OCEAN OBSERVATORIES INITIATIVE

PROFILING MOORING WORKSHOP REPORT

July 10-12, 2007
Denver, CO

Sponsored by the
Consortium for Oceanographic Leadership
(Formerly Joint Oceanographic Institutions)

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Overview

The Consortium for Ocean Leadership (formerly Joint Oceanographic Institutions) Ocean Observing Activities Program sponsored a workshop to discuss the status and engineering challenges of advancing profiler mooring technology. The Profiling Mooring Workshop was held July 10 - 12, 2007 in Denver, Colorado. Profilers are essential to the Ocean Observatories Initiative (OOI) infrastructure. The current OOI Conceptual Network Design calls for highly capable cabled and uncabled profiling moorings in coastal, deep-water, and remote high-latitude environments. The goals of the workshop were to (1) assess the current status of profiling mooring capabilities, including development in progress, (2) compare the current capabilities to the program's expectations and requirements for profiling moorings, and (3) provide recommendations for further development, where needed.

The workshop participants (see Appendix 5.2) included 29 U.S. and international academic researchers, engineers, and representatives from industry who have developed or have an interest in profiling moorings. The workshop was a unique opportunity for collaboration and information sharing among these groups.

The workshop opened with a brief status report on the evolution of the OOI Conceptual Network Design, followed by a series of presentations on profiler mooring technology currently available or under development. Speakers provided characteristics for different types of profilers, including information on the availability, platform type, power and bandwidth capabilities, operational conditions, surface area to support different sensors, and possible integration of new sensor packages to reduce space, power, and bandwidth requirements (see compilation of profiler characteristics in Appendix 5.3). In addition, there was a talk on sensor-related considerations in determining appropriate profiling platforms and a discussion on "lessons learned" based on on-going profiling mooring development and deployment experiences.

The participants then divided into three working groups to compare the current profiler mooring capabilities with the needs of the OOI for (1) cabled profilers (shelf and deepwater), (2) uncabled shelf profilers, and (3) uncabled deep-water profilers. Working groups utilized several science use case scenarios that link the OOI science needs with the available profiler technology to develop a set of recommendations for the short and long term requirements of profiling moorings.

1. Introduction and Background

The National Science Foundation's (NSF) Ocean Observatories Initiative (OOI) is a research-driven program which will enable advancement in understanding of critical ocean processes that are not easily addressed using traditional ship, mooring, or satellite based observations. In particular, episodic events, non-linear interactions, and dynamic systems that change slowly over months to decades have been difficult to study using traditional approaches. The OOI was developed based on recommendations resulting from over 30 national and international workshops and planning meetings dating back to 1988 (see the executive summary of the *Ocean Observatories Initiative Science Plan*, 2005 (*http://www.oceanleadership.org/ocean_observing/Publications*). The OOI also is the NSF's contribution to the broader U.S. Integrated Ocean Observing System (IOOS) and the international Global Earth Observation System of Systems (GEOSS).

The NSF's Major Research Equipment and Facilities Construction (MREFC) account, which will provide support to build the OOI physical infrastructure and cyberinfrastructure, is intended to provide funding for transformational tools and facilities that will allow different disciplines to make significant advancements in science. The OOI Network will be located in a variety of ocean and sea floor environments, which will require different types of platforms and facilities to support sensors and instruments.

Profiling platforms are one type of infrastructure considered to be an essential component of the OOI facility. Profilers are critical to achieving the high vertical resolution (i.e., unaliased by tides) sampling necessary to determine both episodic events over seconds and long term trends over decades from the air-sea interface to the sea floor. Profilers also are cost effective as they minimize the number of sensors needed to obtain a simultaneous water column profile of many parameters. Although a few types of profilers have been operational for some years, they are not yet broadly in use and several new types of profilers are currently under development. Thus, an evaluation of current profilers and those under development was urgently needed in order to develop engineering requirements for the OOI and to acquire a risk assessment of critical OOI infrastructure.

The Consortium for Ocean Leadership's Ocean Observing Activities Program sponsored the Profiling Mooring Workshop to discuss the status and engineering challenges of advancing profiler mooring technology. The Workshop was held July 10 - 12, 2007 in Denver, Colorado. The current OOI Conceptual Network Design calls for highly capable cabled and uncabled profiling moorings in coastal, deep-water, and remote high-latitude environments. The goals of the workshop were to (1) assess the current status of profiling mooring capabilities, including development in progress, (2) compare the current capabilities to the program's expectations and requirements for profiling moorings, and (3) provide recommendations for further development, where needed.

The workshop opened with a brief status report on the evolution of the OOI Conceptual Network Design (see Agenda, Appendix 5.1). Two examples of Science Use Case Scenarios were provided as examples of the types of information required for a "needs assessment" of profilers for the OOI. This information is reported below in Section 2. Following the Use Case Scenarios, there was a talk on sensors issues related to profiling platforms and then a discussion on "lessons learned" based on on-going profiling mooring development and deployment experiences. Section 3 presents the text from the sensors talk. The remainder of the first day was given to a series of presentations on profiler mooring technology currently available or under development.

Speakers provided characteristics for different types of profilers, including information on the availability, platform type, power and bandwidth capabilities, operational conditions, surface area to support different sensors, and possible integration of new sensor packages to reduce space, power, and bandwidth requirements (see Appendix 5.3). In addition, available information on characteristics of different types of sensors which may be deployed on the OOI was compiled by the organizing committee for use by the participants (see Appendix 5.4). The breakout groups met on Day 2 and the morning of Day 3. Each breakout group utilized the science use case scenarios which link the OOI science needs with the available profiler technology to develop a set of recommendations for short and long term requirements of profiling moorings.

The workshop participants (see Appendix 5.2) included 29 U.S. and international academic researchers, engineers, and representatives from industry who have developed or have an interest in profiling moorings. The workshop was a unique opportunity for collaboration and information sharing among these groups.

Lastly, the organizing committee thanks Susan Banahan, Julie Farver, Emily Griffin, and Laura Snow-Thakral for organizational and travel support for the meeting and for providing editorial assistance on the report.

2. Science Use Scenarios

The design of the OOI infrastructure must be driven by the needs of the scientific community who will use the facility, with consideration for engineering constraints and capital versus life-cycle costs, etc. Towards this end, two science use case scenarios were presented to workshop participants to provide examples of complex, interdisciplinary science questions, which are anticipated to be addressed by the OOI network, and the types and capabilities of sensors and infrastructure platforms needed to investigate those questions.

2.1. Example 1: Science Use Scenario – Climate-driven changes in the upper ocean.

Scott Gallager (Woods Hole Oceanographic Institution)

Question. How do climate-driven changes in physical and chemical properties and biological community composition modulate the particulate and dissolved elemental composition and flux near the surface and in the mesopelagic zone?

General statement of the problem and sampling approach. Flux and chemical composition of material both biological and abiological from the surface through the mesopelagic zone are controlled by biological processes, such as primary and secondary production, grazing and respiration, and physical processes, such as turbulence, vertical mixing, and horizontal transport. These processes are both time and space dependent, particularly in the vertical domain. In order to evaluate how the ecosystem responds to climate-driven changes over decades, as a result of large-scale processes such as the North Atlantic Oscillation (NAO) and El Nino, measurements must be made at much shorter time scales to determine sources of variability. Processes occurring on time scales of hours to days include tides, internal waves, and storms. As such, sensors to measure physical, chemical and biological processes will need to sample throughout the water column from the air/sea interface and through the mesopelagic zone (i.e., 0-500 m) at a minimum frequency of six profiles per day, so as not to alias tides.

Given the expense of multiple sensors along a mooring line, the most efficient approach is to mount a suite of sensors on a profiling platform capable of sampling continuously and capable of stopping at various depths to acquire a time series (as is necessary for turbulence measurements) or to respond to events such as a phytoplankton bloom above the nitricline. Such adaptive sampling requires either internal intelligence to determine when an event has taken place or telemetry of data in real-time back to shore where shore-based controllers would decide how the sampling protocol should change. Since it is very hard to predict how the ecosystem will respond to events, the most realistic approach is to work with real-time data on shore, where both humans and computers would have access to the full data set. Moreover, as new, potentially transformative sensors come on line in prototype stage they will undoubtedly be large, heavy, and power and communication intensive. To take advantage of these new sensors the profiling package must be expandable and offer a wide rage of physical mounting options and power capabilities.

Given these restrictions, the current scenario develops a vertically profiling package with full bandwidth communications and power from shore on an optical-electromechanical ground cable. The operating depth of 500 m, sampled six times per day precludes the use of non-conducting cable, internally driven, winched profilers. The requirement to sample the air/sea interface precludes use of a wire-guided profiler, which requires a surface or sub-surface expression. Note that the sensor payload requirements as described below far exceed the capabilities of most bottom mounted winch-driven systems.

The conclusion based on the configuration described below, is to design a bottom mounted winch with a capacity of 1000 m of electro-optical tether (2:1 scope) with nearly unlimited and expandable payload and communications capability. The entire system would be based on 10/1000/1000 ethernet for data and control communications and 400VAC, 48, 24, and 12 VDC for power. In this configuration a 2 kW profiling system is not out of the question. The hotel load (without sensors) should be 1k W or less. Although the current payload for sensors should be capable of at least 326 W, capacity up to 1 kW is required.

The following sampling requirements need to be considered for a winched profiler needs assessment.

Time scales of processes:

- Hours: tides, internal waves, storms
- Decades: El Nino, North Atlantic Oscillation (NAO)

Spatial scales of processes:

- Vertical: since biological generation of particles occur from the air/water interface to sea floor, a sampling system capable of sampling this range is required.
- Horizontal: temporal evolution and changes in particle flux and composition could be quantified throughout an along-shelf transport process by locating a series of vertical profiling systems along the Northeast coast to take advantage of the north to south along shore current. A reasonable correlation length scale for inter-profiling system placement might be determined by transport speed and biological generation times. For example if transport is on the order of 6 nautical miles/day and copepod generation times are 25 days then a sampling system located every 150 to 200 nautical mile might be reasonable.

Variables and processes measurements needed to address the science question:

- 3-dimensional water mass transport
- water column turbulent mixing to predict aggregate formation and disbursal
- phytoplankton (pico, nano) standing stock
- zooplankton (nano, micro, meso) standing stock
- fish abundance
- primary production
- secondary production
- CO_2 flux
- pH
- macro and some micro nutrients
- temperature, salinity
- dissolved oxygen

Examples of Sensors (no endorsement of particular models is intended).

Physical

- 3-D Transport: Acoustic Doppler Current Profiler (ADCP)
- turbulence: Acoustic Doppler Velocimeter (ADV), Modular Acoustic Velocity Sensor (MAVS)
- benthic boundary layer shear: ADV, MAVS

- Chemical
    - Nutrients
        - Nitrate: ISUS, Envirochem
        - Phosphate: Envirochem
        - Silicate: Envirochem
        - Iron: Envirochem
        - pH: Seabird
        - O_2: Aanderra optode
        - CO_2: SAMI

- Biological
    - Bio-optics
        - Backscatter, fluorescence, colored dissolved organic matter: EcoPuck
        - Down-welling irradiance: Satlantic
        - Up welling radiance: Satlantic
    - Phytoplankton: Flow cytometer
    - Zooplankton: Simrad EK60, video plankton recorder (VPR) for ground truth
    - Fish: Didson or BlueView
    - Large pelagic organisms: sector scanning sonar, Imagenix 881a
    - Passive acoustic hydrophones

- Engineering data for platforms/sensors
    - Vehicle Roll, pitch, yaw (location in x, y, z)
    - System power consumption
    - System voltage
    - System ground faults

Winched Profiler Platform Requirements.

- General Characteristics:
    - Conductive tether: 2-3 fibers, 4 conductors
    - Bottom up winch profiling package
    - Ascent/descent rates: 0-50 cm/s
    - Sampling rate (# cycles/day): up to 12/day
    - Interactive/adaptive control of sample rate, profiler speed, etc., both internal adaptive and from shore control
    - Limitations
        - Maximum currents: can reach surface in 2 kts
- Power source:
    - Cabled
        - Cable to shore: up to 2 kW
- Operational depth:
    - 0-500 m
- Hotel load (no sensors):
    - During travel: 1000W
    - At rest: 20W

Payload available (science sensors):
- 326W now, expandable to 1000W

Communications:
- Cabled
  - Cable to shore: 3 fiber, 6 conductor
- Communications Transmission mode
  - 10/100/1000 Ethernet over fiber
- Communication Protocol
  - Ethernet
- Bandwidth
  - Continuous
  - Burst
  - Hotel load (no sensors)
  - Available to sensors

Internal logging capability:
- None

Sensor suite:
- Internal engineering suite
  - Roll, pitch, yaw, current, ground fault
- Science suite (see Appendix 5.4)
  - Physical
  - Bio-optical
  - Chemical
  - Biological

Durability and Longevity:
- Bio-fouling issues – mooring components; sensors.
- Service interval: six months profiling package, one year winch and tether

Deployment duration:
- 1 year minimum, 10 years max.

Linear distance traveled:
- 2190 km/year

Travel speed:
- 0-50 cm/s

2.2. Example 2: Science Use Case Scenario – The ocean’s role in storing carbon.

Kendra Daly (University of South Florida)

The science question discussed below was designated as a high priority question by the ocean sciences community at various workshops. This is one example of many questions, which require an observatory facility to make significant new progress in understanding complex ocean processes. Table 1 illustrates an example of a Science Use Case Traceability Matrix, which links a science question to the observatory facility infrastructure.

Science Question. What is the ocean’s role in storing carbon via the solubility and biological pumps? What factors influence variability in the strength and efficiency of the biological pump?

General statement of the problem and sampling approach. Figure 1 depicts many of the processes that must be investigated in order to address this question. Atmospheric processes affect

Table 1. Example 2: Science Use Case Traceability Matrix

Overarching science question: What is the ocean's role in storing carbon?

Science Questions	Processes	Measurements Required	Spatial Scale	Temporal scales	Sensors Required
What is the variability of CO2 gas transfer across the air-sea interface? (Sabine and Key, 1998)	molecular diffusion wind shear-generated turbulence convection air entrainment wave breaking formation of spray and droplets bubbles	fluxes (momnetum, heat, CO2) across the air-sea interface sea water temperature pCO2 in atmosphere and ocean wind velocity size distribution of bubbles	Point air measurements 3 m above water surface (this assumes use of bulk formulas) "Surface" water measurements ~ 1 m below surface Horizontally - scale of wind field ~100s km	Air-sea: 1-60 s depending on isntrument	Air: Temperature Relative humidity Barometric pressure Wind velocity Short-wave radiation Long-wave radiation Precipitation Aspirated air temperature pCO2 Sea surface (~1 m): CTD O2 pH pCO2
What is the role of near-surface and vertical and horizontal mixing (and stratification) as it modulates irradiance, nutrients, and plankton/nekton community structure and function?	interactions between producers and consumers mixing Langmuir cells vertical and horizontal advection/migration marine snow dynamics	physical structure (temperature, salinity, density), physical dynamic processes (turbulence, bubbles, internal waves, current velocity and direction, irradiance), chemical properties (pH, dissolved oxygen and carbon dioxide), bubble size distribution, nutrients (nitrate, phosphate, silicate) and trace elements (iron) through the water column particle size distribution (includes marine snow) phytoplankton/zooplankton species and biomass phytoplankton/zooplankton density, distribution and characteristics Optical and bio-optical properties Fish abundance	Vertical profiles over entire water column: 1 m, except turbulence quantities 1-10 cm Vertical sampling and sensors depend on process and function, e.g., irradiance and phytoplankton functional group sensors are necessary only in upper 200 m Horizontal: local (~ km) to mesoscale (~100 km) and eastern boundary current scale (~500 km)	Air-sea: 1-60 s depending on isntrument instrument Water: 10 Hz for turbulence, 1 s for others	Air/sea sensors as above The following assumes a combination of fixed and profiling measurements. Basic measurements through water column: Velocity: ACM, ADCP CTD O2 pH pCO2 optical backscatter and fluorescence (bulk particulate concentration, chlorophyll) Specific: VADCP (5 beam for upper ocean turbulence) nitrate, nitrite, phosphate, silicate, iron optical CDOM mass spectrometer flow cytometer split-beam echosounder fish & squid abundance multi-frequency acoustics systems (e.g., TAPS-6: 120-1800 kHz) for zooplankton densities and size distribution Imaging system (zooplankton species abundance and size; e.g., SIPPER)
What is the variability (stength, efficiency) of the **solubility pump** (the exchange of CO2 from the air-sea interface into the deep ocean as it is controlled by sea water temperature) and the **biological pump** (the biologically-mediated processes that transport carbon in particulate and dissolved forms) as a function of spatial and temporal scales from the surface euphotic zone to the ocean's interior ? (OOI Science Plan, p23) [scales from short, local to long, basin (climate)]	mixing, dissipation and diapycnal diffusion episodic events such as storms and blooms Timing and evolution of phytoplankton blooms bubble formation changing stratification upwelling and downwelling dissolution/precipitation of CaCO3 photosynthesis/respiration sinking particulate matter and marine snow remineralization/decomposition Interactions/advection between remote (basin, West Wind Drift) and local scales (California current slope and shelf)	fluxes (momentum, heat, CO2) across the air-sea interface (see above) physical structure (temperature, salinity, density), physical dynamic processes (turbulence, bubbles, internal waves, current velocity, irradiance), bubble size distribution, chemical properties (pH, dissolved oxygen and carbon dioxide), nutrients (nitrate, phosphate) and trace elements (iron) through the water column particle size distribution plankton (phytoplankton, zooplankton) size distribution, composition, abundance microbial abundance and rates CDOM (colored dissolved organic matter) density and type of nekton (e.g., squid, fish, mammals) Spatial extent of basic measurements: low mode/wavenumber temperature, velocity, vorticity distributed point and integral measurements; sections	Vertical profiles over entire water column: 1 m, except turbulence quantities 1-10 cm Vertical sampling and sensors depend on process and function, e.g., irradiance and phytoplankton functional group sensors are necessary only in upper 200 m Horizontal: local (~ km) to mesoscale (~100 km) and eastern boundary current scale (~500 km)	Air-sea: 1-60 s depending on isntrument instrument Water: 10 Hz for turbulence, 1 s for others	Air/sea sensors as above Following is a combination of fixed and profiling measurements through water column: Velocity: ACMs, ADCP, VADCP CTD O2 PAR (irradiance) nutrients: nitrate, nitrite, phosphate, silicate, iron pH optical backscatter, transmissometer, fluorescence, CDOM (bulk particulate concentration, chlorophyll) hyper-spectral resolution absorption and attenuation (ac-s; phytoplankton functional groups) Zooplankton imaging system (e.g., SIPPER) Multi-frequency acoustic echosounder (zooplankton size distribution) Microbial characterization (e.g., Environmental Sample Processor [ESP]) bubble size distribution (acoustic resonator, slant range sonar, hydrophone) directional wave spectra - ADCP optics for particle size distribution (i.e., small vs.large phytoplankton, marine snow aggregates; e.g., LIST) zooplankton acoustic echosounder broadband acoustic transceiver for tomography, navigation, and ambient sound fish/squid echosounder broadband passive hydrophones (whales, wind, rain, integrated bubble volume) Acoustic modem (communication, navigation) Other sensors are desirable including a flow cytometer, mass spectrometer Gliders to provide spatial extent of point sensors: CTD, O2, pH optical backscatter and fluorescence depth averaged currents large scale temperature (part of acoustic tomography)
What are the relationships between temporally-varying particulate fluxes and benthic community processes . How important are episodic versus seasonal pulses of pelagically derived organic carbon to benthic communities?	bottom boundary layer dynamics interaction between turbulence and marine snow/particulates megafauna (> 1 cm) feeding activities (consumption and caching) and mixing (bioturbation) episodic events (e.g., blooms)	velocity profile from bottom to 500 m temperature, salinity, oxygen camera turbulence velocity profiles through the bottom boundary layer (100 m) broadband Hydrophone acoustic communications and navigation multi-wavelength fluorometer optical backscatter particulate organic matter (POM) flux fluorescence quanitity and characterize particles sediment community oxygen consumption	Vertical velocity profiles through bottom boundary layer (e.g., 500 m) 1 m, except turbulence quantities 1-10 cm Other sensors on bottom Horizontal: local (~ km) to mesoscale (~100 km) and eastern boundary current scale (~500 km)	Air-sea: 1-60 s depending on isntrument instrument Water: 10 Hz for turbulence, 1 s for others	Bottom mounted: ADCP 75 kHz CTD O2 Camera Horiz electric field/Pressure/Inverted echosounder HPIES 300 kHz 5-Beam vertical beam ADCP (VADCP) Broadband Hydrophone Acoustic modem/navigation 3 wave Fluorometer sensor Combo backscattering meter and fluorometer Sediment trap Benthic rover

physical (momentum, heat, water) and chemical (dust, nutrients, trace elements, gases) fluxes. Investigations of variability in the biological pump requires understanding of the species abundance and food web interactions of all living organisms (small to large), the nutrients they utilize, the effects of vertical mixing and advection, and behavior (e.g., thin layers, vertical migration). The seafloor is involved both because it is often a long-term carbon sink (after passing through complex bioturbation processes), but also because it is a source of both inorganic carbon (e.g., volcanoes) as well as organic carbon in the form of the “deep hot biosphere”.

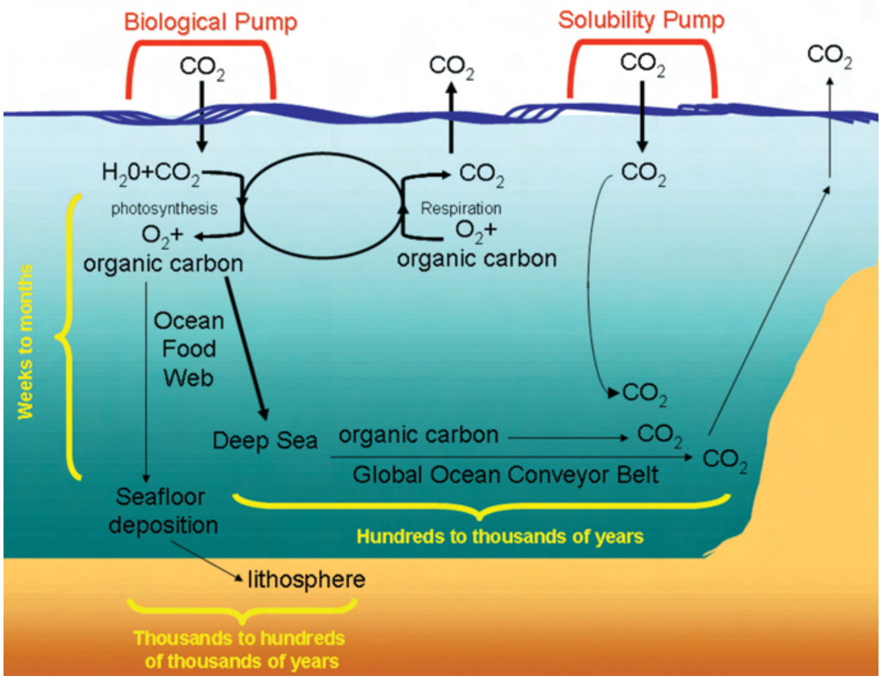

Figure 1. The biological and solubility pumps and their role in transporting atmospheric carbon to the deep sea. Figure courtesy of Oscar Schofield, OOI Science Plan, 2005.

Many of these processes are episodic (phytoplankton blooms and CO_2 drawdown, flux of particulate material), non-linear (food web interactions and response to physical forcing), and vary over scales of minutes to seasonal, interannual, or decadal scales. For example, the oceanic eastern boundary current upwelling system may act as a source or sink for atmospheric CO_2 depending on environmental conditions. Processes also vary on vertical spatial scales of millimeters to the full depth of the water column (~3,000 m).

The power and communications capabilities of the cabled systems are the sine qua non for this science. Table 2 provides a list of sensors needed to fully address the above science question in a deep-water (i.e., offshelf) site and the power and data requirements of those sensors. Although many of the sensors listed will not likely be “core” sensors (those initially purchased with MREFC funds), it is expected that they will be added through community and/or investigator proposals in the coming years. **Table 2 clearly demonstrates that there is a critical need for the OOI facility to provide high power and bandwidth platforms for sensors.** Science questions will not be able to be fully addressed unless there is sufficient power and data rate/communications to support a diverse array of sensors on OOI platforms.

Table 2. Power and data rate requirements of sensors needed to address the carbon cycling on a cabled deep water profiling mooring (Science Use Case Scenario 2). This example illustrates the critical need for platforms with high power and bandwith capabilities to ensure the success of the OOI facility. Information provided by B. Howe (UW)

Sensor	Example model	Location on mooring	Average Power (W)	Average data rate (b/s)
Acoustic current meter	Falmouth 3D-MP	winched float	0.1	288
CTD	Seabird 52MP	winched float	2	80
O2	Seabird 43F	winched float	1	40
optical backscatter/fluorometer	WetLabs ECO-BB2F	winched float	1	480
pH	pH	winched float	0.1	16
Fluorometer, 3 wavelength	Wet Labs Triplet	winched float	1	144
Multi-wavelength optical absorption and attenuation spectrophotometer	Wet Labs AC-9	winched float	10	864
Nitrate analyzer	Satlantic ISUS	winched float	12	16
Acoustic resonator	Acoustic resonator	winched float	1	32,000
Sub-total			**28.2**	**33,928**
Zooplankton/fish/squid acoustics	TAPS	subsurface float node	10	512
Velocity profile/turbulence	300 kHz 5-Beam vertical beam ADCP (VADCP)	subsurface float node	1	16,000
CTD	Seabird 52MP	subsurface float node	2	80
O2	Seabird 43F	subsurface float node	1	40
optical backscatter/fluorometer	WetLabs ECO-BB2F	subsurface float node	1	480
pH	Seabird 18	subsurface float node	0.1	16
pCO2	Sunburst SAMI-15000	subsurface float node	0.1	16
Fluorometer, 3 wavelength	Wet Labs Triplet	subsurface float node	1	144
Nitrate Analyzer	Satlantic ISUS	subsurface float node	12	16
Camera	DSP&L LED Multi SEACAM 2055	subsurface float node	12	3,200,000
Acoustic modem/navigation	WHOI micromodem	subsurface float node	1	6,300
Zooplankton/fish/squid acoustics	TAPS	subsurface float node	10	512
Multi-wavelength optical absorption and attenuation spectrophotometer	Wet Labs AC-9	subsurface float node	10	864
Fish and Zooplankton sonar	Simrad ER 60 38 kHz	subsurface float node	100	31,457,280
Broadband acoustic array	Naxys eHyd	subsurface float node	10	49,152,000
Slant beam sonar, 100 kHz	SIO	subsurface float node	24	1,222
Sub-total			**195.2**	**83,835,482**
Acoustic current meter	Falmouth 3D-MP	200-600m profiler	0.1	288
CTD	Seabird 52MP	200-600m profiler	2	80
O2	Seabird 43F	200-600m profiler	1	40
optical backscatter/fluorometer	WetLabs ECO-BB2F	200-600m profiler	1	480
pH	Seabird 18	200-600m profiler	0.1	16
pCO2	Sunburst SAMI-15000	200-600m profiler	0.1	16
Fluorometer, 3 wavelength	Wet Labs Triplet	200-600m profiler	1	144
Broadband acoustic receiver	Naxys eHyd	200-600m profiler	10	49,152,000
Sub-total			**15.3**	**49,153,064**

Sensor	Example model	Location on mooring	Average Power (W)	Average data rate (b/s)
Velocity profiler	ADCP RDI 75 kHz	600 m node	1	16,000
CTD	Seabird 52MP	601 m node	2	80
O2	Seabird 43F	602 m node	1	40
optical backscatter/fluorometer	WetLabs ECO-BB2F	600 m node	1	480
pH	Seabird 18	600 m node	0.1	16
pCO2	Sunburst SAMI-15000	600 m node	0.1	16
Fluorometer, 3 wavelength	Wet Labs Triplet	600 m node	1	144
Low frequency acoustic transmitter/ broadband receiver	Webb Research 250 Hz sweeper/ STAR	600 m node	10	12,000,000
Fish and Zooplankton sonar	Simrad ER 60 38 kHz	600 m node	100	31,457,280
Sub-total			**116.2**	**43,474,056**
Acoustic current meter	Falmouth 3D-MP	600-3000m profiler	0.1	288
CTD	Seabird 52MP	600-3000m profiler	2	80
O2	Seabird 43F	600-3000m profiler	1	40
optical backscatter/fluorometer	WetLabs ECO-BB2F	600-3000m profiler	1	480
pH	Seabird 18	600-3000m profiler	0.1	16
pCO2	Sunburst SAMI-15000	600-3000m profiler	0.1	16
Fluorometer, 3 wavelength	Wet Labs Triplet	600-3000m profiler	1	144
Broadband acoustic receiver	Naxys eHyd	600-3000m profiler	10	49,152,000
Zooplankton/fish/squid acoustics	TAPS	600-3000m profiler	10	512
Sub-total			**25.3**	**49,153,576**
Velocity profile	ADCP RDI 75 kHz	bottom node	1	16,000
Velocity profile/turbulence	300 kHz 5-Beam vertical beam ADCP (VADCP)	bottom node	1	16,000
CTD	Seabird 52MP	bottom node	2	80
O2	Seabird 43F	bottom node	1	40
optical backscatter/fluorometer	WetLabs ECO-BB2F	bottom node	1	480
pH	Seabird 18	bottom node	0.1	16
Fluorometer, 3 wavelength	Wet Labs Triplet	bottom node	1	144
Camera	DSP&L LED Multi SEACAM 2055	bottom node	12	3,200,000
Horiz electric field/Pressure/Inverted echosounder	HPIES	bottom node	0.1	9,600
Broadband acoustic receiver	Naxys eHyd	bottom node	10	49,152,000
Acoustic modem/navigation	WHOI micromodem	bottom node	1	6,300
Sub-total			**30.2**	**52,400,660**
MOORING TOTAL			**410.4**	**278,050,766**

Sensor	Example model	Location on mooring	Average Power (W)	Average data rate (b/s)
Autonomous glider sensors				
CTD	Seabird	Glider	3	128
O2	Seabird	Glider		
Current Velocity	Acoustic receiver (RAFOS-2, Doppler)	Glider	2	40,000
optical backscatter/fluorometer	WetLabs ECO-BB2F	Glider	1	480
pH	Seabird 18? Japan (Shitashima and Kyo?)	Glider	0.1	16
Acoustic modem/navigation (interrogate outlying subsurface instruments)	WHOI micromodem	Glider	1	6,300
Sub-total			**7.1**	**46,924**
Meteorological Surface Buoy				
Air temperature	Platinum resistance thermometer	Surface buoy, autonomous	1?	1?
Barometric pressure	Quartz crystal, AIR DB-1A	Surface buoy, autonomous	1?	1?
Relative humidty	Rotronic MP-100F	Surface buoy, autonomous	1?	1?
Wind velocity	Wind monitory, R. M. Young 5103	Surface buoy, autonomous	1?	1?
short wave radiation	Temperature compensated Thermopile Eppley PSP	Surface buoy, autonomous	1?	1?
long wave radiation	Pyranometer, Eppley PIR	Surface buoy, autonomous	1?	1?
precipitation	Self-siphoning rain gage, R. M. Young Model 50201	Surface buoy, autonomous	1?	1?
Aspirated air temperature	Platinum Resistance Thermometer with R. M. Young Aspirated Shield 43408	Surface buoy, autonomous	1?	1?
pCO2	?	Surface buoy, autonomous	1?	1?
CTD	Seabird 52MP	Surface buoy, autonomous, 1 m below	3	3?
O2	Seabird 43F	Surface buoy, autonomous, 1 m below	3	3?
pH	pH	Surface buoy, autonomous, 1 m below	0.1	1?
pCO2	Sunburst SAMI-15000	Surface buoy, autonomous, 1 m below	0.1	1?
TOTAL ALL SENSORS			**1251.6**	**834,246,147**

3. Sensors: Considerations for Profiling Platforms

Andrew Barnard (WET Labs, Inc) & Percy Donaghay (University of Rhode Island)

The science questions addressed by the science community will determine the appropriate sensors required by the OOI Network. A follow-on question is: What is the appropriate platform from which to make measurements? The topics listed below need to be considered in discussions on a needs assessment of profilers. Sensors and sampling capability of the platforms must be able to resolve the spatial scale and resolution of the processes of interest and the temporal frequency of processes, etc. Another critical feature to keep in mind is the need to build for the future. OOI platforms and infrastructure must be expandable.

3.1. Examples of Potential Science Topics and Sampling Requirements

- Thin Layers
  - Sub-meter scale resolution
  - Platform stability, control, disturbance
- Air-sea flux
  - Upper water column measurements, profile to/through surface
  - Above water measurements
- Bottom boundary layer transport
  - Ability to sample to seabed
  - Range and resolution of measurements
- Harmful Algal Bloom Dynamics (HAB)
  - Identification of phytoplankton
  - Controlling processes (nutrients, light, stability)

3.2. Profiling Platform Perspective *(see Appendix 5.3 for characteristics of existing profilers)*

- Form factor (size, weight)
  - Dimensions
  - Volume
  - Weight (air & water)
  - Detection volume (external/internal)
  - Mounting
  - Connector type
  - Potential corrosion effects (dissimilar metals, anoxic conditions)

  Examples: Eco sensors, Environmental Sample Processor (ESP), SIPPER

- Power
  - Input voltage (range, nominal)
  - Current draw
  - Duty cycle
  - Total & peak power consumption
  - Isolation, over current protection
  - Continuous, sleep, startup, warm-up

  Examples: Temperature (1 W), scanning sonar, holography (100s W)

- Data rate
  - Sampling rate
  - Baud rate
  - Bandwidth (bps)
  - Burst or continuous
  - On board storage/reduction

  Examples: ECO sensors, acoustic backscatter, hydrophone

- Instrument interface
  - Interface protocol
  - Instrument identification
  - Autonomous/command modes
  - External measurements required
  - Ancillary measurements

  Examples: Serial, Ethernet, digital/analog, video

- Acquisition period
  - Measurement duration
  - Warm-up period required
  - Accurate timing needed
  - Environmental effects (pressure, temperature, power)
  - Calibration/reference cycle

  Examples: Nutrient sensors, seismic sensors, ESP, imaging flow cytometry, dissolved oxygen

- Maintenance
  - Service interval
  - Consumables
  - Biofouling effects
  - Calibration requirements (frequency, in lab, factory)
  - Corrosion issues

  Examples: Wet chemistry sensors, optical sensors, ADCP, CO2

- Special requirements
  - External triggers
  - Physical sample collection
  - Validation data collection
  - Measurement interference, cross-talk
  - Hazardous materials, permits
  - Platform stability
  - Anti-fouling devices

  Examples: Nutrients, radiometry, ESP, cytometry, hydrophones

3.3. Recommendations to Consider

- One type of profiling platform does NOT fit all applications
- Must work closely with instrument providers/developers to insure effective integration
- Match platform capabilities with questions to be addressed
- Provide reliable, routine measurements of key parameters with high rate of success
- Provide ability for new novel sensors to be integrated/evaluated
- Mixture of platforms will be necessary
- Build in a complete, rigorous testing cycle before deploying in an operational mode that involves operators, developers, platform/sensor providers, and scientists

4. Summary and Recommendations from the Breakout Groups

Three breakout groups were formed: (1) Cabled (to shore) Coastal and Deep Water Profiling Moorings, (2) Uncabled (to shore) Coastal Profiling Mooring, and (3) Uncabled (to shore) Deep-Water Profiling Moorings. Participants were charged with (1) assessing the current status of profiling mooring capabilities, including development in progress (see Appendix 5.3), (2) comparing current profiler capabilities to the OOI's expectations and requirements for profiling moorings, and (3) providing recommendations for further development, where needed. In particular, an assessment of profiler capabilities related to the following characteristics was considered critical:

- Power
- Bandwidth/near real-time data
- Real estate: surface area (volume, weight) to support different sensors
- Biofouling
- Control of profiler depth and rate of speed
- Adaptive sampling
- Cable dynamics
- Extreme environments (shallow water)
- Service intervals (1 year deep water, 3 months on shelf)
- Vertical stability (x, y, z location, critical for parameters such as radiometry)
- Extendable (can add new sensors)
- Rigorous testing/validation

4.1. Cabled (to shore) Coastal and Deep Water Profiling Moorings Breakout Group

Participants: Gene Massion (Discussion Leader), Kendra Daly, Percy Donaghay, Ann Gargett, Bruce Howe, Michael Mathewson, Peter Phibbs, Mario Tamburri.

All participants agreed that profiling moorings were essential infrastructure to include on the Regional Cabled and Coastal Endurance Array Nodes to address OOI science questions. One of the most transformational technologies of the OOI will be the powered, fiber optical cable. The cable will provide unprecedented levels of power and communication bandwidth to seafloor observatories and water column moorings, which will support an array of sensors and instruments necessary to address the OOI's high priority science questions. Many of the potential science questions that will be supported by the OOI infrastructure are discussed in the *Ocean Observatories Initiative Science Plan* (http://www.oceanleadership.org/ocean_observing/Publications) and the *Ocean Observatories Initiative Scientific Objectives and Network Design: A Closer Look* (http://joiscience.org/files/ocean_observing//OOI_SciProsp_1Oct07_lowres.pdf). The necessity for high power and bandwidth moorings is evident by the power and data requirements of sensors needed to fully address many of the science questions (Table 2). The estimated total power and data rate requirements of these sensors is 1.2 kW and 834 Mb/s, respectively, which cannot be achieved by most current ocean science mooring technology (Appendix 5.3) and satellite data communications (Appendix 5.5). A more diverse array of sensors (Appendix 5.4) was proposed as part of the OOI Request for Assistance (RFA) proposals. Therefore, an even higher power and data rate would be required for the OOI to meet the potential envisioned by the authors of these proposals. In addition, the supporting infrastructure itself consumes substantial power (e.g., dc-dc converters are only ~80% efficient). While it is recognized that the complete list of sensors will not be initially deployed on the moorings, the mooring technology needs to be capable of expanding to support a range of sensors in the next two to three decades.

The operational requirements of the moorings ideally include the following:

- Ability to support sensors to measure multidisciplinary parameters at high temporal frequency for decades.
- Ability to profile from near the seafloor to the air-sea interface at a minimum of six full water column profiles per day to remove tidal cycles. More frequent sampling may be required to address specific science questions.
- Ability to determine continuous x, y, and z position as a function of time of all sensors.
- Expandable profiler platforms to accommodate many large-sized (volume/weight) sensors (e.g., low frequency acoustic transducers, imaging systems, mass spectrometers, etc.).
- Optimize technology to reduce life cycle costs, e.g., platforms and subassemblies that can be deployed and maintained by ROVs; standard interfaces.
- Ability to enable event detection/adaptive sampling/instrument control. This requires: Near real-time data communication and, thus, continuous connectivity (and high data rate exchange across an inductive coupler), accurate fine depth control (cm resolution), variable profiling speed, and interactive control of depth and speed.

Individual moorings should be considered as elements of a spatially distributed observing array. In the case of the northeast Pacific nodes of the OOI, this array would consist of the cabled (and possibly uncabled) coastal moorings, the moorings associated with the Regional Scale Cabled Nodes, and a Global Scale uncabled buoy at Ocean Weather Station Papa. This array may be augmented by other moorings, such as proposed for NEPTUNE Canada and the ALOHA Cabled Observatory, the NOAA DART buoy system (*http://nctr.pmel.noaa.gov/Dart/index.html*), NODC/NOAA's meteorological/wave measurement buoys (*http://www.nodc.noaa.gov/BUOY/bnep.html*), as well as satellite observations and mobile platforms. Gliders and powered autonomous vehicles (AUVs) can provide spatial underwater measurements to augment the fixed mooring array. In addition, acoustic networks on various scales from local around a mooring to regional and basin scales, can provide varying levels of communications, navigation, and timing capability for the mobile platforms, while simultaneously providing tomographically-derived temperature and absolute currents.

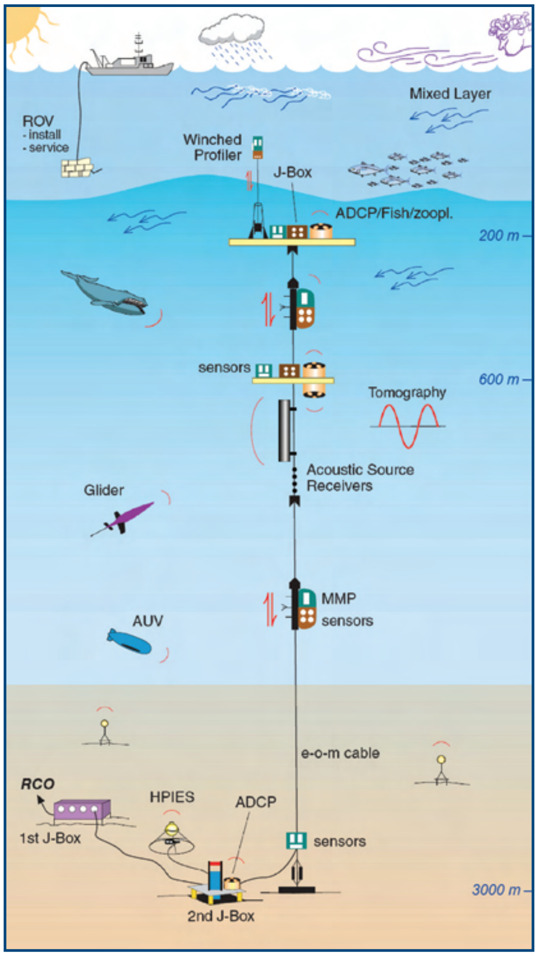

Figure 2. Illustration of the ALOHA-MARS mooring, showing the mid-depth and 200 m platforms, the winched profiler on the 200 m platform, and wire-guided profilers at deeper depths.

Conclusions for Cabled Moorings

4.1.1. Deep-water moorings.

After reviewing the available technology, the breakout group participants determined that the optimal profiling mooring for the deep-water cable sites is very similar to the "ALOHA-MARS" mooring (Fig. 2) currently planned for deployment at the MARS observatory in Monterey Bay during 2008. **Participants viewed this mooring as a key enabling technology for the cabled array and a critical technology needed to address science questions within the OOI network.**

The ALOHA-MARS mooring is an electro-optical-mechanical (EOM) system. Each mooring system consists of subsystems integrated together. The deep-water cabled nodes range from 2,500 to >3,000 m depths. A mooring conceptually consists of several nodes in the water column, extending the power and communications from the seafloor to discrete points/platforms in the water column. At these fixed nodes are collections of instruments, some making intrinsic point measurements (for data redundancy and check for measurement drift on profiling sensors), and some using acoustics or optics to remotely sense the surrounding environment. Different types of profilers will be needed to sample the water column in between the fixed points. These profilers include wire guided profilers in deeper water and winched systems for the upper mixed layer to sample close to the air-sea interface. These mobile platforms are constrained to move vertically and complement the fixed nodes (mid-water platforms) by providing varying degrees of power and communication through the water column.

The desired configuration has one fixed platform below the bottom of the winter surface mixed layer, approximately 200 m deep. This platform also is below the euphotic zone to reduce biofouling and below any significant wave action to reduce motion and mechanical stresses on the mooring system. The second fixed platform is at the bottom of the main thermocline, about 600 m deep. The two platforms would provide power, bandwidth and real estate sufficient for instruments that don't need to be, or can not be, mounted on profilers. Wire guided profilers would operate on the mooring risers between the bottom and the 600 m platform and the riser between the 600 m and 200 m platforms. A winched profiler on the 200 m platform would provide measurements from the platform to the surface.

4.1.1.1. Wire-guided profilers (e.g., McLane MMP and Ocean Origo SeaTramp).

There are several operational crawlers currently available with very different technological approaches (see Appendix 5.3). The wire-guided profilers were considered for the ALOHA-MARS mooring. Currently, these profilers can support self-powered, self-logging instruments suites of limited size. Neither of these two profilers can presently support the full envisioned sensor suites. The MMP is friction wheel driven with a modest payload. In principle, it can be expanded longitudinally (vertical dimension) by adding additional sections; practically maybe one or two more 12-inch sections could be added to the MMP used for the ALOHA-MARS mooring system. The SeaTramp is a buoyancy-driven profiler, which is currently being modified to employ an inductive charging/communication system, which will allow near real-time data communication and adaptive sampling, as part of a recently funded NSF grant (M. Alford, UW). The SeaTramp may be expanded somewhat more easily than the MMP to accommodate more sensors. To fully accommodate the full suite of envisioned sensors, however, it is likely that a new profiler development effort will be necessary. These profilers also cannot be used for the 0-200 m profiling because they require a taut wire with a subsurface float and, therefore, can't operate up to the sea surface interface.

4.1.1.2. Winched profilers.

A winched profiler is required on the deep-water mooring in order to access the near air-sea interface from the 200 m platform. There are several winched profilers available with different operational characteristics. Currently, the platform-mounted winched profiler (i.e., PRIMO) is the only technology that can provide the power, bandwidth, real time connectivity, and real estate for the large instrument suites identified for next generation experiments. PRIMO is currently under development by Scott Gallagher at WHOI and has had several deployments to date in shallow water. It is designed to reach the surface in two knots of current. A Japanese profiler being modified and further developed by Nichiyu Giken Kogyo Co (ngk-ocean) for NEPTUNE Canada also has potential; more will be known after its first deployment in 2008. A third winched profiler is being developed by a WET Labs/Oregon State University partnership based on the WET Labs AMP-X10 profiler. This Coastal Autonomous Profiling and Boundary Layer System (CAPABLE) has a winch on board the profiler (as opposed to a winch on the platform) and a platform controller to allow dynamic, adaptive mission control of sampling over fine vertical scales to investigate surface layer processes, such as biological thin layers. The system is optimized to work in the upper 200 m of the water column, in up to 1 knot currents and 10 foot waves. It can be powered from batteries or connected to a fiber optic cable. The current configuration does not have real-time connectivity. Instead, data are relayed when the profiler docks at the end of a profile. Extensive testing and deployment was scheduled for 2007.

In summary, the capabilities of the current platform-mounted and profiler-mounted winched profilers need to be carefully evaluated to determine the optimum surface layer profiler for the ALOHA-MARS mooring system. For example, the platform-mounted winch provides real-time connectivity, but there may be size, weight, and cost restrictions that may prohibit its deployment on the ALOHA-MARS mooring 200 m platform. All surface profilers should be capable of being deployed and maintained by an ROV to reduce operations and maintenance (O&M) costs.

4.1.2. Coastal moorings.

Winched profilers were considered to be appropriate for the shallow water, cable connected applications, e.g., the OOI cable-connected coastal moorings off Oregon. Potential leveraging of similar technologies between the shallow (200-0 m) and deep-water profilers could reduce overall life cycle costs by reducing the number of individual development efforts and simplifying the operations and maintenance logistic efforts. However, here again the capabilities of various profilers need to be carefully evaluated for the cabled coastal sites. The shallow coastal profilers have different constraints than the deep-water profilers, which need to be considered, such as resistance to sedimentation/abrasion and fish trawling. Biofouling was recognized as a major impediment to long term deployment of coastal moorings, and a major cost driver because of the necessary frequent maintenance in coastal systems. While some progress has been made, it was recognized that more needs to be done.

Recommendations for Cabled Moorings

(1) **The primary recommendation is to start a comprehensive, science driven in situ test and development program for cable-connected profiling moorings.** The overwhelming conclusion of this breakout group was that profiling moorings are a critical technology that will be required from the start of the OOI Program to implement the next generation of transformative science experiments the OOI is designed to address. The breakout group recommends that the OOI Program and the Regional Scale Nodes Implementing Organization adopt the ALOHA-MARS design for the deep-water cabled profiling mooring. The breakout group was very excited about the initial development of the ALOHA-MARS mooring. However, it was noted that additional funding support will be essential to continue the development and testing of ALOHA-MARS, which is needed to convert the existing prototype system into a hardened, robust, reliable profiling mooring.

This section provides an outline for a development program that can be implemented as soon as possible. All the technologies required to implement deep and shallow water cable-connected profiling moorings described above are underway to varying extents. *What is required is a coordinated development program aimed at refining and integrating these technologies with the intent of delivering a robust, field proven, system ready for science when the cabled nodes are installed.* The development program outlined here identifies specific examples of technologies required for the Cable-Connected Profiling Mooring to progress. This is not intended to preclude the development of other profiling technologies.

There are three elements of this development program. (1) The first element combines on-going development efforts that appear to meet the OOI cabled profiler needs. (2) The second element is focused on developing the instrumentation and algorithms required to allow cable-connected profilers to address the adaptive sampling experiments identified in the OOI Science Plan and other reports. (3) The third element of the program provides economical access to existing facilities, such as the MARS test bed, for all groups, academic and commercial, engaged in developing the required technologies.

   (1) *Development Program.* We recommend that a more rigorous evaluation of the available winched profilers be carried out to assess capabilities, size, weight, costs, and ROV support. A development program will be required to add a winched profiler to the top platform of the ALOHA-MARS mooring and test it at the MARS cabled observatory. One candidate is the winched profiler currently being developed for the PRIMO observatory (under ice in Antarctica). However, it was noted that some modifications to the winch system (240 V ac to 400 V dc, reduce frame size and weight) and minor modifications to the mooring float node (e.g., provide 400 V on a connector) will be necessary. Workshop participants recognized that these modifications and testing efforts will require additional funds to the mooring projects and recommended that the OOI Program Office work closely with the NSF to ensure the successful development of these critical platforms prior to the OOI commissioning.

   (2) *The operational requirements (e.g., adaptive sampling requirements) of cabled profiling moorings are listed in the introduction of this section.* Percy Donaghay presented an excellent example of a profiler with sampling characteristics [Ocean Response Coastal Analysis System (ORCAS) profiler, and subsequent versions by WET Labs: AMP-WQ50, AMP-ES100, AMP-X10] designed to follow a thin layer (~10 cm thick) in near-surface waters. OOI science questions require that users be able to adaptively control the sampling depth of profilers, which will drive the profiler requirements in this area. For example, after a standard water column profile is completed, science users may request enhanced fine-scale sampling at depths of specific features.

   (3) *Inherent in the previous two development aspects are opportunities for other groups to make use of these same facilities.* For instance, to mitigate risk, it is suggested that the winch-on-board profiler being developed by WET Labs/OSU also be adapted to be used on the subsurface float of the ALOHA-MARS mooring. Furthermore, the ngk-oceans profiling mooring development should be tracked and evaluated when delivered to NEPTUNE Canada. In order to implement the third element, two tasks must be accomplished. The ocean sciences community must be made aware that the profiling technologies will be available on testbeds, such as MARS, to facilitate further technology development. Second, policies need to be defined to allow economical access to these facilities, e.g., reduced port costs on MARS.

(2) **Wire-guided profilers need to be carefully evaluated.** The available wire-guided profilers need to be evaluated to determine the appropriate technology for the bottom to 600 m and 600 to 200 m profilers on the ALOHA-MARS mooring. Additional development of these profilers also will be needed to allow real-time data communication, size-space needed to carry needed sensors, and ability to reliably profile on an EOM riser cable.

(3) **Wire guided profilers should be ROV serviceable.** In other words, an ROV should be able to place a wire-guided profiler on the mooring riser cable, as well as remove it. This implies standardizing a docking station for inductive power transfer and high speed communications, so that different profilers could be used.

(4) **Inductive communications modem development is needed.** For example Seabird Electronics, as well as other interested companies, should be strongly encouraged to improve the capability of their inductive communications modems in order to enable real-time communication with moving profilers. Specifically, the data rates should be increased to at least 19.2 kbit/s and precise timing should be included (better than 0.1 ms).

(5) **Development is needed for a larger, more capable profiler to accommodate the full suite of envisioned sensors, some of which are large and power hungry.** This would be considered a longer term objective. Special attention will have to be paid to assuring the sensors observe and sample a common water volume.

(6) **Biofouling prevention measures are needed.** NSF should encourage proposals to develop not just anti-biofouling coatings and measures, but also inherently non-fouling coatings. The OOI operations and maintenance (O&M) budget is limited and, thus, would benefit if biofouling prevention results are obtained prior to initial deployment and could be incorporated into the life cycle design and costing.

4.2. Uncabled (to shore) Coastal Profiling Moorings Breakout Group

Participants: Scott Gallager (Discussion leader), Sue Banahan, Andrew Barnard, Jack Barth, Brian Beanlands, Chad Lembke, Keith Raybould, Michael Mathewson, Koji Ochi

The coastal breakout group considered three key science drivers: (1) climate variability and ocean food webs and biogeochemical cycles, (2) coastal ocean dynamics and ecosystems, and (3) turbulent mixing and biophysical interactions, with respect to available profiler technology. They concluded that profiling technology is essential to achieve the transformative science goals.

The participants also reviewed the current uncabled profiling technology for coastal regions in relation to the science questions (Fig. 3). They noted that the OOI may need to employ a mix of profiler technologies to meet OOI science requirements. Many of the science questions require measurements near surface (upper 10-20 m) or near the sea floor. Such measurements cannot be obtained by the crawlers (e.g., MMP, Seatramp) or the SeaCycler, owing to their configurations. The wave-powered SeaHorse may obtain measurements through most of the water column, but has a surface buoy and, therefore, the profiler is not surface piercing. Only the winched profilers can sample the critical interface regions.

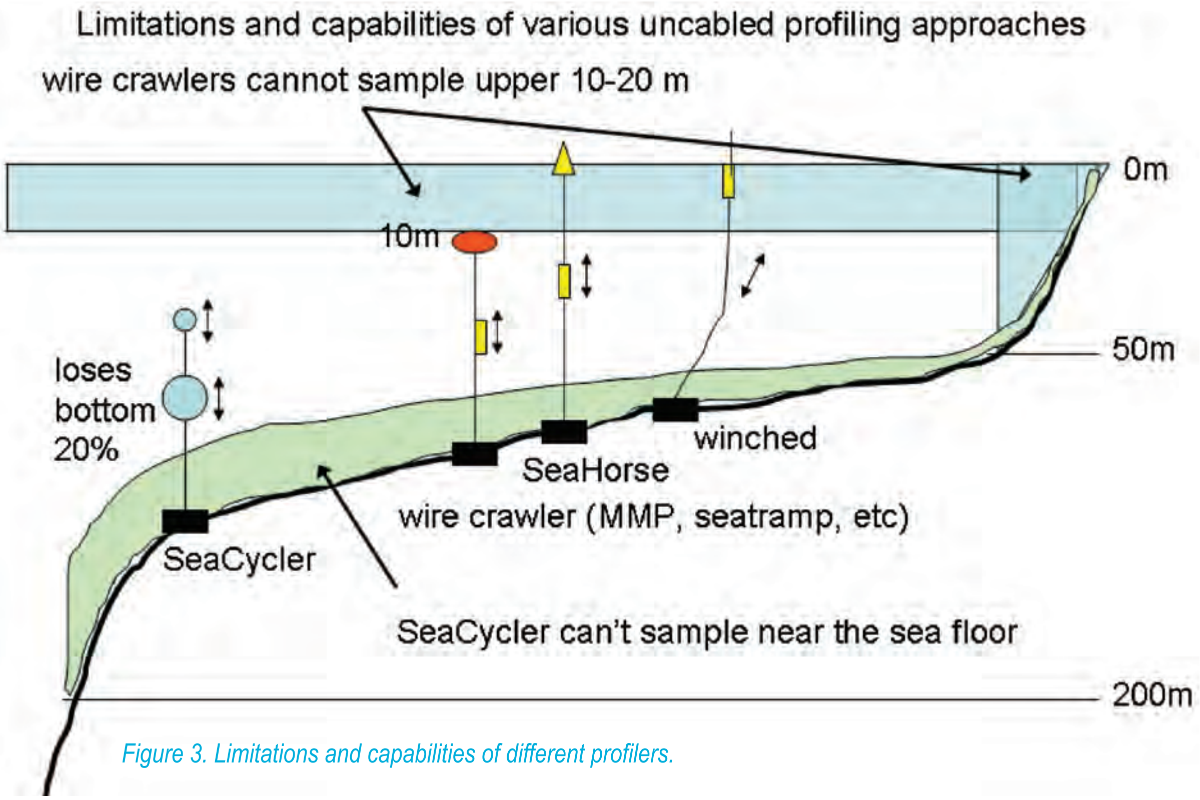

Figure 3. Limitations and capabilities of different profilers.

Recommendations for Uncabled Coastal Moorings

(1) **A mix of profiler technologies may be needed to meet OOI science requirements in coastal environments.** For example, it was noted that the crawlers planned for the coastal Pioneer Array will not be able to sample near surface or at the air-sea interface. They also will not allow a full sensor payload to address chemical/biological and ecosystem questions.

(2) **Two or more profilers/crawlers may be needed for deep water shelf regions in order to provide full water column coverage.** A single profiler at 500 m would restrict the number of profiles per day. Multiple profilers on one mooring would allow for flexibility in sampling (e.g., more profiles in shallow section without affecting deeper sampling). In addition, a mid-water buoy could serve as a sensor platform.

(3) **There is a critical need to foster improvement of power and bandwidth capabilities for uncabled moorings, with an eye toward commercial development.** Due to current advancements in compression and telemetry, power may be the primary limitation in the future rather than bandwidth. Only a limited number of sensors will be able to be deployed on the uncabled moorings. Some power options to investigate include: fuel cell, wave power, wind power, and solar power.

(4) **A focused effort on enabling adaptive sampling should be a priority.** Transformative science requires the ability to do adaptive sampling. A connection to cyberinfrastructure must be made early in the planning stage. The recommendation was to start with shore-side algorithms and later migrate to on-board systems.

(5) **The OOI Office and/or NSF should support collaborative development of profiling technology among private engineering (platforms, sensors) and researchers.** Funding collaborations are critical to the development of transformative technologies. The participants noted that extensive testing is required before deployment as a risk mitigation. It is also important to have parallel development of sensor packages (especially miniaturization, reduced bandwidth using internal processing, and reduced power) in order to integrated them with the profiling platforms.

(6) **The OOI Office should continue to fund workshops, and other forms of communication, to promote information sharing and technology advancement among engineers, scientists, and industry.**

4.3. Uncabled (to shore) Deep-Water Profiling Moorings Breakout Group

Participants: Doug Au (Discussion Leader), George Fowler, Ann Gargett, Keith von der Heydt, Larry Langebrake, Doug Luther, Randy Russell, Uwe Send, Sverker Skoglund, Laura Snow-Thakral

Profilers are essential for achieving the science goals of the open-ocean component of the OOI. In order to meet the goals of the OOI and address the high priority science questions, the global moorings will need to support a number of different types of sensors and achieve data communication in near real-time. Global moorings also have the constraint that maintenance visits by ship will occur only about once a year; hence the mooring, power sources, and sensors must be highly durable. In addition, OOI interim Observatory Steering Committee members recently (June, 2007) recommended that the OOI should emphasize fewer, more capable moorings over more numerous, less capable ones (i.e., with traditional capability) and that there should be a focus on high latitude sites.

A review of mooring technology currently used by the ocean science community indicates that about 10 – 40 W of power is typically available for sensors, and data rates using an Iridium satellite link are on the order of 2 Mb per day. This is significantly below what will be needed by the OOI. A simple science use case scenario can be used to demonstrate what capabilities are required of the global moorings. Consider, for example, a physical oceanographer who would like to use a McLane Moored Profiler (MMP) to measure currents and basic water properties over a 1,000 m vertical range. A high vertical resolution would be necessary, because he/she would need to accurately measure turbulence and intrusions, which would require a high sampling rate. To resolve tidal currents from all the other low-frequency variability, he/she would need at least three observations of currents at each depth for every 12 hour period. Thus, three 1,000 m profiles would be needed every 12 hours, or three roundtrips of the profiler every 24 hours, for a total of 6,000 m traveled per day. If only measurements of horizontal currents (acoustic current meter), plus conductivity, temperature and depth from the CTD are made, these two instruments alone on the MMP would generate 200 bytes of data per meter (*http://www.mclanelabs.com/mooredprofiler.html*). All of the data are needed by the scientist on shore. Multiplying 200 bytes/m * 6,000 m = 1.2 Mbytes of data per day acquired just from these two simple instruments. If another investigator wanted to address turbulence or tidal questions in just the upper 1,000 m of the water column, little to no bandwidth would be available for any other sensors. This would limit space in the MMP for other sensors. In addition the current meter and the CTD would require about 2-3 W. Other sensors, such as Acoustic Doppler Current Profilers (ADCP) and Acoustic

Doppler Velocimeters (ADV), have power requirements ranging from 1.5-115 W, which would exceed typical mooring capability unless an additional power supply was provided. Thus, the current mooring technology will only allow measurements by a few low power and bandwidth sensors. Clearly, the development of deep-water global moorings faces several challenges, two of which are power and data communication.

Most of the participants believed that some initial transformative science can be achieved with innovative use of battery-run, interactive mooring systems, deployed unattended for one year. With judicious sampling strategies, these systems could be used to accomplish some of the OOI goals early in the program.

Recommendations for Uncabeled Deep-Water Moorings

(1) **Enhanced power options need to be investigated and developed.** Recharging from moored batteries or power delivered to seafloor should be developed. This capability is important to many aspects of OOI. There is a critical need to support investigation and implementation of emerging power options to provide the profilers power at the sea floor. For example, one emerging technology is wave driven power on buoys (e.g., Ocean Power Technology *http://www.oceanpowertechnologies.com/index.htm*). The new technologies need to be considered in terms of capital and installation costs and O&M costs.

(2) **There is a need to support investigation and implementation of emerging satellite and underwater communications technology.** There should be an upgrade path to these emerging technologies if they are not implemented for the initial installations. Appendix 5.5 summarizes some available information.

(3) **Secondary paths for power and data must be implemented, since these systems may rely on single elements to provide a primary path for communications or power.** An example scenario would be when a surface profiler is unable to reach the surface and establish satellite communications. For this scenario, a secondary acoustic communications path would still allow a lower bandwidth path to return data. Because these systems are going to be deployed with the expectation of no more than annual maintenance schedule, internal battery backup systems or external charging systems may be appropriate.

(4) **Support must be provided for rigorous testing and configuration management to ensure reliable operation.** As mentioned previously, these systems will be deployed for long periods of unattended operation. Maintenance is projected to be on an annual basis.

(5) **Participants recommended three vertical sampling regions for a 4,000 m deep mooring: seafloor (4,000 m) to 1,000 m, 1,000 m – 200 m, and 200 m to the surface.** Because of the great ocean depths over which measurements need to be made at the global mooring sites and the speed of profilers and crawlers, multiple profilers or crawlers will be necessary to cover the water column in a timely fashion and to allow for different sampling requirements. The 4,000 to 1,000 m, 1,000 m – 200 m, and 200 m – surface portions of the water column may require different sampling frequencies depending on the science questions being addressed. For instance, to investigate questions related to the interaction of current flow and topography would require at least six (roundtrip) profiles a day (three profiles for every 12 hour period) between near bottom and 1,000 m to resolve tide variability and inertial oscillations. A higher frequency of profiles may be needed in the 1,000 – 200 m depth range, whereas resolution of tides in the upper 200 m may not require even six profiles a day. The vertical spatial and temporal scales of physical and biogeochemical processes must be carefully considered to determine the optimum profiling strategy. For example, higher temporal resolution may be needed if rapid changes in processes are expected near dawn and dusk.

(6) **Profiling platforms must have an architecture that is expandable in terms of space, weight, power, and interface in order to accommodate new community and PI-sensors, in addition to the initial core sensors supported by the OOI MREFC funds.** The moorings also must be able provide adequate power and an appropriate electro-mechanical interface (i.e., standard connectors and brackets). Furthermore, standardized software interfaces to allow Plug N Play capability should be considered. Current mooring profilers and crawlers may have limited real estate to accommodate a large number of bulky sensors. The breakout group attempted to quantify what might be considered a typical volume for many sensors, using currently available nitrate and CO2 sensors as examples. Considering the requirements for housings and cabling, they estimated a 10 liter volume for each of these sensors.

(7) **Issues related to mooring knockdown due to current conditions must be carefully considered for deep water mooring designs.** Issues related to vertical excursions or "knockdown" of subsurface moorings in strong currents must be considered in designing moorings. The RMS vertical excursion of moorings with 2000 lb buoyancy spheres at 400 m depth beneath the Gulf Stream (Hogg, 1986*) was ~100 m, with a maximum knockdown of about 520 m in 75 cm/s of current. Knockdown depends on the nature and depth of the buoyancy, the total drag on the mooring, and the vertical profile of currents. Transient knockdown "events" of as much as 1,000 m are possible in a "worst-case" scenario. Mooring models should be used along with available information about vertical current structure at the deployment site to optimize the mooring design and predict the expected knockdown. Based on these results, instrumentation must be designed to survive at depths that may be significantly greater than their target deployment depth. This may place important engineering constraints on surface profiling systems and sensors that are typically rated to ~200m.

*Hogg, N.G., 1986. On the correction of temperature and velocity time series for mooring motion. *J. Atmos. Oceanic Technol.*, 3: 204-214.

(8) **Another risk-factor which needs to be considered in developing profiling systems is fish-bite.** Many institutions around the world have moved to equip moorings with wire rope in the upper 1,000 m or more, since synthetic materials may be damaged or cut by fish biting them. In addition to moorings having been lost apparently from fish severing the mooring line, large teeth have even been found in buoyancy elements (syntactic foam floats), and recently gliders have shown signs of damage from fish attack. A profiler that moves up/down a mooring line can easily be protected by using wire rope. However, winched profilers using a synthetic line are at risk, and conscious choices/tradeoffs regarding this potential failure mode need to be articulated and considered.

(9) **Self-powered interactive and adaptive systems that exist or are under development should be considered for early implementation.** Continued funding support is needed to bring adaptive sampling capabilities to maturity.

5. Appendices

5.1. Agenda

Workshop Charge: The current Ocean Observatories Initiative (OOI) Conceptual Network Design (*http://www.oceanleadership.org/ocean_observing/initiative/cnd*) calls for highly capable cabled and uncabled profiling moorings in coastal, deep-water, and remote high latitude environments. The goal of this workshop will be to assess (1) the current status of profiling mooring capabilities, including underway development, (2) how this status compares to the OOI expectation and requirements for profiling moorings, and (3) if further development is needed, provide specific recommendations. This assessment will include power and bandwidth capabilities, profiling speeds, depth ranges, and types of platforms/surface areas to support different sensors.

Tuesday, 10 July 2007

8:00am	*Continental breakfast*
8:30-8:45	Meeting organization and charge
8:45-9:30	Introduction of participants (2 min ea)
9:30-10:00	OOI science use case scenarios for profiling mooring requirements (Gallager/Daly)
10:00-10:30	*Coffee Break*

Profilers Currently Available and Under Development (20 min talks, 10 min questions)

10:30-11:30	Scott Gallager (WHOI)
11:30-12:00	Michael Mathewson (McLane Research Lab)
Noon-1:00pm	*Lunch*
1:00-1:30	Svenker Skoglund (Ocean Origo)
1:30-2:00	Koji Ochi (ngk Ocean) past and future plans
2:00-2:30	Uwe Send (SIO)/George Fowler/Brian Beanlands (DFO)
2:30-3:00	George Fowler/Brian Beanlands (DFO)
3:00-3:30	*Coffee break*
3:30-4:00	Andrew Barnard (Wetlabs)
4:00-4:30	Jack Barth/Murray Levine (OSU)/Andrew Barnard (Wetlabs)
4:30-5:00	Bruce Howe (UW)
6:30pm	*Reception*

Wednesday, 11 July 2007

8:00-8:30am	*Continental breakfast*
8:30-9:00	Sensors currently used on profilers (Andrew Barnard, Percy Donaghay)
9:00-10:15	Profiling mooring “lessons learned” (Panel: Percy Donaghay, Scott Gallager)
10:15-10:45	*Coffee Break*
10:45-11:00	Plenary: charge for breakout groups
11:00-noon	Breakout groups
Noon-1:00PM	*Lunch*
1:00-3:00	Breakout groups
3:00-3:30	*Coffee Break*
3:30-4:30	Breakout groups
4:30-5:00	Plenary: Brief (10 min) working group reports

Dinner on own

Thursday, 12 July 2007

8:00-8:30am	*Continental breakfast*
8:30-8:45	Plenary: Questions/issues for breakout groups
8:45-10:00	Breakout groups complete recommendations
10:00-10:30	*Coffee Break*
10:30-11:30	Breakout group summarize recommendations (20 min each)
11:30-Noon	Group discussion, priorities on recommendations
Noon	*Lunch*

End Meeting

5.2. List of Participants

Participants	Insititution	Contact information
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5.3. Profiler characteristics

http://www.oceanleadership.org/files/Appendix_5.3.xls

5.4. Proposed sensors for OOI profiling moorings

http://www.oceanleadership.org/files/Appendix_5.4.xls

5.5. Satellite Communications Information

	Example of Buoy-to-Shore Satellite Communications Options												
	Service Provider	**Service / Plan Name**	**Terminal or Modem PN**	**Current Satellite Coverage**	**Antenna**	**Uplink / downlink Raw Data Rate kbps**	**Estimated uplink kbps**	**2007 Air-time Cost per Minute**	**Maximum Feasible Data per Day**	**Power required when trans. Watts**	**Airtime cost per Mbyte**	**Joules per Kbyte**	**Cost per year for 22MB/day buoy**
Currently Available	Globalstar	Liberty 48000 dial-up	Qualcomm 1620	Coastal regions to 200 miles from shore	omni-directional	to 9.6/9.6 kbps	7.8	$0.14	30 MB (2)	8	$2.58	8.2	$20,717
	INMARSAT	F-33, MPDS	KVH TracPhone F33	Spot beam, most of americas	stabilized, 14” dia.	28/64 kbps	28	billed per Mbit	68 MB +	60	$30.00	17.1	$240,900
	Iridium	PPP or RUDICS	NAL Research, A3LA-D	Worldwide	omni-directional	to 2.4/2.4 kbps	2.4	$0.85	15MB (3)	2.5	$48.35	8.3	$388,251
Potentially Feasible 2008	CLS America	ARGOS-3	Kenwood or Elta	Global	omni-directional	4800/400	4.8		3.75kB (store and forward)	2		3.3	
	INMARSAT (best case)	BGAN Class 9 UT	Thrane & Thrane Marine Mobile Terminal	All but Western, Central Pacific (1)	stabilized, F33 size	Max rate 238/384kbps (4)	238	Billed per Mbyte	68 MB +	100	$3.09	3.4	$24,813
	INMARSAT (worst case)	BGAN Class 9 UT	Thrane & Thrane Marine Mobile Terminal	All but Western, Central Pacific (1)	stabilized, F33 size	Guaranteed rate 32/64 kbps (5)	32	Billed per Mbyte	68 MB +	100	$3.09	25.0	$24,813
	INMARSAT	BGAN Class 5 (Omni) UT	Thrane & Thrane Marine Mobile Terminal	All but Western, Central Pacific (1)	omni-directional	TB	TB	TB	TB	TB	TB	TB	TB

(1) - The launch of the INMARSAT BGAN Pacific region satellite is scheduled for 2007.
(2) - Actual uncompressed data return at 40% satellite availability.
(3) - Calculated data return at 95% satellite availability.
(4) - This is at the maximum system data rate, depends on network loading.
(5) - This is at the minimum guaranteed system data rate.