Two significant delays of one year each occurred. First, the viability of the ACO was in doubt (on technical and funding grounds), ultimately leading us to decide to deploy the mooring on the MARS Observatory in Monterey Bay. Next, reduced UNOLS funding postponed the deployment cruise from 2006 to 2007. Most recently, the MARS node installation has been delayed, with commissioning now likely in January 2008. While these factors have allowed additional time to solve technical problems and to develop a more robust system—they have resulted in increased cost. The primary reason for the increase is underestimating the technical challenges and effort with the associated costs.

The testing of the mooring system is now under way in Puget Sound. The seafloor cable, node, and instrument package are working in place. A short version of the mooring system is was deployed for summer 2007 in a water depth that can be serviced by SCUBA divers (30 m). Additional funding has now been obtained for FY2008. When the shallow tests are complete and the equipment serviced, the system will be deployed in Monterey on the MARS observatory in winter/spring 2008 and recovered in late summer 2008. A successor mooring will be proposed for the ACO after a cabled node is finally installed in November 2007 at that site. Additional moorings of this type will play a significant role in the NSF

funded ORION program and its Ocean Observatories Initiative (OOI).

The role of co-PI Lukas at the University of Hawaii is to manage and analyze data, and to develop adaptive sampling; this remains unchanged. When the mooring system is in the water and operating at MARS, he will start to contribute in these areas in a major way. The role of co-PI Boss at the University of Maine was in bio-optical sensor selection and advising and is now complete, though maintaining involvement.

In this document, we first provide a current as-built description of the mooring system. The following section describes the work yet to be completed, the specific tasks, and levels of effort. This report is based on a status report prepared to support the request for supplemental funding in July 2007.

The ALOHA-MARS Mooring (AMM) project will demonstrate the scientific potential of combining adaptive sampling methods with a moored deep-ocean sensor network. It is designed for use with seafloor observatories with power and communications provided by a connection to shore via an electro-optical cable. This system will address the challenge of sampling the ocean with both high temporal and vertical resolution. The scientific justification for the project is not reviewed here. Pertinent references, as well as ones concerning the present engineering effort are given in the list of references at the end. This includes the project web page, conference publications and presentations, the original proposal, engineering documents, a wiki for software, the Seahurst Observatory, and ORION documents (science plan, Concept Network Design, and the Daly et al. RFA concept proposal that describes science using moorings of this type).

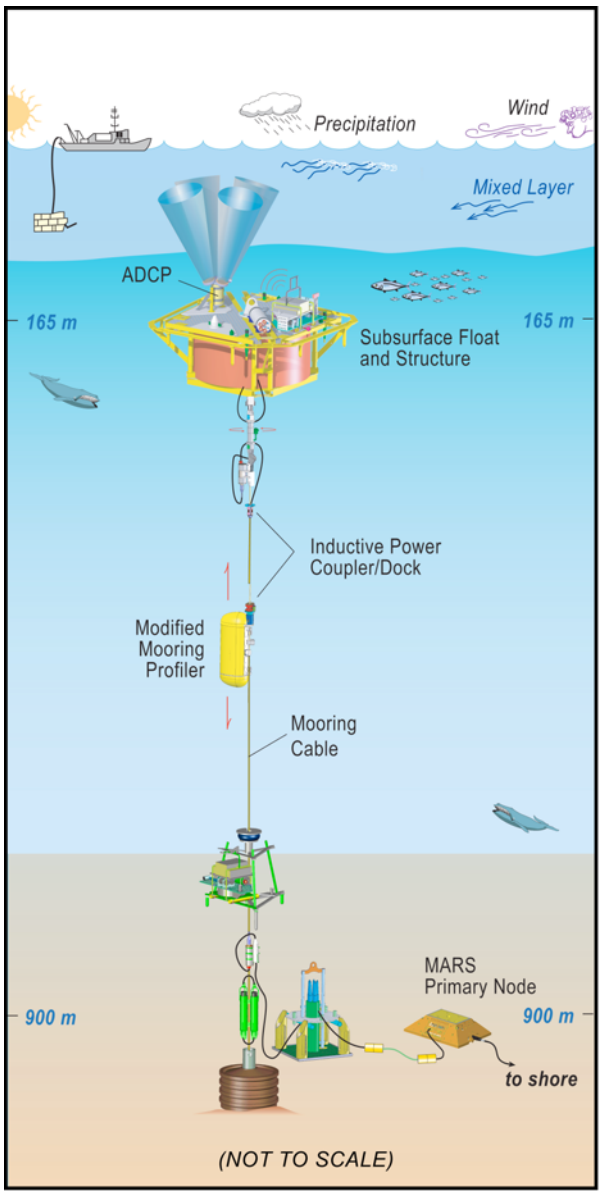

Figure 1. ALOHA-MARS Mooring (AMM) system

Mooring system

The mooring system consists of three main components (Figures 1 and 2): a near-surface float at a depth of 165 m with a secondary node and suite of sensors, an instrumented motorized moored profiler moving between the seafloor and the float that will mate with a docking station just beneath the float for battery charging, and a secondary node on the seafloor with a suite of sensors. Both secondary nodes have ROV-mateable

connectors available for guest instrumentation. The profiler has real-time communications with the network via an inductive modem that provides some remote control functions to allow the sampling and measurement capabilities to be focused on the scientific features of greatest interest. The power and two-way real-time communications provided by cabled seafloor observatories will enable this sensor network, the adaptive sampling techniques, and the resulting enhanced science. The sampling and observational methods developed here will be transferable to ocean observatories elsewhere in the world.

The entire system has been tested in the laboratory. It is now installed at the Seahurst Observatory. The system description given here reflects all the work accomplished to date. The following sections provide more detail on the individual components.

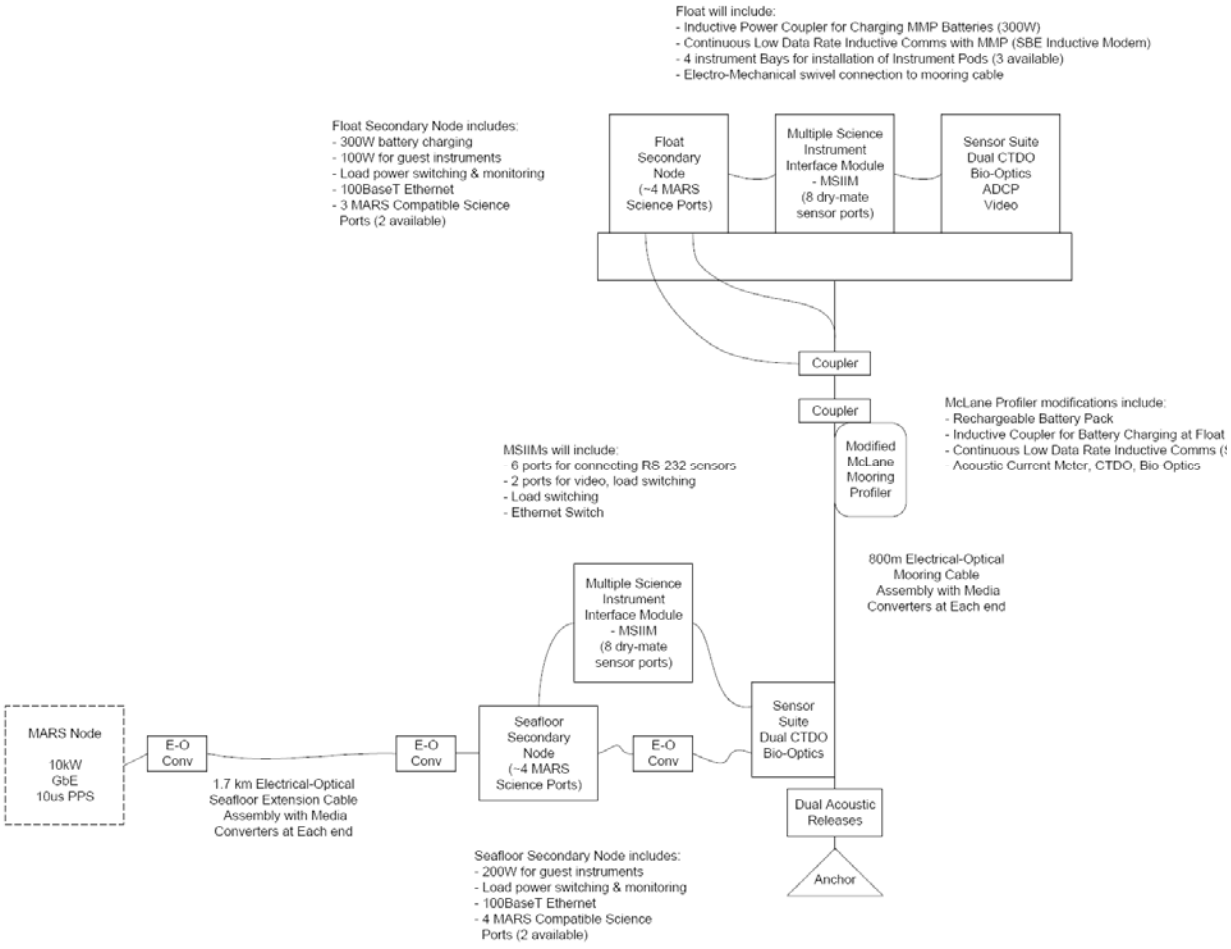

Figure 2. AMM system diagram

Seafloor cable and EO-converters

ROV-mateable connectors on the MARS Observatory primary node will provide 375 V, 48 V, 100Base-T Ethernet, and a 1 pulse-per-second (PPS) precise timing signal. The mooring system is designed for a maximum of 1200 W with 320 W for the profiler charging and 270 W for guest users. In-line electro-optical media converters (Figure 3) are required to convert electrical communication and timing signals to optical form for transmission over any significant distance using optical fibers and back again. The seafloor and mooring riser cables both have four single mode fibers. One optical fiber is used for the Ethernet communications, and one for the PPS/RS-422 time distribution and two are spares. Wave division multiplexers (WDMs) allow bi-directional data transmission using 1310 and 1550 nm wavelengths on the fibers. The 1.7-km cable between the primary node and the seafloor secondary node junction box is a 12.7-mm diameter electrical/optical cable with six electrical conductors and the optical fibers in a 1.2-mm stainless steel tube. ROV-mateable connectors allow connection of the cable to the primary and secondary nodes. The seafloor cable (with EO converters and connectors) will be installed by ROV with a reel that will be mounted in the cable laying tool sled on the ROV; the spool will be left on the seafloor at the end of the cable laying process.

Figure 3. EO converters with ROV-mateable connectors on the green cables and the black seafloor cable between

These, and all mooring system components, have a depth rating of 5000 m.

The profiler has required a significant amount of software associated with the transfer of data from the MMP controller, communications over the inductive modem, acquisition of data from non-MMP sensors (the BB2F), and the battery charging/docking process. The software and profiler have been operated nearly continuously on the bench since June 2006 for testing/burn-in.

We have postponed effort in the area of data management until we have a working system. The original plan was to construct a simple time-stamped ascii data base for each sensor (this has been implemented); co-PI Lukas at Univ. Hawaii would then read this and import it into the ALOHA HOT live action server (more about this follows).

Testing

Profiler testing – June 2006

In June 2006 the modified moored profiler was tested in shallow water (Figure 9) using the APL-UW R/V *Henderson* at the dock with McLane personnel assisting. The set up was not ideal—fresh water and only 17 ft depth—but the profiler successfully cycled every 8 minutes for 2 days, collecting sensor data (CTD, acoustic current sensor, Wet Labs BB2F optics sensor), transmitting the data in near-real time with the SeaBird inductive modem, transferring the data to an on-shore server using a serial-Ethernet device server, and battery charging with the custom inductive power coupler (~200 W). The sensor data were available on-line and web graphing tools were used for presentation. In this test, the water depth was a limiting factor —the profiler hit the anchor before it ramped up to full speed. The profiler senses that the pressure/depth is not changing and it times out and waits for the next profile.

Seahurst Observatory

The original proposed plan for realistic testing prior to open ocean use was to use the VENUS cabled system in Saanich Inlet near Victoria, British Columbia. This system was significantly delayed; it was only installed in March 2006. This, combined with a realization that it would be more expensive and difficult to access than originally thought, led us to consider installing a test facility closer to home in Puget Sound. A suitable site was found at Seahurst Park in the city of Burien, just west of the Sea-Tac International Airport. The Sea-Tac Occupational Skills Center Marine Technology Program occupies a marine station on the shore of the park; this program offers high school classes and maintains salmon fish tanks in the building. The latter require continuously pumped water, with pipes perfect for housing and protecting a cable out to a water depth of 8 m at a distance of 270 m offshore.

Starting in March 2006, volunteers from APL-UW worked to run a messenger line through one of the pipes, with success in July. In November, a power cable and a fiber-optic communications cable were installed. In late February 2007, a “simple” node and instrument package (Figure 13) were installed at the end of the pipe. The node provides a 48 Vdc and 100 Mb/s Ethernet electrical connection to the instrument package SIIM, which has a simple CTD and video camera; the latter recorded the seal shown in Figure 14 (see references at the end for the web page). The node also provides one port with 375 Vdc and 100 Mb/s Ethernet on a ROV-mateable connector, to which we connect the AMM seafloor cable.

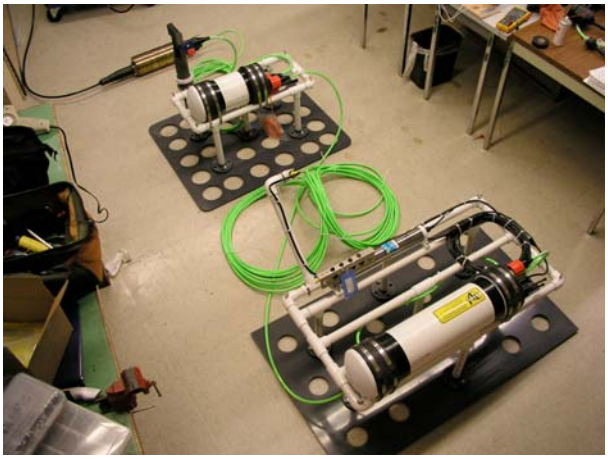

Figure 13. Seahurst node and SIIM with CTD

Figure 14. A picture from the Seahurst node – a harbor seal in the foreground

Seafloor cable, secondary node, and instrument package

On 8 March 2007, the AMM seafloor cable, secondary node and instrument package were installed in 30 m of water from the R/V *Miller* with the aid of divers. The vessel was put in a three-point moor and the cable floated shoreward toward the Seahurst node. When in place it was sunk and connected. The seaward end on the vessel was connected to the secondary node/instrument package and tested with success. The components were disconnected, deployed, and reconnected by the divers. But then the system did not work.

Subsequently on 19 March, the components at the seaward end were recovered; all functioned normally on deck. No explanation for the earlier failure was found. A 70-m cable was installed between the seaward EO converter and the node, so the system could remain connected during deployment. Everything worked, as well as the instrument package. After 6 h of working, the communications beyond the seaward EO converter began to suffer dropouts and then failed altogether.

On 28 March, we returned and found that the strain relief grip on the cable at the seaward EO converter connector had frayed and come off, with the cable at a 90° angle, subjecting the connector to considerable strain. While no water was evident in the connector when brought on deck, the cable failed to carry Ethernet signals. The maximum theoretical length of an electrical Ethernet cable is 100 m; the 70-m cable clearly did work earlier but apparently was marginal. With the original 13-m cable between the EO converter and the secondary node, the system was reinstalled and all worked; see plots of data on the Seahurst web page, and Figure 15.

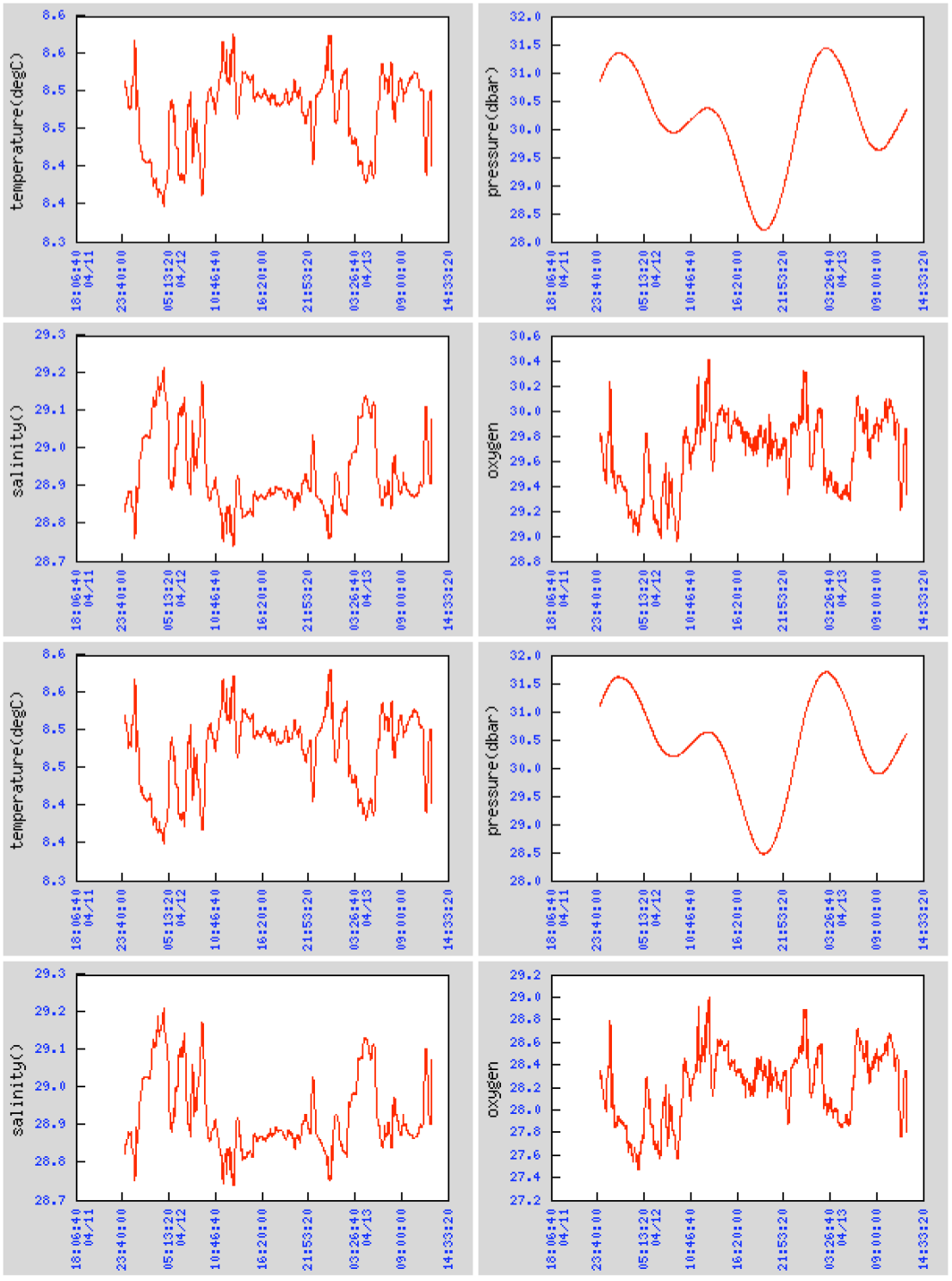

Figure 15. Temperature, salinity, oxygen and pressure from the dual sensors on the seafloor instrument package at 30 m connected to the Seahurst Observatory. Dual sensors will significantly improve the scientific reliability and value of the data.

Deck rail system

The deck rail system that will be used to deploy the subsurface float from the fantail of the R/V *Thompson* (or any of the large UNOLS ships) has been fabricated, assembled and tested, Figure 16. It has subsequently been painted and is ready for use for the deployment.

Figure 16. Deck track and trolley system.

Profiler testing – May - June 2007

On 2 May, the profiler was tested in Puget Sound on a 20 m test mooring cable under 1000 lb tension. The profiler moved up and down the cable and was able to dock, charge, and move out again. There were some communications problems. After making some changes, and while moored in nearby Shilshole marina (deeper water than at the APL dock), the MMP was again tested. This time, though, the wheel continually slipped on the wire and the profiler would not move. After sending the MMP controller back to McLane, there was some improvement (slow intermittent movement), but it was still necessary to add a strip of rubber to increase friction. We have worked with McLane to specify and fabricate a new wheel surface; we have also modified the existing polyurethane wheel surface to increase friction/reduce hydroplaning. The profiler was tested with this modified wheel at Shilshole Bay 22-24 June with success, with over 90 profiles run, including docking and battery charging. Phase

Mooring Test Deployment in Puget Sound

On 26 June, the 30-m test version of the mooring system was installed successfully at Seahurst using the APL R/V *Miller* in a three-point moor. A view of the shore-side marine station from this location (nominally 100-ft water depth) is shown in Fig. 17. The next paragraphs describe the installation.

Figure 17. View of the Seahurst Marine Station from the R/V *Miller* in the tri-moor in 100-ft water depth.

The first step was to recover the cable reel and the seafloor secondary node with the instrument package, Figs. 18 and 19. As can be seen, biofouling is significant. These components were recovered so that the entire system could be tested on deck before deployment.

Figure 18. The cable reel, EO converter, seafloor secondary node and instrument

package after recovery.

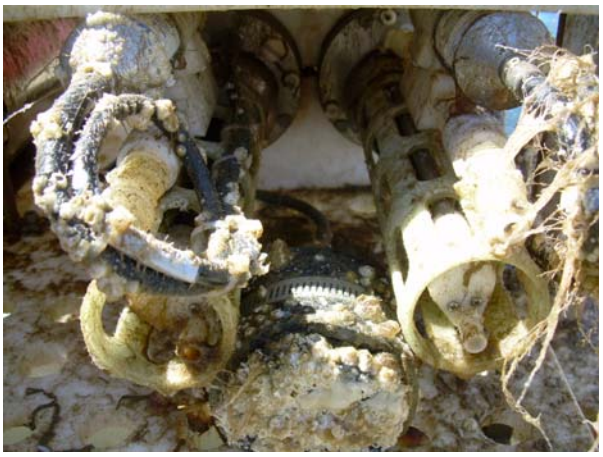

Figure 19. The seafloor instrument package dual CTDs and BB2F after recovery.

Once the entire system was checked out, the next step was to redeploy the cable reel, seafloor node and instrument package. The the mooring was installed float first/anchor last. The first step was to deploy the subsurface flotation. Rather than deploying the large and heavy subsurface float and structure, we used a 1 m steel sphere float (Figs. 20 and 21) with smaller anchor (~1500 lb). This allows us to deploy and service from the APL R/V *Miller* with a flexible schedule. The day rate of the *Miller* is $2000/day. To deploy the full subsurface float and structure would require the use of a crane barge at more than twice the cost and an inflexible schedule.

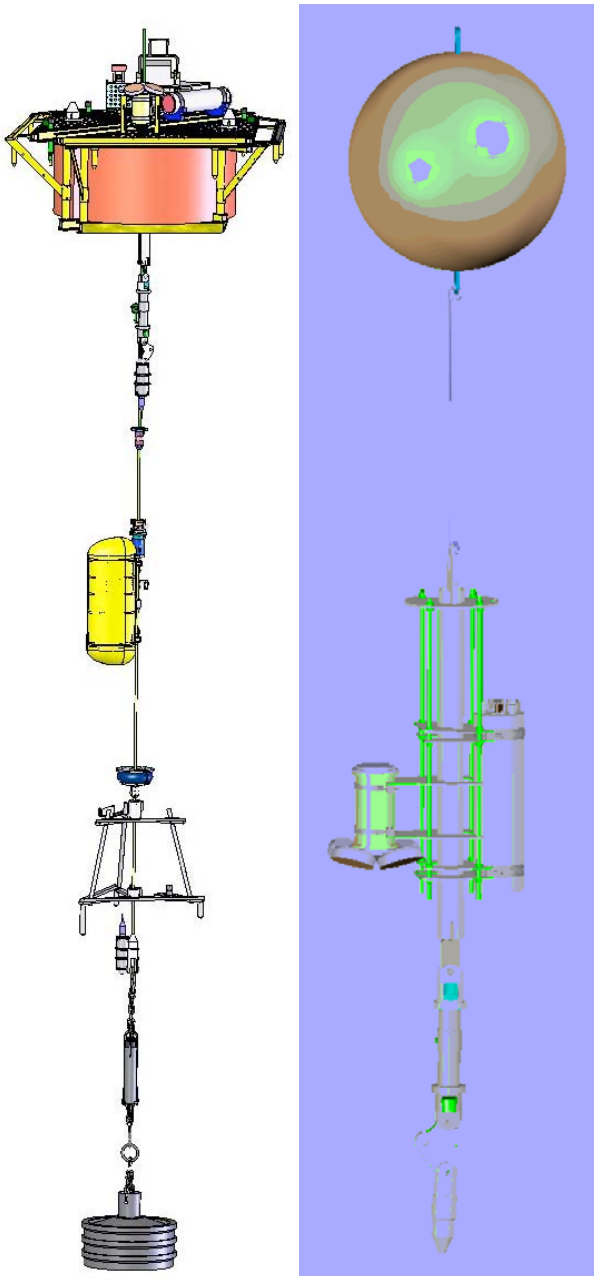

Figure 20. (left) full mooring system, (right) modified top portion as deployed at Seahurst

Figure 21. The 36-inch diameter steel sphere flotation.

The float secondary node and the ADCP are attached to the titanium post, which in turn is connected to the steel sphere float (Figs. 22 and 23).

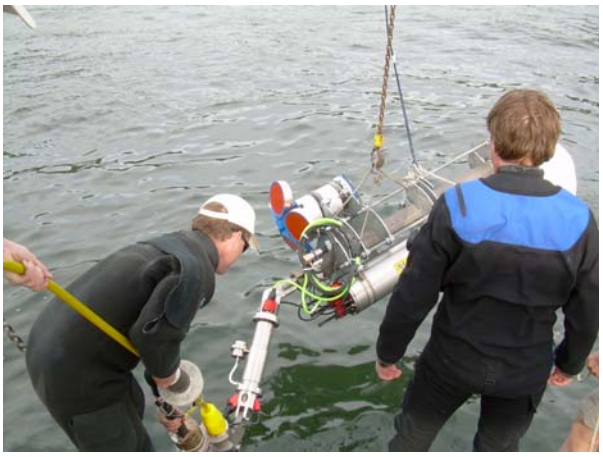

Figure 22. Titanium post with float secondary node, ADCP, camera, swivel/slip rings, mooring termination, EO converter, and inductive power coupler primary.

Figure 23. Steel sphere float (on right) connected to the titanium post.

Then the MMP profiler was put over the side, Fig. 24.

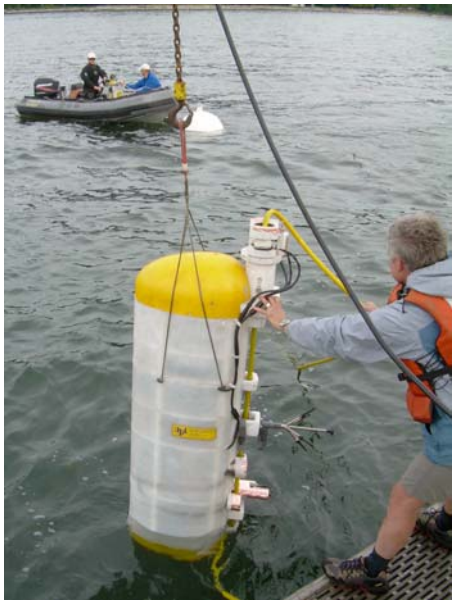

Fig. 24. Putting the MMP over the side.

Then the anchor with the mooring termination, EO converter, and wet mate connector was installed, Fig. 25.

Fig. 25. Deploying the anchor with EO converter. The MMP lower bumper is visible.

In the last two steps/dives, the divers connected the seafloor node to the seafloor cable, and then the mooring to the seafloor node. As part of the last operation, the divers took down and connected the float instrument package, in this case connected to the seafloor node.

Figures 26 – 34 show examples of pictures, science data, and engineering data from the mooring system.

Figure 26. MMP in the docking station

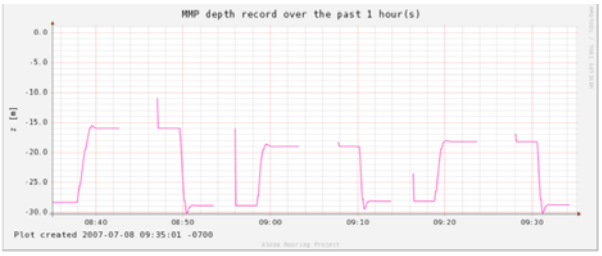

Figure 27. MMP Depth vs. time for three profile cycles, from 8 July.

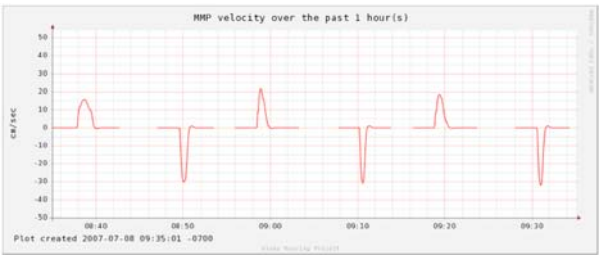

Figure 28. MMP vertical velocity vs time. There has been some slow down over time, likely due to growth/biofouling on the cable.

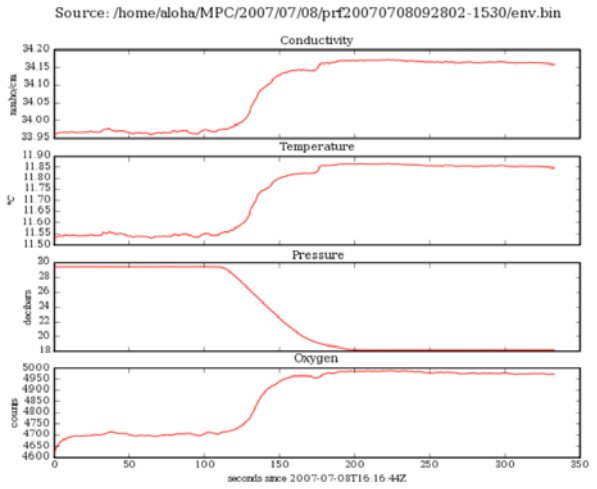

Figure 29. MMP CTDO2 data from the last dive shown in the preceding figures.

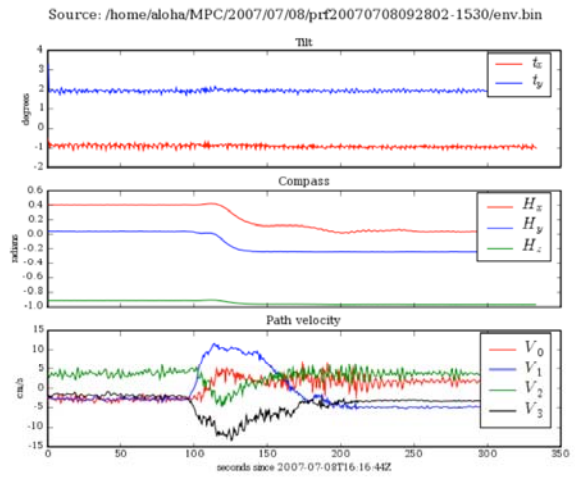

Figure 30. MMP acoustic current meter data

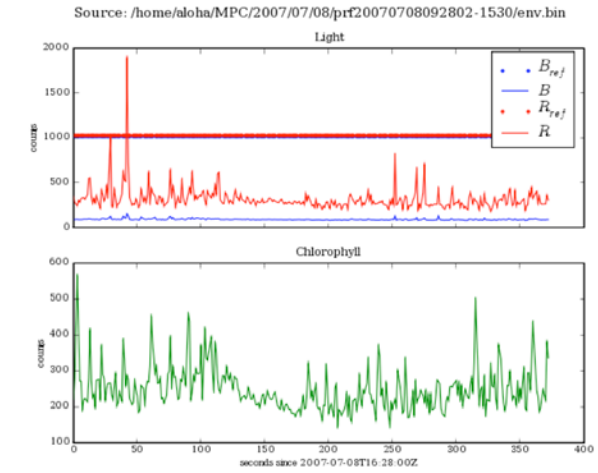

Figure 31. MMP BB2F optical data

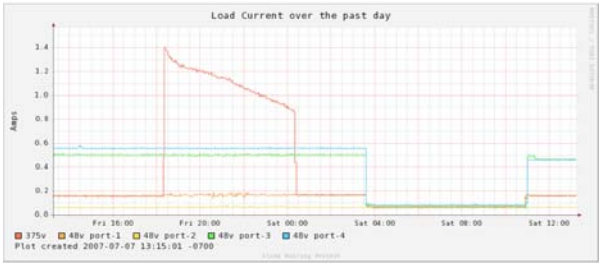

Figure 32. Currents in the seafloor node during MMP charging. Connection to float node turned off between 0400 and 1100.

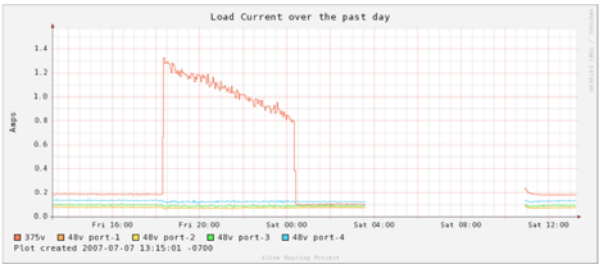

Figure 33. Currents in the float node during MMP charging.

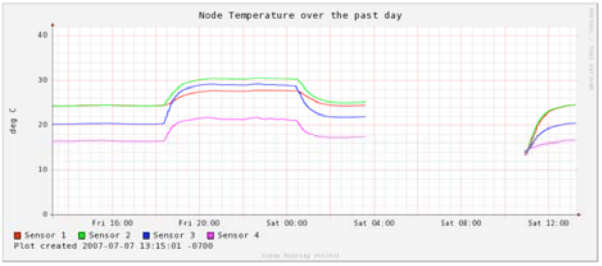

Figure 34. Temperature in the float node during charging.

The mooring system was recovered 12 September; the seafloor cable and node were left in place. During the deployment various problems arose or became evident:

1. Wheel surface – due to slippage of the wheel against the mooring cable, the system was first deployed with a neoprene band over the stock wheel. After McLane delivered a special wheel with grit impregnated in the polyurethane, this was installed by divers on 24 July. Upon recovery in September, the surface was found to have completely deteriorated. Further, the stainless steel screw holding the tensioning spring had failed, possibly due to corrosion. Solution: go back to neoprene band, and verify metal types on screws.

2. The minimum depth/pressure had been set too shallow so that the profiler came into the dock every cycle and started charging. To prevent overcharging, the charging circuit was turned on manually. Once, combined with a power outage on shore, the profiler ran out of energy and divers had to re-position it. Further, the entire

float node was re-booting each time the profiler rose into the dock. Solution: Use a minimum pressure below the docking station and increase current limiting thermistor.

3. Inductive power unit failed in float secondary node at end of August. Solution: minimize inductive kickback by adding free-wheeling diode. Send back to S&K for diagnosis (why FETs failed) and repair.
4. A ground fault of ~2.5 mA had been present on the float node 48V common. This was traced to EO-converter at the base of the mooring. Solution: re-seat boards with plastic spacers.

Software

In December 2006, MBARI volunteered to help with "cyberinfrastructure," namely the interface to sensors, the data acquisition, management, and user interface. We have gratefully accepted their offer, tentatively with them handling most of the conventional fixed sensors. They see this project as providing a useful test bed for their SIAM and MOOS software systems, and the Marine Metadata project. They are acquiring data from the seafloor instrument SIIM BB2F optical sensor and one of the two $CTDO_2$ sensors (see: devices 1608 and 1612 http://new-ssds.mbari.org/ssdsdata/ssds/generated/qc/device/index.htm); this will be followed with the float ADCP (presently still in the lab). APL-UW will remain responsible for serving all the data from the profiler as well as the modems, hydrophone, video camera, and engineering sensors. Per the original proposal, Roger Lukas will access the data archives at MBARI and APL-UW to feed into the ALOHA/HOT live-action server. The data will be analyzed, feeding into the development of adaptive sampling methods and techniques.

Work to complete

The mooring system requires another round of integrated testing in Puget Sound (Phase 1) before subsequent deployment and recovery on the MARS Observatory (Phase 2). Here we describe the tasks and effort for each phase (see also the table below).

Phase 1: Puget Sound

In October and November 2007, the solutions described above will be implemented and the mooring system re-deployed at Seahurst in November-December.

Phase 2: MARS

This phase includes preparation, seafloor cable installation, mooring deployment, and recovery.

Preparation will include cleaning all equipment after the Seahurst operations, calibration of sensors, any necessary modifications and further component testing, and acquisition of spares as necessary.

The seafloor cable will be transferred to a MBARI ROV cable reel. The seafloor system (cable, secondary node, and instrument package) will be tested at MBARI connected to their MARS node simulator. This test will familiarize the ROV pilots with the gear (recall, they were intimately involved in the design), functionality, setting of IP addresses at MBARI, data acquisition and archiving, etc. The seafloor system will be deployed in January using a MBARI ROV with cable laying sled to be sure all is working before the mooring is installed. It is important to get the seafloor portion of the system installed on MARS as soon as possible after MARS primary node installation so there is time to take any corrective action if necessary. The installation of the MARS system has slipped, affecting this project's schedule. We originally planned to install the mooring in November 2007, but now MBARI advises a prudent time would be March 2008 or later.

However, it should be noted that the MARS node will be installed in two steps. In the first, an electronics node package that uses a prototype medium voltage (MV) converter (10 kV to 375 V dc) supplied by Alcatel will be installed as a test. We would install the seafloor cable, node, and instrument package after this so as to have the maximum amount of lead time to fix any problems that might arise. Then, in the second step, the node electronics package will be removed, the MV converter replaced with a production unit, and then replaced. After testing, the system will be formally commissioned, ready for use in January 2008.

We assume the use of the R/V *Thompson*. Dynamic positioning, a high A-frame (26.5 ft), and a deck long enough for the winch and track system is required (40 ft). The deployment and recovery cruises are tentatively scheduled for 1 – 19 April and 8 – 19 August, respectively.

Deployment includes mobilization, the cruise itself, and demobilization. Mobilization includes winch preparation and testing (we will be borrowing a winch with a split bay drum from SIO), mounting of float deployment deck trolley/rail system, loading all equipment on the ship, testing equipment, practicing various aspects of the deployment (and recovery), and verifying real time precise GPS navigation and dynamic positioning. The cruise will be from Seattle to San Diego via Monterey. The MBARI vessels R/V *Western Flyer* with ROV *Tiberon* and R/V *Lobos* with ROV *Ventana* will be used, which ROVs used when is yet to be determined. Cruise participants will include Howe, McGinnis, Siani, Wen, and Boget; Kenney and Miller will be on shore.

A detailed mooring deployment plan showing every step of the process with realistic solid works model figures is on the project web page (Docs_Under_Config_Control). Figures 35-38 are representative of the various steps.

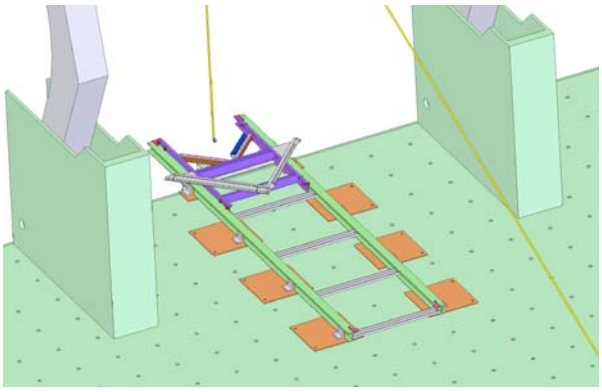

Figure 35. Trolley and track on fantail

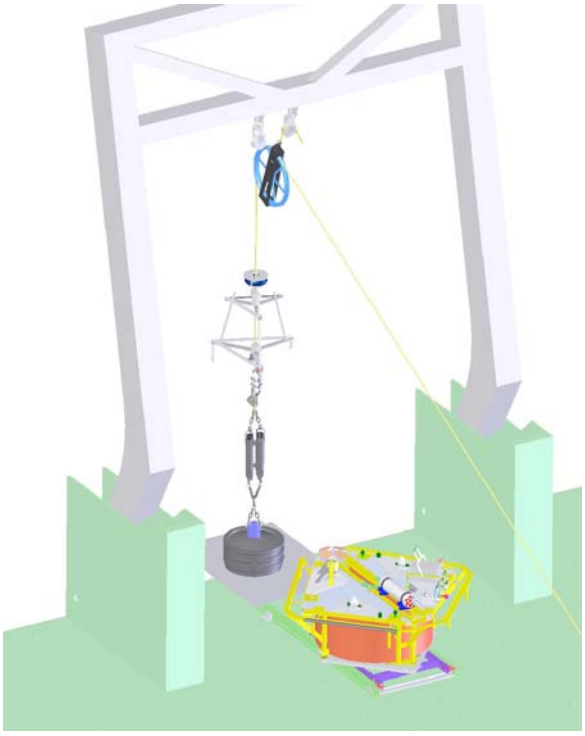

Figure 36. Ready to lower anchor

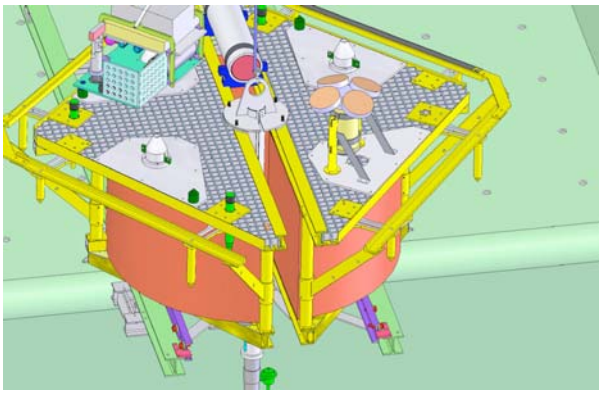

Figure 37. Titanium center post, clamped to track frame and bolted in float slot

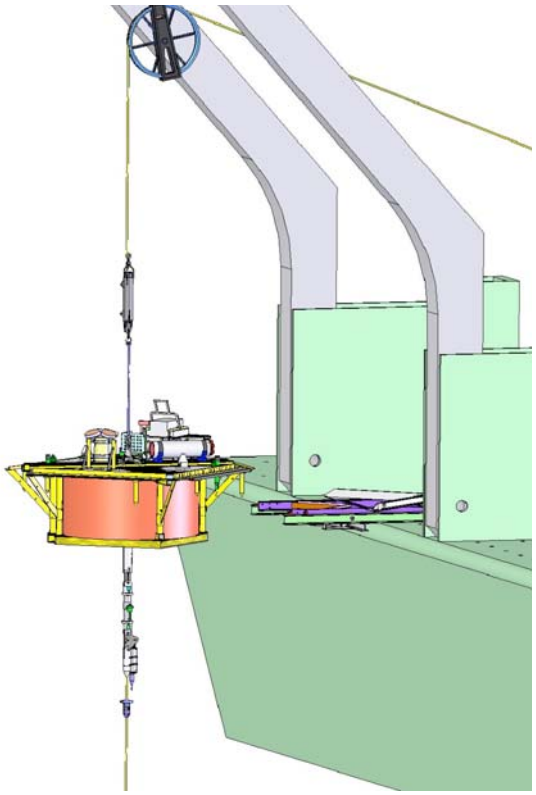

Figure 38. Lowering the float

After the cruise and demobilization, work will continue at a low level on refining the software, verifying smooth flow of data, interaction with MBARI and UH regarding data management, archiving and analysis.

We originally intended to conduct one service call mid-way through using an ROV, but given the budget constraints this is no longer planned.

The recovery vessel will be the R/V *Thompson*, loading in San Diego and ending in Seattle with dates given above. Again, a MBARI ROV will be used to disconnect the mooring and recover the seafloor equipment.

After final recovery, all the system documentation will be finalized, and the final project report submitted.

Project tasks

	Task
Phase 1	
July – Dec 2007	Install, test, debug, service mooring at Seahurst using the *Miller*
Phase 2	
	Repair and refurbish
?? Jan 2007	Deploy MARS seafloor cable
1-19 Apr 2008	Deploy cruise, Seattle-Monterey-San Diego
8–19 Aug 2008	Recovery Cruise, San Diego-Monterey-Seattle
30 Sep 2008	End of project

Related work and projects

As has been already mentioned, MBARI will be taking responsibility for data from the fixed sensors ($CTDO_2$, BB2F, and ADCP).

The NASA project "A Smart Sensor Web for Ocean Observation: System Design, Modeling, and Optimization" funded by the Advanced Information Systems Technology program, with Payman Arabshahi as PI (Howe is a co-PI), will be developing an open source network protocol for the WHOI

micromodem (or any acoustic modem, in general). This will be tested in 2008 in Monterey Bay using several gliders with modems flying around the AMM system. Yi Chao (JPL) is also a co-PI and will be assimilating much of the data from all sensors into his ocean modeling and prediction system. Lee Freitag (WHOI) is assisting with the modems, and as part of his NSF grant, "Acoustic communications for seafloor observatories," will be installing an "all digital" modem on the MARS node.

Tom Sanford (UW) and Doug Luther (UHawaii) are working to deploy their recently developed HPIES (horizontal electric field, pressure, inverted echosounder) on the AMM seafloor secondary node; it is important to be far from any sea ground, specifically the MARS primary node sea ground. John Horne (UW) has just received a state-of-the-art scientific marine echosounder from Simrad and is working to prepare it to also attach to our seafloor node. Simrad has donated this instrument.

If the system proves itself, Chris Scholin (MBARI) will install his environmental sample processor (ESP) on the subsurface float.

NSF has recently funded a proposal (Matthew Alford, PI) to develop an autonomous version of this profiler mooring. It will depend on much of the technology developed here, especially the inductive power system.

Lastly, this work directly contributes to the NSF ORION program objectives for moorings in the global, regional and coastal scale components. For instance, the ORION March 2007 Concept Network Design document calls for nine such moorings for the coastal component Pioneer and Endurance arrays, four for the regional cabled observatory, and one for the global component. At the recent June 2007 ORION Observatory Steering Committee meeting, moorings of the type we are developing here were strongly endorsed – significant power and communications capability in the water column are essential for the envisioned transformational science.

References

Project

The project web page: http://alohamooring.apl.washington.edu, with publications (see below), project event log, proposal in the documentation section under project/proposal, system description, status report (8 July 2007) and many of the engineering documents, are on the same web page under Docs_Under_Config_Control

Software documentation wiki http://aloha.apl.washington.edu/wiki/index.php/Main_Page

Seahurst Observatory http://seahurst.apl.washington.edu.

Seahurst Observatory AMM data http://seahurst.apl.washington.edu/mars

Publications available on project web page:

Howe, B. M., P, Arabshahi, W. L. J. Fox, S. Roy, T. McGinnis, M. L. Boyd, A. Gray, and Y. Chao, "A Smart Sensor Web for Ocean Observation: System Design, Architecture, and Performance," *2007 NASA Science Technology Conference (NSTC2007)*, University of Maryland, 19-21 June 2007 *(2,024 KB PDF)*

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ORION

Science plan http://www.orionprogram.org/PDFs/OOI_Science_Plan.pdf

Concept network design http://www.orionprogram.org/capabilities/cnd.html

Daly et al. concept proposal on water column science in the regional cabled observatory, http://www.orionprogram.org/RFA/Proposals/Daly.pdf