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1 Executive Summary

Although the ocean is central to the habitability of our planet, it is largely unexplored. Biological, chemical, physical, and geological processes interact in complex ways in the ocean, at the seafloor, and at the air-sea interface. Our ability to learn more about these processes is severely limited by technical infrastructure, and developing a more fundamental scientific understanding of these relationships requires new and transformational approaches to ocean observation and experimentation.

The Ocean Observatories Initiative (OOI) will lay the foundation for future ocean science observations. OOI will enable powerful new scientific approaches by transitioning the community from expedition-based data gathering to persistent, controllable observations from a suite of interconnected sensors. The OOI's networked sensor grid will collect ocean and seafloor data at high sampling rates over years to decades. Researchers will make simultaneous, interdisciplinary measurements to investigate a spectrum of phenomena including episodic, short-lived events (tectonic, volcanic, biological, and meteorological), and more subtle, longer-term changes and emergent phenomena in ocean systems (circulation patterns, climate change, ocean acidity, and ecosystem trends).

The development of this preliminary design from the conceptual design incorporates the response to the OOI Conceptual Design Review (CDR), and maximizes OOI's transformational impact. The OOI will enable three scales of marine observations (coastal, regional and global) that are integrated into one observing system via an overarching cyberinfrastructure. The coastal component of the OOI will expand existing coastal observing assets, creating focused, configurable observing regions. Regional cabled observing platforms will 'wire' a single region in the Northeast Pacific Ocean with a high speed optical and power grid. The global component addresses planetary-scale problems via moored open-ocean buoys linked to shore via satellite. The whole of OOI allows scientists and citizens to view phenomena irrespective of the observations' sources (e.g., coastal, global, regional, ships, satellites, IOOS).

Through a unifying cyberinfrastructure, researchers will control sampling strategies of experiments deployed on one part of the infrastructure in response to remote detection of events by other parts of the infrastructure. Distributed research groups will form virtual collaborations to collectively analyze and respond to ocean events, adding to the globally accessible environmental signal that digitally represents our planet. The OOI's introduction of dedicated power and bandwidth to remote parts of the ocean will provide the ocean science community with unprecedented access to detailed data on multiple spatial and temporal scales, complementing fixed platforms with a variety of mobile assets.

OOI will create the technological and organizational infrastructures to create radically new opportunities in ocean observing, ocean prediction, and scientific collaboration. By
applying the best technologies for ocean science, ocean data systems, and community collaboration, OOI will enable new science, make existing science more effective, and change expectations about what can be and should be achieved. This *OOI Preliminary Network Design* presents driving motivations for this work, the requirements that have been identified, and the designs for each of the OOI components.

## 2 Motivation and Background

Ocean science has long been a franchise of individual scientists and small groups, working to solve problems within one or a few science domains at a time. Cooperation, when sought, was limited in time, space, and logistical reach, as humans pervasively organized the experiments, the data sharing, and the analysis of results. Collaborative studies (e.g., the Intergovernmental Panel on Climate Change; RIDGE2000) and technology initiatives (e.g., the Argo program of free drifting profiling floats; the U.S. National Ocean Bottom Seismograph Instrument Pool) have yielded important outcomes, but such approaches have not been widely applied even as their value has become obvious. The broad scientific and civil demands for multidisciplinary and interdisciplinary research coupled with exponential growth in information technology are changing oceanography and Earth sciences.

In the 21st century, long-standing traditions in ocean science are being enhanced, and sometimes overrun, by the cultural and technological transformations under way. Since the advent of computers and electronic data-taking technologies, the need for interoperable data systems for environmental science has been proclaimed and demonstrated. Every technological improvement in data management and exchange has led to new discoveries and new science proposals leveraging the previous achievements. Yet pervasive interoperability of environmental science systems and data seems has not been achieved.

The National Science Foundation is initiating such a transformation of ocean science with the OOI. The OOI will lay the foundation for the future of ocean sciences and of environmental science generally. OOI will create the technological and organizational infrastructures to create radically new opportunities in ocean observing, ocean prediction, and scientific collaboration. Through the application of the best technologies to the confluence of ocean science, ocean data systems, and ocean community collaboration, OOI will enable new science, make existing science more effective, prompt additional scientific interest in oceanographic issues, and change expectations about what can be and should be achieved.

### 2.1 What is Different About OOI?

The OOI is conceptually unique in its components and in its aggregation. From unusual high-capacity platforms and advanced instrumentation, to high-speed fiber-optic connectivity and always-on power, to a deeply interconnected architecture enabling a
sophisticated web of sensors and communities, OOI is designed from the start to provide these key features for ocean science:

- **Persistence**: Designed for long-term (greater than 25-year) operation, support, and data access
- **Geographic Range**: Consistently occupying larger volumes of multiple oceans to adaptively observe ocean processes on multiple scales
- **Mobility/Portability**: Able to go where the action is and the science demands
- **Control/Adaptability**: Responsive to commands addressing real-time needs
- **System Interoperability**: Common ways to exchange information and do science
- **Intercommunication**: Connected systems
- **Power/Bandwidth**: Experiments and observations freed from traditional limits
- **Sensor Capability**: Increased spatial, temporal, and measurement resolution
- **Community**: Building sharing and interactions across all scientific endeavors

These characteristics are central to addressing the premier, and potentially critical, ocean and environmental science questions of our time. Individually they are novel or state of the art in ocean science; in combination they provide capabilities previously impossible in any environmental science domain.

### 2.2 Science Themes

Multiple workshops and reports have identified the high priority areas of ocean research that require the infrastructure envisioned in a state-of-the-art ocean observing network area. These topics have been described in the *OOI Science Plan* (1), *Ocean Sciences at the New Millennium* (2), and *Ocean Research Interactive Observatory Networks (ORION) Workshop Report* (3). The science in these reports mirrors many interdisciplinary themes described in *Charting the Course for Ocean Science in the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy* (4). The main research areas can be summarized as:

**Ocean-Atmosphere Exchange.** Quantifying the air-sea exchange of energy and mass, especially during high winds (greater than 20 ms\(^{-1}\)), is critical to providing estimates of energy and gas exchange between the surface and deep ocean, and improving the predictive capability of storm forecasting and climate-change models. Conventional technology has been unable to support observations under high wind conditions.

Observations supporting the study of chemical and biological change in the ocean are key to following the global carbon cycle as well, yet must be augmented by science that cuts across scientific domains. Understanding the exchange of substance and energy between the ocean, atmosphere, and terrestrial land requires simultaneous observations and data access across the physical boundaries of land, sea, and air.
Climate Variability, Ocean Circulation, and Ecosystems. As both a reservoir and distributor of heat and carbon dioxide, the ocean modifies climate, and is also affected by it. Understanding how climate variability will affect ocean circulation, weather patterns, the ocean’s biochemical environment, and marine ecosystems is a compelling driver for multidisciplinary observations.

OOI provides extended observing capabilities both within and above the ocean, covering previously unobserved ocean areas and depths, and continuing through the coastal regime to create seamless coverage of the land-sea-air boundaries.

Turbulent Mixing and Biophysical Interactions. Mixing occurs over a broad range of scales and plays a major role in transferring energy, materials, and organisms throughout the global ocean. Mixing has a profound influence on primary productivity, plankton community structure, biogeochemical processes (e.g., carbon sequestration) in the surface and deep ocean, and the transport of material to the deep ocean. Quantifying mixing is essential to improving models of ocean circulation and ecosystem dynamics.

To understand processes at all oceanographic scales, from ocean basin to tidal basin, seafloor to surface, and within the thin sections of wave fronts and stratified nutrient layers, requires the complete set of observing and computational assets envisioned for the OOI. Many assets must be capable of finding and following transient and localized phenomena, wherever they occur, while other platforms must provide stable reference points over time and space. The short-term nature of many processes demands reactive control of high-speed measurements, while large-scale phenomena must be measured consistently over months, years, or decades.

Coastal Ocean Dynamics and Ecosystems. Understanding the spatial and temporal complexity of the coastal ocean is a long-standing challenge. Quantifying the interactions between atmospheric and terrestrial forcing, and coupled physical, chemical, and biological processes, is critical to elucidating the role of coastal margins in the global carbon cycle, and developing strategies for managing coastal resources in a changing climate.

Measurements must be taken across disciplines, as physical forces induce biological and chemical effects, which in turn mediate other (sometimes severe) biological changes, in some cases feeding back into physical changes. Comprehensive sensing systems must be collocated and interoperable to enable studies across different science domains and observing regimes. Multiple science communities must likewise interact to provide a coherent, integrated view of the results, and this can only be fully enabled with a system like the OOI that has been designed for full engagement of the broader community.
**Fluid-Rock Interactions and the Subseafloor Biosphere.** The oceanic crust contains the largest aquifer on Earth. Thermal circulation and reactivity of seawater-derived fluids can modify the composition of oceanic plates, can lead to the formation of hydrothermal vents that support unique micro- and macro-biological communities, and can concentrate methane to form massive methane gas and methane hydrate reservoirs. The role that transient events (e.g., earthquakes, volcanic eruptions, and slope failures) play in these fluid-rock interactions and in the dynamics of subseafloor microbial communities remains largely unknown.

The long-term sensor deployments on the ocean floor, fully networked and controllable in response to short-term changes and objectives, will provide unique observing opportunities of tectonic events and their catalytic role in biological activity. Sensors deployed on nearby moored platforms or in profiling mode in the water column, unconstrained by power limitations, will track related changes into the overlying hydrosphere. The OOI's on-demand abilities to interconnect sensor systems to make measurements, and combine data systems to analyze measurements, will empower new collaborations between the geological and marine biology communities.

**Plate-Scale, Ocean Geodynamics.** Lithospheric movements and interactions at plate boundaries at or beneath the seafloor are responsible for short-term events such as earthquakes, tsunamis, and volcanic eruptions. These tectonically active regions are also host to the densest hydrothermal and biological activity in the ocean basins. The degrees to which active plate boundaries influence the ocean from a physical, chemical, and biological perspective are largely unexplored.

The persistent plate-scale sensors of the OOI will provide extensive scientific data about plate deformation and its causes and effects. The OOI provides a network of seismographs capable of understanding plate interactions and Earth’s deep structure and geodynamics. The permanence, power, and bandwidth associated with this network will provide critical data that cannot be economically obtained using other approaches.

Beyond the unique observing opportunities provided by the OOI, still more integration is needed for true multi-disciplinary science. Once OOI data have been collected, they must be combined with non-oceanographic data from many other observing systems. In its cyberinfrastructure design, the OOI contains the keys to enable widely accessible, transparent, effective exchange of science data, allowing oceanographers to access the data from terrestrial and atmospheric systems, while allowing scientists from those domains to easily interact with the ocean systems – and the ocean scientists – enabled by the OOI. Highly accessible and interoperable system and data interfaces will engender faster access to data, more and better tools for working with data, and the ability to integrate scientific programs and experiments across continental and global scales.
2.3 Extended Benefits

The opportunities offered by the collaborative framework presented by the new OOI elements when combined in a single, remotely controllable, integrated system through its cyberinfrastructure (CI) will begin to change the way ocean and environmental scientists think of conducting their studies. Even at the most basic level of performance, the ability to access detailed near-real-time data from the entire OOI system, across multiple ocean systems and multiple spatial and temporal scales, will enable new studies and applications. Sensor-related characteristics of the CI such as sensor self-description, consistent sensor controls and access to sensor data, and sensor data stream publication will combine with other features such as event detection, automated post-processing algorithms, assimilation of data into models, and automated quality control features, to create sophisticated real-time and off-line analyses. Manual and automatic modifications to observing plans, both for the OOI itself and unrelated environmental observing assets, will become common (and expected) scientific benefits.

Beyond the simple improvements for sensor observations, the collaborative opportunities created by the OOI will be equally transformative. Today, capabilities made available by the Internet are pervasively changing and accelerating social interactions. With OOI, similar changes will finally become available to scientific research. Existing networks for scientific collaboration will extend further into cyberspace, and will integrate observations, research teams, and interested onlookers, whether scientific, educational, or the interested public. These connections will be made both systematically and spontaneously, according to areas of interest and need, and can be controlled according to the dictates of each participant.

With these integrated CI capabilities easily at hand, ocean science will begin to enjoy the benefits of systems that can help researchers, beyond just making their tasks easier to perform. By connecting researchers and other users to resources of potential interest – papers, colleagues, projects, instruments, or even data – the OOI will create a new wave of ocean science and ocean application. As has happened elsewhere on the Internet, researchers, teachers and students, industry, and tourists will all create new opportunities enabled by OOI, for the benefit of themselves and others. The OOI will provide the first comprehensive demonstration of a new approach to ocean science, and its impacts on the community of the oceans.

2.4 A Brief History

Multiple disciplines individually conceived of long-term observatories in the ocean, consistent with the multiple, independent fields characteristic of oceanography in the 20th Century. The first series began with solid Earth studies in 1988, forming the International Ocean Network (ION) in 1993, and beginning the first national committee in 1995 with NSF funding through the Consortium for Ocean Research and Education
This effort broadened into the Dynamics of Earth and Ocean Systems (DEOS) committee leading to the Ocean Research Interactive Ocean Network (ORION) concept. A design study of NEPTUNE, a cabled observatory in the northwest Pacific, was funded in 1998. The first National Research Council (NRC) study on ocean observatories was released in 2000.

While some physical oceanographers, especially those outside the U.S., participated in ION and DEOS, the first International Conference on the Ocean Observing System in San Rafael, France in 1999 focused interest in fixed and mobile observing systems. The international Global Eulerian Observatory (GEO) committee was formed the same year and later (1993) became OceanSITES that continues to this day. In 2000, the NSF approved the OOI Major Research Equipment & Facilities Construction (MREFC) Program to provide a mechanism to begin the construction of an interdisciplinary, multi-scale ocean observatory.

Figure 1: Major milestones in the development of the Ocean Observatories Initiative.

Figure 1 summarizes major milestones since 2000. Two nationally circulated science and technical reports reflect broad community involvement in this complex initiative. Two high-visibility documents, the Pew Ocean Commission’s 2003 report, *America’s Living Oceans: Charging a Course for Sea Change* (5), and the U.S. Commission on Ocean Policy’s 2004 report, *An Ocean Blueprint for the 21st Century* (6), also highlight the importance of science-driven ocean observing. Recently, the National Science and Technology Council’s Joint Subcommittee on Ocean Science and Technology issued the report *Charting the Course for Ocean Science for the United States for the Next Decade: An Ocean Research Priorities Strategy* (4), which identifies the OOI’s key role in addressing near-term national priorities. The NSF Coastal Ocean Processes (CoOP) representing interests in coastal studies joined in planning for the OOI in 2003.

In 2004, through a cooperative agreement with the NSF Division of Ocean Sciences, Joint Oceanographic Institutions (JOI) established a project office to coordinate further OOI planning. In 2005, JOI issued a broadly focused request for conceptual proposals.
that resulted in 48 full experimental design submissions, representing the efforts of 550 investigators and spanning 130 research and education institutions. JOI instituted a large advisory structure of six committees comprising approximately 80 ocean scientists to assist in guiding development of a Conceptual Network Design (CND; 7,8,9,10) informed by these submissions and other program activities. In March 2006, the potential user community reviewed the draft CND at a Design and Implementation Workshop (11). In August 2006, NSF convened a formal Conceptual Design Review (CDR) to assess OOI scientific goals and merit, the proposed facility’s technical feasibility and budget, the project’s management plan, including schedules and milestones, and education and outreach plans. In its report (12), the 20-member panel affirmed that the OOI as proposed would transform oceanographic research in the coming decades, and that the CND provided a good starting point for developing the OOI network. The history of the OOI is complex, but reflects the need for interdisciplinary research for addressing broad problems and changes in funding aligned more with these needs than concentrating on individual studies.

2.5 Evolution Since the Conceptual Network Design

Preparation of the Preliminary Network Design was carried out under the Cooperative Agreement 0418967 between the National Science Foundation and the Consortium for Ocean Leadership, a not-for-profit membership consortium of over 40 ocean science and education institutions formed by the merger of JOI and CORE in 2007. Since the Conceptual Design Review in August 2006, the OOI project office at the JOI Division, Consortium for Ocean Leadership has been addressing top recommendations and facilitating work on technical and cost design details to refine the CND into the Preliminary Network Design, which is presented in Sections 4-8 of this document. As described in the CND, the OOI infrastructure will comprise coastal, regional, and global scale marine infrastructure, a cyberinfrastructure, and infrastructure to enable education and outreach. The Preliminary Design Review will occur in December 2007.

The major partners in the OOI construction process, called Implementing Organizations (IO), were selected in 2007 by a competitive acquisition process similar to that used in large federal acquisitions. Subwards are in place to University of Washington for design studies to develop the Regional Scale Nodes (from March 2007), University of California San Diego (UCSD) as the IO for the Cyberinfrastructure (from May 2007), and the Woods Hole Oceanographic Institution with two consortium partners, Scripps Institution of Oceanography and Oregon State University, as the IO for the Coastal and Global Scale Nodes (from August 2007).

In early 2007, the OOI project office, in consultations with its advisory structure, further refined the CND in light of guidance from NSF to use annual cost escalation factors to plan within a target budget, resulting in a revised CND (13) in March 2007. The project office posted the revised CND for community comment (14), and also received comments from NSF’s Ocean Sciences Division (15). At its June 2007 meeting, the
program’s interim Observatory Steering Committee considered the comments together with views of ad hoc community “tiger teams” organized by the project office. The Committee issued guiding principles and specific recommendations (16) to be used by the project office and IO’s as they continued design refinements. For the Regional Scale Nodes (RSN), design refinements were also informed by a series of technical studies or “white papers” carried out under the RSN subaward. For the Coastal and Global Scale Nodes (CGSN), the IO was not selected until after the Committee’s recommendations, so an ad hoc team including domain experts from within the CGSN IO and community representatives was formed to consider comments and make recommendations (17) to the project office. A Blue Ribbon Panel of scientists assembled by NSF provided a non-advocate review of the OOI’s scientific objective and network design in October 2007, endorsing the OOI as a worthy investment. The Panel's recommendations (18) also informed finalization of the PND presented here.

As discussed in NSF’s Large Facilities Manual (19), budget estimation at the preliminary design stage should be more advanced than at the conceptual design stage. In the case of the OOI, the cost estimates accompanying this PND are done from the “bottom up” by costing over 600 individual work packages in the Work Breakdown Structure. Each package defines a discrete amount of work, with costs broken down into categories of labor, materials, equipment, subcontracts, and travel. Each cost is derived from a “basis of estimate” (vendor quote, engineering estimate, or engineering judgment) and assigns a corresponding degree of risk that is used to calculate a risk-based contingency. Risk considerations include cost of 1) labor and 2) materials, technical aspects of 3) design and 4) manufacturing, and 5) schedule. Further information is contained in the OOI Cost Estimation Plan (20). As discussed in the OOI Project Execution Plan (21), contingency will be managed by the project office to be able to respond to fluctuations and changes during project execution.

Unlike the CND, which was largely developed by the advisory structure, the PND was largely developed by the IO’s coordinated by the project office. PND development was guided by recommendations and principles established by the advisory structure and the NSF, respectful of long-standing program concepts, responsive to the OOI Science User Requirements (22) and OOI System Requirements (23), and constrained by the contractual responsibility of performing to the cost, schedule, and scope baselines. NSF’s current, authorized capital investment for the OOI is $331M, with an anticipated $50M per year in 2013 dollars available as a continuing budget for steady-state operations and maintenance of the network. These budget realities place restrictions on the scope of the facility that will be realized when compared with the more comprehensive, initial concepts.

In light of the affordability consideration on envisioned project scope, recent guidance from NSF has asked the project office to consider the OOI PND in terms of a baseline design with up-scope options. This document presents the OOI design in this way. Some infrastructure elements in the CND have moved into the up-scope category. Up-
scope actions are envisioned to be funded via allocating unused project contingency, cost savings, or partnerships with other funding entities. The interim Observatory Steering Committee has developed criteria for prioritizing up-scope options, and up-scope decisions will be made in a larger framework involving external scientific oversight organized by the NSF and significant community input. Up-scope options for the marine infrastructure are explicitly stated in Sections 6 and 7.

2.6 Summary

The long-term introduction of the power and bandwidth to support observations at remote parts of the ocean will provide the ocean science community with unprecedented access to detailed data on multiple spatial scales, studying the coastal, regional, and global-scale ocean. The scales of the OOI network will be bound together by an interactive CI backbone that will link the infrastructure elements, sensors, and models into a coherent system of systems. The OOI CI will allow access to other (i.e., non-OOI) data streams and modeling results, to provide users with a coherent four-dimensional view of the ocean.

The use of large numbers of interconnected, space- and time-indexed, remote, interactive, fixed, and mobile assets by a global user community, collaborating through the Internet and Internet-enabled software, represents the most fundamental shift in oceanic investigative infrastructure since the arrival of satellites. It will induce major changes in funding strategies, our community structure, the nature of our collaborations, the style of modeling and data assimilation, the approach of educators to environmental sciences, the manner in which the scientific community relates to the public, and the recruitment of young scientists. The discoveries, insights, and the proven new technologies of the OOI effort will continuously transfer to more operationally oriented, ocean-sensing systems operated by other agencies and countries.

3 OOI User and System Requirements

3.1 Introduction

OOI is an integrated system collecting data on the ocean environment at multiple scales and distributing that data in real time. In addition to inheriting requirements of the entire system, each of the set of instruments (connected at nodes to the system) has its own unique requirements. The CI incorporates the requirements that address the integration of the nodes, and much of the transformative nature of the project. Bracketed numbers throughout Section 3 refer to identifiers from the OOI System Requirements document.
3.1.1 System Requirements

As an overall system, the OOI System Requirements lay out the overall goals to "provide an interactive, globally distributed and integrated observatory network to enable next-generation studies of the complex, interlinked physical, chemical, biological, and geological processes operating throughout the global ocean ... [observing] phenomena at the spatial and temporal scales appropriate to the processes and systems being studied ... [via] observatories operating at regional, coastal, and global scales." [S-S-1 through S-S-3]

These and other system-level requirements from the OOI System Requirements are applied to all the OOI nodes. The major system-level requirement categories include system approach, (deployed) environment, cost-effectiveness, open design, support services, instruments, and interoperability, expandability, maintainability, and reliability.

3.1.2 Node Requirements

Each of the instruments has a set of functional requirements for that node. These can be broadly categorized as power network, communication network, time distribution, science instrument interfaces, instrument packages, observatory control, data quality control, and data calibration.

Structural (i.e., non-functional) requirements for the nodes are categorized in the OOI System Requirements into security, operations, reliability, and environment. These typically cut across some or all of the functional requirements categories above.

The transformative features for ocean science from the last section (Persistence, Geographic Range, Mobility/Portability, Control/Adaptability, System Interoperability, Intercommunication, Power/Bandwidth, Sensor Capability, and Community) are laid against these lists, as are the specific requirements laid out in the Science Requirements Matrix at the end of the OOI Science Prospectus. The OOI System Requirements captures the resulting specific requirements in each of the observatory functional requirements categories.

In addition, the requirements for the cyberinfrastructure described later in this section must also be considered within the observatory functional requirement categories described above. For example, CI requirements for networked interactivity with deployed sensors have a significant presence in the requirements for the science instrument interfaces and the communication network of the deployed instruments.

3.2 Requirements Development and Constraints

The requirements originate from the OOI Science User Requirements and the OOI System Requirements. The OOI System Requirements presents more detailed
requirements than the *OOI Science User Requirements*, and contains the science requirements for the system.

The process for discovering and tracing those requirements has been described and demonstrated in the *OOI Science User Requirements, OOI Science Prospectus* (23), and elsewhere. The science drivers are captured in the *OOI Science Prospectus* through a series of science questions that are traced down to a particular location and a list of sensors necessary to answer the science questions. Requirements will be refined and carried through to the subsystems in subsequent requirements development meetings with scientists, other users, and the implementing organizations.

All the requirements, starting with the science user requirements at the top level, will be maintained in a Dynamic Object Oriented Requirements System (DOORS) database. OOI follows a standard systems-engineering approach for setting requirements at successive levels of detail, maintaining traceable relationships between them, and testing them appropriately. The relationships between science requirements, system requirements (at all levels), and conformance tests will be maintained using DOORS.

We note that OOI is being developed under a constrained budget, and that funders and developers do not anticipate delivering a complete system that meets all of the requirements originally envisioned. Given this reality, the development process includes regular evaluations of the implementation plans against the current cost framework. The requirements are then adjusted as needed per the direction of the OOI project office. Such changes will be entered into the DOORS system, which will maintain configuration control and traceability of all changes.

### 3.3 System-Level Requirements

The system science requirements previously quoted present the primary intent of the OOI. The requirements in the following sub-categories detail some of the more detailed specifications and constraints on achieving that overall goal.

#### 3.3.1 Support Services

Support service requirements focus on the interactions of potential observatory participants, particularly those building instruments. Required services interface simulators, testbeds, and instrument calibration. This section also emphasizes the integration of the OOI components.

Maximize integration of support services between Implementing Organizations as perceived by the end-user scientist/instrument owner. [S-SS-1]

Provide standard, simulated test interfaces and testbeds for instruments users/designers. [S-SS-2]
3.3.2 System Approach, Cost-Effectiveness, and Open Design

The system approach and cost-effectiveness requirements emphasize minimizing the overall cost of the observatory, while maximizing reuse and collaboration. The overall cost is analyzed in terms of the complete life cycle of the observatory, including all operational costs during that time. Re-use opportunities include technologies developed for and applied to the Monterey Accelerated Research System (MARS), installed in 2007 in California’s Monterey Bay.

Design, installation, implementation, operating, and maintenance costs are to be considered for the purpose of minimizing life-cycle cost. [S-CE-4]

Maximize collaboration and cooperation between all Implementing Organizations via the Systems Engineering function. [S-SA-1]

Maximize use of common components between observatory elements. [S-CE-3]

Maximize reuse of electrical subsystem design tested by the existing MARS ocean observation networks. [S-CE-2]

The open design requirements strongly emphasize the open nature of the OOI. Not only will science data from the OOI be openly available, but all of the work performed in building the OOI will be made available for public reuse. This approach is intended to maximize the impact of the OOI development, by making its concepts more visible and reusable, and also by making other environmental science projects economically feasible, since they won't have to redevelop the components. Furthermore, the direct benefit to projects adopting this technology will be matched by the interoperability across all the compatible projects.

3.3.3 Interoperability, Expandability, Maintainability, and Reliability

OOI is expected to last at least 25 years, and so extensive effort must be allocated to maximize its durability and value during that time. Interoperability, compatibility, and cooperation with other existing systems is emphasized. Expansion is expected at every level: instruments, connected segments, platforms, science nodes, data, and participants.

Establish data and communications compatibility with NEPTUNE Canada (IOOS) (EarthScope). [S-I-4 (S-I-5)(S-I-6)]

The system shall accommodate installation of additional science nodes. [S-E-4]
Cost-effective system reliability and maintainability are critical to ensuring a long operational lifetime for the system. Individual observatories (see below) carry these concepts further with additional diagnostic and reporting requirements.

The system shall be single fault tolerant. [S-R-6]

To the extent practical, provide sufficient fault isolation to ensure that failures can be isolated to individual instruments nodes/elements/branches of the network. [S-R-3]

At a system level the OOI shall deliver data at rated capacity 80% of the time. [S-R-1]

3.3.4 Instruments and (Deployed) Environment

The deployment of reliable science instruments into the contemplated environments is a significant engineering challenge. Many different environmental threats – physical, electrical, biological, and constructed – can directly impact data collection or system operation. The selected IOs must apply their considered experience in marine deployments, and extensively instrument the systems that are deployed to facilitate monitoring and repair. Note that even correctly operating instruments can impact data collection of other instruments, so a sophisticated awareness of potential interactions must be applied.

Remain operational during storms and extreme events
  Survive Category # storms, Sea State #
  Operate [in] Category # storms, Sea State #. [S-EN-1]

Instruments located in high bio-fouling areas should be designed to maximize time between maintenance/cleaning. [S-IN-1]

Maximum local currents shall be specified upon site selection and surveying. [S-IN-2]

Minimize interference between instruments. [S-EN-9]

All OOI observatories shall include engineering sensors as required to collect data concerning observatory state- of-health. [S-EN-5]

3.4 Node-Level Requirements

This section provides a very brief summary of requirements unique to each node, in this case focusing more on structural requirements associated with the node’s environment. The functional demands on each node are presented in detail in the OOI Science User
Requirements, the OOI Science Prospectus, and in the specific requirements for each node in the OOI System Requirements.

Note that each node plays a role in most science themes, because the OOI has been designed for integration, synthesis, and interoperation. In addition to their digital integration, many of the observatory platforms are physically collocated or intermingled, and many measurement devices are deployed across multiple platform types. Nonetheless, each node also focuses in some specific areas, and provides capabilities and science that is not possible elsewhere.

3.4.1 Regional Scale Nodes

The science themes particularly associated with the RSN involve both benthic (ocean floor) and water column measurements. Deep earth structure, plate deformation, tectonic processes, hydrothermal vents and volcanoes, and material exchange across the benthic boundary are uniquely measurable by sensors situated on the ocean floor for extended periods. Likewise, biological processes associated with the sea floor must be monitored remotely, in situ, and biological sensors enabled by the RSN will be uniquely situated to monitor these activities for extended periods. Water column measurements made from fixed platforms and in profiler mode will enable interdisciplinary observations of open-ocean processes in a region strongly forced by air-sea interaction, shelf-slope interactions with the deep sea, and coupled atmospheric/oceanic phenomena that produce variations in North Pacific circulation. These measurements, enabled by high power levels for frequent profiling, and near-real time connectivity for adaptive sampling, will begin to characterize a large volume of ocean in three dimensions.

The RSN requirements reflect the observatory’s emphases: connectivity (of power and communications) and persistence, and the typical installation depths for most instruments. The requirements call for a system capable of expansion, anticipating regular upgrades to instrumentation and occasional upgrades to core systems. Power and communication system requirements reflect a high level of sustained power delivery (up to many tens of kW) and a very high level of bandwidth (10-40 Gb/s) in a physically challenging environment; the need for remote observatory control and diagnosis is explicitly addressed. As on any shore communications network, explicit latency and bandwidth metrics are specified, and likewise for power levels available at each node. Special considerations are required for instrument interfaces (for communication protocols and power configurations, as well as underwater mating requirements) and physical security of the system (e.g., from trawler damage).

Extensive analysis has been performed on site location and network configuration for the RSN, and this analysis is reflected through conclusions of corresponding white papers, as described in Section 7 below. These configuration decisions are not
specified as requirements, and may evolve further according to reflect funding and other considerations.

3.4.2 Coastal Scale Nodes

The CSN emphasizes oceanographic themes like ocean-atmosphere exchange, climate variability, ocean circulation and mixing, with a special emphasis on coastal ocean dynamics. CSN are in some cases connected to the RSN, but their high-level requirements are essentially the same as for GSN, and the two sets of requirements are combined in the *OOI System Requirements*.

Unique CGSN requirements reflect the combination of assets that make up these nodes. Assets are usually not cabled to shore (or each other), and typically have self-contained power sources. Any given node may consist of platforms that are currently communicating wirelessly, may communicate regularly at various rates, or are connected only intermittently (e.g., when they dock). These circumstances require allowing for highly irregular communication protocols, even while common cyberinfrastructure goals of data access and control are supported as fully as possible.

The CGSN shall include a combination of fixed, moored and mobile observing platforms and infrastructure, in-situ and cabled power supplies; a communications network providing high bandwidth communications from surface expressions and in the water acoustic and cabled communications to underwater instrumentation; functional control of accessible infrastructure components; and some level of control over instruments in the observatory network. [CGSN-G-2]

The CGSN requirements emphasize optimizing the operations and maintenance of the system, in this case due to the number of platforms and components deployed in unstable and biologically challenging environments (e.g., the ocean surface). The potential interference of the installed technologies (e.g., power generation systems) with observations (e.g., atmospheric measurements) is also a key consideration in CSN requirements.

3.4.3 Global Scale Nodes

GSN themes closely track CSN themes, but add key characteristics: physical distribution into the open ocean, availability of baseline measurements untainted by direct coastal influences, and the particular science topics associated with specific node locations. The configuration of platform instrumentation will be tailored according to the particular science being performed at each site; these detailed requirements will be captured at the subsystem requirements level.

The GSN provide unique and essential value to the OOI, but also presents analogous development challenges. In particular, the maintenance and operation of platforms in
the Global Scale Nodes will be more challenging due to their remoteness, achieving the reliability and communication goals laid out in the OOI System Requirements will require additional consideration. However, the intent is to identify common technical solutions across the entire coastal and global network, as has been described elsewhere.

3.5 Cyberinfrastructure: Functional Requirements

This document focuses on the functional requirements for the OOI CI, as those are the areas of greatest challenge and scientific interest. The other (non-functional) cyberinfrastructure project requirements – for project management, system engineering, hardware development, implementation, and operations and maintenance – are specified in Section 2.2 of the OOI System Requirements, and apply to all the functional requirement areas discussed below. Many system engineering requirements are addressed by the quality assurance aspect of the Work Breakdown Structure (WBS), which includes system test, integration, and validation.

The major functional requirement areas for the OOI CI are Sensing and Acquisition, Analysis and Synthesis, Data Management, Common Operating Infrastructure, Common Execution Infrastructure, and Planning and Prosecution.

The Common Operating Infrastructure and Common Execution Infrastructure embody many of the core capabilities of the system. The Common Operating Infrastructure addresses most of the requirements in the OOI System Requirements categories relating to communications, mediation, governance, identity, policy, and most resource management categories. The Common Execution Infrastructure is concerned with most of the requirements from the Resource Management-Process and Resource Collaboration Management categories, and will also leverage the work related to the other Resource Management requirements. While these are at best rough guides, they can be used to understand the requirements and the WBS work areas; of course, the DOORS database described earlier will precisely track the relationship between individual requirements and the WBS work areas.

The following subsections illuminate key requirements of the CI, and their relationship to the science questions and motivations described in the previous section. The requirements outlined in these subsections reflect only a small part of the total, and serve to highlight requirements intended to create transformative results. For more complete requirements, the reader may refer to the OOI System Requirements Document, and the detailed requirements in the CI Source Requirements. As noted elsewhere, the CI-related requirements will continue to be refined through meetings with the science community and other stakeholders in the OOI.

3.5.1 Sensing and Acquisition
OOI and its cyberinfrastructure are designed to consistently acquire and communicate data from the most challenging environments, for example the deep-sea nodes necessary to measure the Earth's lithospheric movements and interactions. Data will be made readily available to scientific programs and other users. This approach also allows using the data for rapid response predictions in case of extreme geologic events.

The CI shall be available on a 24/7/365 basis with no more than 20% downtime. [CI-PI-7]

The CI shall provide near-real time (i.e., minimum delay) communication capability. [CI-OC-1]

Public access for data from all core sensors shall be available: all information is open by default. [CI-PI-10]

Multiple actors shall be able to access the same resource simultaneously according to their privileges. [CI-IRU-14]

In the epipelagic (near-surface) regions of the ocean, equipment must be replaced frequently to avoid fouling by marine organisms. At the scale of OOI operations, these maintenance operations can be greatly facilitated by the conceptually simple approach of recognizing and putting it into service as soon as it is plugged in to an observatory. This also minimizes the observing down time of systems, and increases the reliability of observatory operations.

The CI shall automatically detect and manage the attachment/detachment of physical resources. [CI-IRU-13]

An instrument shall be placed in service by simply plugging it in. [S-I-12]

In many sensing applications, especially in remote environments and underwater installations, it is not always possible to maintain high quality networked connections from/to shore-based access and control rooms. In the most extreme case, mobile assets such as autonomous underwater vehicles (AUVs) can spend hours or to months away from reliable communication connections. To support the diverse science goals of the project, in particular on-demand observation controls needed to investigate intermittent events like tectonic activity, the cyberinfrastructure must be capable of gracefully managing a challenging communication environment. Indeed, it must be aware of communication issues, and incorporate adaptive mechanisms to achieve effective science interactions and optimal data acquisition.

The CI shall facilitate communication in the presence of high/low available bandwidth, low/high channel latency and periodic/on-demand connection. [CI-OC-8]
3.5.2 Analysis and Synthesis

There is a wide range of scientific applications utilizing observed data. From real-time event detection, to post-processing and analysis, to integration with running models, a huge number of applications will simultaneously expect data – sometimes the same data – in wildly diverse protocols, formats, and even vocabularies. The CI must mediate these needs, providing a selection of the most common and useful frameworks for disseminating data. It must also be capable of integrating these varied data sources for access via a single pathway.

The CI shall provide a [varied] communication capability. [CI-OC-2 through CI-OC5]

The CI shall provide for simultaneous interaction with resource groups. [CI-IRU-9]

The CI shall facilitate the integration of multiple data streams or data sets into a single stream or set, including elimination of redundant entries. [CI-U-36]

Data shall be provided in a TBD standard format. [S-I-11]

As studies become interdisciplinary and global in nature, for example to study global carbon exchange processes, the OOI will have to be capable of interoperating with other systems and users that use different vocabularies and concepts. A basic knowledge representation infrastructure must enable smooth interactions between these different semantic frameworks.

The CI shall facilitate mapping between senders and receivers with different vocabularies. [CI-OM-1]

Resource discovery shall operate in the presence of mixed vocabularies. [CI-IRD-2]

3.5.3 Data Management

All scientific studies depend on ready access to data that are as complete, correct, and well-characterized as possible, without regard to the particular source of the data. This is especially true when the studies cut across observation domains or scientific disciplines, as the researchers may not be as familiar with the context in which the data were collected or the terminology used by the collectors. OOI science topics like air-sea mixing and global carbon cycles exemplify the multi-disciplinary nature of OOI research. At the same time, data originators often require time to review the quality and validity of
their data. These potentially conflicting needs for privacy and visibility are resolved in OOI by comprehensively consider the requirements in their design.

All data produced on an OOI node shall be archivable. [CI-IRE-1]

The CI shall provide services to publish (subscribe to) data from non-ORION sources. [CI-IRP-5 (CI-IRP-7)]

OOI resource rights and allocation policies shall be established and enforced. [CI-OP-5]

The CI shall provide services for automatic initial data QA/QC. [CI-IRE-11]

All resources connected to an OOI observatory shall be discoverable by the CI either directly, by content or through their associated metadata. [CI-IRD-1]

Access privileges for resources and their associated metadata may be different. [CI-OS-6]

In typical data systems, reprocessing of a data set to improve its validity or usefulness often undercuts the reproducibility that is the goal of any strong science study. To a degree never before available in scientific data systems, OOI provides sophisticated mechanisms to ensure reproducibility of analyses and identification of provenance for all data produced and managed by the system.

Data-product generating resources shall provide a statement of provenance/lineage that associates the input, resultant, and generating resources. [CI-IRC-8]

Data-modifying resources shall maintain OOI standard metadata. [CI-IRC-9]

OOI standard metadata shall be bound to all resources from inception to destruction. [CI-IRC-5]

The CI shall facilitate third party metadata enrichment throughout the life cycle of a resource. [CI-IRC-10]

The CI shall provide notification of resource state change [CI-IRP-3]

OOI data archives shall subscribe to evolving data versions. [CI-IRE-7]

3.5.4 Common Operating Infrastructure
Just as the OOI provides “glue” for scientists to interactively perform ocean science and global environmental science, the Common Operating Infrastructure also provides “glue” within the OOI system, interconnecting cyberinfrastructure components and connecting the OOI participants to each other and to the OOI resources. At the macro level, the OOI CI provides most of the interfaces that connect the OOI to other observatories and systems, within and external to oceanography. It also provides interfaces for users to access the capabilities of the system, whether those users are OOI participants or members of other organizations.

The CI shall be interoperable with cooperating systems inside and outside the marine community...especially IOOS and NEPTUNE Canada. [CI-PI-6]

The CI shall enforce OOI resource security and access policies independent of membership in the OOI. [CI-OS-7]

The CI shall provide secure communication protocols. [CI-OC-7]

The CI shall support identity federation. [CI-II-3]

At a more detailed level, the Common Operating Infrastructure is directly responsible for the complete range of interoperation of OOI components. These interactions must be reliable, secure, private, and nuanced. More important, the structure for the interfaces for all these interactions should be clear and consistent to make development of OOI components (including science-related applications) as straightforward as possible.

All resources (and observatory actors) connected to an OOI observatory shall be...authenticated. [CI-OS-2 (CI-OS-3)]

The CI shall verify and validate the identity of all resources (and observatory actors) connected to any OOI observatory. [CI-II-1 (CI-II-2)]

Transport and message level security, authorization and authentication shall be provided. [CI-OS-8]

Different levels of access to resources shall be provided for actors with different levels of authorization. [CI-OS-5]

Additionally, the Common Operating Infrastructure provides the basis for advanced interaction capabilities among participants and components of OOI. While these advanced interactions are commonplace in the broader social and collaborative Internet community, they have not been integrated into the scientific process or, for the most part, the science community. OOI will provide a leading capability in social networks for environmental science collaborations.
Correlation of observations between observatory nodes shall be facilitated by a common cyberinfrastructure. [S-S-4]

The CI shall facilitate interaction with distributed resources from any compatible networked location. [CI-IRU-7]

The CI shall provide services to group resources. [CI-IRU-8]

The CI shall provide for simultaneous interaction with resource groups. [CI-IRU-9]

3.5.5 Common Execution Infrastructure

Much of the in-depth analysis of OOI results will come through extended, distributed offline processing, either by post-processing OOI data or assimilating it into extended runs of models and simulations. Most global analyses involving ocean science, including climate change and carbon transport, depend on the ability to perform such extensive computations and analyses on data. The OOI CI must provide a comprehensive, integrated system to (a) utilize OOI resources, particularly its observational data but also including computing resources, (b) integrate OOI results with existing applications and resources, and (c) register the results of those analyses with the OOI system, for other OOI users to leverage.

The CI shall support delayed mode QA/QC by resource providers. [CI-IRE-12]

The CI shall provide event triggered data services. [CI-U-34]

The CI shall provide tools to compose (configure, compile, verify, save, and execute) processes.

The CI shall identify resources (local, distributed, or external) as needed to perform collaborative tasks. [CI-IS-1]

The CI shall trace resource utilization to the initiating actor. [CI-IP-2]

3.5.6 Planning and Prosecution

As the OOI and CI development progresses, opportunities for integrated observing programs with real-time and automated control will increase. Such sophisticated capabilities are required to construct experiments that can change sampling programs in seconds, based on unpredictable events like plate movements or major physical transport episodes. The requirements for the core system design build upon each other to allow completely integrated responses to be performed, not just by humans acting on shore, but also by agents operating autonomously in any node of the system.
The CI shall provide the capability for resources to act on behalf of other resources in an auditable manner. [CI-IRU-3]

Utilization of a resource shall be governed by the rights and allocations of the initiating actor. [CI-IP-3]

A policy-based decision support system for resource management shall be devised. [CI-OP-3]

3.6 Summary

The requirements described above, traceable to specific scientific objectives and transformational opportunities, illustrate the scope and transformative potential of the OOI CI. Core scientific activities dictate corresponding functional requirements, but achieved across the entire infrastructure for cost and interoperability reasons. More advanced activities are associated with more sophisticated cyberinfrastructure requirements, whose implementation will have far-reaching impact on scientific opportunities.

4 Overview of the Preliminary Network Design

The OOI is a broadly distributed network of physical infrastructure and virtual capabilities enabled by a dedicated cyberinfrastructure. Figure 2 depicts the various components of the physical infrastructure with the cyberinfrastructure capabilities in a simplified integrated view. Starting with the physical depiction of the OOI, the CGSN and the RSN transmit data gathered in the marine environment and receive command and control information via Marine Cyberinfrastructure Points-of-Presence (CyberPoP). As a physical manifestation of the CI, a CyberPoP embodies capabilities for instrument access, data modeling, distribution and persistence via flexible data grids, observation planning and control, flexible computational grid processing – together with capabilities for managing cross-cutting concerns, such as policy definition and enforcement, governance, failure management, federated identity management, security, authentication, and authorization. CyberPoPs can be thought of as the locale for the physical server nodes that implement these capabilities. The capabilities of the CI are offered via service/data interfaces (analogous to Application Programming Interfaces; APIs) to all nodes that are to be connected to the CI.

The marine components transmit data by various modes. The RSN communicate through dedicated cable to two West Coast shore stations linked into a single CyberPOP in Portland, Oregon. The Pioneer Array, part of the CSN, communicates with a CyberPoP on the East Coast by satellite and wireless links. Two separate moorings comprise one node of the costal-scale Endurance Array that connects through the RSN cable; a third mooring (node) is wireless. GSN in the open ocean are
connected via commercial communications carriers which will most likely communicate with CyberPoPs on the East Coast or near San Diego, California.

Figure 2: OOI Simplified Integrated View

The OOI user base (e.g., researchers, free-choice learners, formal education communities) will access the system through OOI-specific portals and other utilities, some developed by the OOI project and others that develop externally.

The OOI Network diagram (Figure 3) shows the top level for each of the marine observing nodes. These relationships are broken down more specifically in the functional block diagrams contained in Appendices 2-14.
Figure 3: OOI Network Diagram
5 Cyberinfrastructure Preliminary Design

The OOI facility will provide the first comprehensive demonstration of a new approach to ocean science. A completely operational research observatory system will be designed to include sophisticated sensor, networking, data transmission, and cyberinfrastructure solutions to maximize the science capabilities of the system. The role of the OOI CI is provision of a common infrastructure connecting, coordinating, and supporting the operations of the two marine observatory systems (GCSN, RSN) covering three spatial scales. The OOI CI must address the issues of data management and distribution, observatory resource management, mission command and control, and the need for meaningful collaboration of OOI participants across a wide range of disciplines. This connected system will let scientists observe and respond to changing conditions in the ocean and their observing systems.

The major components of the OOI system are depicted at a high level in Figure 2. The two groups of observatory nodes shown each have assets deployed in the water as well as ground-based listening and processing stations. Although only two instances of observatories are shown, in practice there will be further physical observatories. In particular, several sites will likely host coastal-global observatories, operating them independently but with the ability to collaborate with the other OOI and non-OOI observatories.

Organized associations of people are connected to the OOI communications network and resources. These associations are of two types: collaborations between individuals working toward a common goal and collections of capabilities that are used on the OOI system. Collaborations will create OOI Laboratories and Classrooms where groups of people work together within a standard on-line framework. Many existing on-line environments outside of ocean sciences now provide similar services; OOI will apply the same concepts to a scientific and educational collaborative environment. The OOI system will provide and rely on many cyberinfrastructure services. Services are obviously needed to link with data storage and computing resources (e.g., for web hosting, data distribution, or running compute-intensive applications).

5.1 Cyberinfrastructure Design – The Logical Architecture
The OOI CI design consists of two infrastructure elements and five services networks:

- **Common Operating Infrastructure (COI) Services Network** provides the technologies and services to play the role of an integration platform, communication conduit, and orchestration, for crosscutting issues including identity, policy, and governance.
- **Common Execution Infrastructure (CEI) Services Network** provides configuration management and demand-driven provisioning of capability at selected locations (CyberPoPs and other computing resources) within the CI network. The CEI is elastic, having the ability to expand and contract the configuration of computing resources as the need rises and falls.
- **Data Services Network** provides an automated data distribution and preservation network with pervasive and universal access subject to OOI Data Policy.
- **Control Services Network** provides the services required to establish the standard models for the management of stateful and taskable resources.
- **Modeling Services Network** provides a coherent framework for modeling, analysis, and consumption of data.
- **Processing Services Network** provides access and scheduling of computations/execution.
- **Instrument Services Network** provides interactive and coordinated access to instrument platforms and instruments.
OOI will not host all of these services directly; some may be contracted out to other organizations, according to a defined set of interface standards and agreements. The ability to precisely specify the operating characteristics and interfaces is another capability provided by the OOI CyberInfrastructure. Further information is contained in the OOI CI architecture document.

5.2 Cyberinfrastructure Deployment – The Physical Network Layout

The components of the OOI CI will be deployed throughout the OOI system and beyond. From a hardware point of view, the CyberInfrastructure Point-of-Presence (CyberPOP) can be deployed throughout the OOI. Four classes of CyberPoP will be provided; the on-demand highly scalable (i.e., elastic) CI CyberPoP that will be used by the Modeling and Processing Services Networks; the high-availability, shore side, Observatory CyberPoP that will be used by the Data and Control Services Networks; the ocean deployable Marine CyberPoP which will be used by the Instrument Services Network; and the high bandwidth stream processor (HBSP) CyberPoP dedicated to the RSN to take advantage of the high bandwidth sensor connectivity.

Figure 5: Physical Network Layout

Figure 5 provides a physical view ranging from the sensors and actuators on deployed instruments and platforms, to the distributed associations and facilities across the country; this view allows a comprehensive discussion of the system layouts, interactions, and responsibilities. Each of the represented components and their
interactions is summarized briefly here. More details are presented in the architecture documents.

Components of the OOI CI may be deployed on oceanographic platforms, including moorings, benthic instrument platforms, and mobile platforms like ships and AUVs. A collection of CI components can be deployed together as a node, enabling a broad range of capabilities on that platform. A component or a node may correspond to a physical entity like a platform or instrument, in which case the cyberinfrastructure entity is a computer representation of the actual physical entity. On the other hand, some OOI resources, like software applications, do not have any corresponding physical presence.

Each CI node deployed on an OOI platform may include a combination of instruments (with sensors and actuators) and OOI resources known as services. Services are software entity resources that provide capabilities such as data storage, data transformation and communications. The number and type of services deployed on each platform will vary according to the platform’s needs and capabilities, but will always include the fundamental communication infrastructure needed to interoperate with other OOI components.

Communication between the CI nodes and the shore station may be via satellite, radio signals, benthic seafloor-to-ocean-surface cables, or other regular or intermittent connection. AUVs and gliders, for example, may have no communication for extended periods, followed by bursts of rapid communication when docked or surfaced. The CI will provide services that facilitate interaction under a wide range of communication models.

The shore station represents a bridging location on land between the ocean-deployed CI components and the land-based components. It provides a networking capability, but is not expected to contain the observatory presence or other facilities provided in the OOI CI concept.

The observatory aggregates data and communications from the data sources, and presents it to users and other observatory components. Nominally, there is an observatory resource for each physical observatory in OOI, but as noted above, other Observatories can be created to fulfill analogous needs of OOI users. There are several functions that demand special attention in an observatory. The ability to monitor science and operational parameters enables maintenance and control of observatory assets. Access to observatory cyber-infrastructure nodes for both monitoring and control is needed. Observatory resources like power and bandwidth must be allocated, and physical components must be managed. Although these functions might be useful in any OOI environment, they will receive particular visibility in the OOI observatories.
A component such as an OOI Laboratory or Facility will emphasize other resources from the OOI collection according to their own particular needs. Laboratories may value collaborative resources and tools, while Facilities may consider auditing capabilities very important. In each case, there is a collection of common OOI services by which the desired resources can be aggregated and, if necessary, enhanced.

A typical deployment operation will leverage three architectural features: the capabilities of a plug-and-work instrument that presents a standardized description of itself to the OOI system, easily used deployment logging and metadata definition interfaces to capture deployment results as effortlessly and accurately as possible, and the CI’s ability to associate this information with the appropriate resource.

Once initially captured, instrument metadata descriptions can also be used to characterize the data that flows through the system to the end users. As those data are used and analyzed, and their metadata examined, the end users can likewise create their own associations by commenting on and correlating the data that are presented to them.

5.3 Highlights of Cyberinfrastructure Design

One of the key elements of the CI design is to respond to the requirements in the OOI Science User Requirements document and the OOI System Requirements Document related to interoperability, expandability, maintainability, and reliability. The design of the infrastructure elements and the resource networks facilitate the responsiveness of the CI system to these ‘ilities’. Another key element is the policy to adopt and use open standards, open interfaces, open protocols, with the additional provision that all software developed under OOI CI will be open source.

The Common Operating Infrastructure (COI) Services Network project brings together the agile integration model of Service Oriented Architecture (SOA) with maturing distributed Grid security to provide a secure and scalable federated operating infrastructure. At its core, it will configure and utilize the Enterprise Service Bus (ESB) suite of technologies, comprising of scalable, reliable, and secure messaging technology for data streams, a service and data presentation and subscription mechanism, a routing and filtering framework for flexible plug-in of governance and policy management components, dependency injection, and a service framework. The flexibility of this ESB-based approach allows the development team to rapidly integrate new capabilities as they become available.

The core software abstractions for the COI is the notion of a CI Capability Container; it factors out the common aspects of communication, state management, execution, governance, and service presentation to provide a very scalable, secure, and extensible model for managing user-defined collections of information and taskable resources. The CyberPoPs mentioned above are the physical deployment locations for
CI Capability Containers.

The Common Execution Environment Services Network project lays the foundation for scalable, immediate mode, reconfigurable, elastic computing with a process integration strategy that will allow OOI to adapt to its participants manner of processing data anywhere in the network.

As an example of resource services network interoperability, expandability, maintainability, and reliability characteristics, we will look at the Data Services Network. The Data Services Network will be able to provision, manage, and present data and metadata supporting the OOI domain, data models, data repositories, collections, and streams. In addition the Data Services Network will provide policy-governed data access, provide user-defined data presentation, negotiate and manage federations of data repositories, collections, and streams. For long-term data maintenance the Data Services Network will negotiate and manage delegation of data preservation and presentation responsibilities, as well as maintain and ensure the integrity of data in perpetuity. The other resource services networks have the same characteristics and are described in more detail in the architecture documents.

The major functional requirement areas for the OOI CI are:

- Sensing and Acquisition
- Analysis and Synthesis
- Data Management
- Common Operating Infrastructure
- Common Execution Infrastructure
- Planning and Prosecution

The Common Operating Infrastructure and Common Execution Infrastructure along with the Data, Control, Modeling, Processing, and Instrument Services Networks provide the core elements for satisfying the OOI CI functional requirement areas.
Figure 6: Distributed Services
The OOI system will provide and rely on many cyberinfrastructure services. Services are obviously needed to link with data storage and computing resources (e.g., for web hosting, data distribution, or running compute-intensive applications). However, many other kinds of distributed services are important to OOI and its users, and some of these are shown in Figure 6.

This conceptual view is divided into three types of facilities. Starting from the bottom are the RSN and the CGSN. Both types of nodes are connected to their respective marine sensor networks through instrument proxies. The instrument proxies provide sensor data to the nodes and provide an interface for command-and-control messages to be sent from the facility to the instruments. Three sets of services are present in the nodes for management of resources, for local storage of data, and for QA/QC review of the instrument data. Each facility is connected through service and data interfaces to the OOI Internal Service Bus.

The OOI Integrated Observatory Facility is also connected to the OOI Internal Service Bus. The five Services Networks (Control, Data, Instrument, Processing, and Modeling) are under the purview of this facility. Access to the distributed federated data repositories, and the on demand computing resources are provided to the OOI through the Integrated Observatory Facility.

There is one other type of OOI association that is implied by this diagram, which reflects the flexibility and application of the OOI CI. The diagram shows a cyberinfrastructure network of components. Each component in the diagram is a collection of computerized information, or a resource, that can be accessed by other computers. Just as the diagram shows two facilities corresponding to OOI’s physical observatories, the OOI CI will allow the creation of facilities that do not correspond to any particular physical entity. In that sense, the Classrooms and Laboratories in the diagram can be virtual environments; there do not have to be corresponding physical classrooms, or laboratories in order to create such collaboration environments.

One obvious application for a virtual node is an “Observatory” representing all of OOI’s observatory systems. By making the OOI’s observed data, resources, instruments, and collaborations from all the OOI observatories accessible within a single virtual observatory, OOI can create a distributed, interoperable view of its diverse observing assets. Other virtual observatories may be oriented to address specific observing themes, geospatial domains, or campaigns. The OOI CI does not predefine these views; they may be constructed at will during OOI system operations. Each observatory may select the OOI resources that it makes accessible, so as to provide a coherent, focused environment for the observatory users.

5.4 Cyberinfrastructure Architecture Documentation
The CI IO decided early in the preliminary design development that a widely recognized, structured set of documents and procedures should be developed to capture the many facets of the CI preliminary design. After review the decision was made to follow the Department of Defense Architecture Framework (DoDAF). This decision was driven by the robustness with which this framework captures the many views of the design and the fact that it was developed by DOD to handle large distributed networked systems like OOI. This document summarizes the information in the high-level All View (AV-1), the high-level Operational View (OV-1) and the high level Systems and Services View (SV) documents. Figure 7 shows a set of DoDAF documents, which augment and expand the high level view summarized in this document.
The CI Architectural Documents (CIAD) develop the architecture and design of the CI component of the OOI system. They do not cover the other OOI components, namely the regional, coastal, and global observatories and their infrastructure components.

Figure 7: Architecture of Documents
As an enabling system and central integration infrastructure component, the CI will define interfaces to the three OOI components outside of the CI, as well as to other external systems.

Furthermore, the operational activities enabled by the CI and described as part of the Operational Views of the architecture span the entire OOI system, making it appear to its users and the environment as one integrated system. The CI provides a “face” to the OOI system.

**Views and Products Developed.** The DoDAF Version 1.5 was used to define the CIAD. The following DoDAF architectural views have been developed:
- AV-1: Overview and Summary Information
- AV-2: Integrated Dictionary
- OV-1: High-Level Operational Concept Graphic
- OV-2: Operational Node Connectivity Description
- OV-4: Organizational Relationships Chart
- OV-5: Operational Activity Model
- OV-7: Logical Data Model
- SV-1: Systems and Services Interface Descriptions

The CIAD provides a comprehensive and integrated architecture and design view on these and potential other individual system engineering artifacts by following the principles of the DoDAF methodology and its underlying Core Architecture Data Model (CADM).

**Architecture.** The architecture serves the goal of providing a consistent, structured, up-to-date representation of the OOI CI architecture and design, providing views for multiple groups of stakeholders. This includes operational views, as required by users and decision makers, as well as deployment and process views, required by CI implementers and subsystem architecture and design teams. The architecture also serves the goal of entraining potential participants in, and advocates for, the OOI CI and its connected observatories.

The architecture design was developed primarily from the viewpoint of its potential users, whether ocean scientists, instrument developers, data providers, subsystem designers, system operators, or data users and analysts.

The Operational Views capture the viewpoints of the potential users, while the System Views capture the subsystem designers and implementer viewpoints.

**5.5 Cyberinfrastructure Operational Overview**

The CI is broken down into five resource services networks that contain different classes of resources and the capabilities needed to manage them. The Instrument
Services Network is focused on the collection of observations. The Data and Modeling Services Networks are centered on the utilization of observations. The Control and Processing Services Networks manage the observation plans and the allocation of resources. These resources services networks are tied together by crosscutting infrastructure elements that serve as the integration platform and communication conduit, and support the activity, resource, service, identity, communication, and presentation models that must be used across OOI. Figure 8 shows the highest level operational nodes (clusters of capability) and needlines (indications for information dependencies) of the OOI CI; detailed views of the services networks and operational nodes are presented in the architectural document OV-2; there each of the operational nodes is unfolded into its own network design.
Figure 8: Highest-level operational nodes (clusters of capability) and needlines (indications for information dependencies) of the OOI CI
The Instrument Services Network provides interactive and coordinated relations with real and/or synthetic environments through the use of transducers (sensors or actuators). It ensures the safe and secure operation of individual sensing platforms, and provides reliable delivery of acquired data with their associated metadata. These capabilities must be integrated with network-wide resource allocation and observation planning. The Instrument Services Network provides the command and control semantics for interacting with an Instrument resource. The Instrument Services Network node provides data from sensors, instrument status information, and requests for resources such as bandwidth or power. It receives instructions to instruments and allocations of resources from the Control and Processing Services Networks.

The Data Services Network provides an automated data distribution and preservation network with pervasive and universal access subject to OOI Data Policy. It provisions a federated system of data streams, repositories, and catalogs that supports the distributed organization of resources.

The Modeling Services Network establishes baseline processes and tools comprising a coherent framework for the analysis and assimilation of data. It provides the command and control semantics for interacting with a Modeling Services Network resource. The capability to network and interact with multiple community-based numerical ocean models for parameter estimation/optimization and data assimilation is integrated into the framework. The network provides a wide range of event detection and response, quality control, hypothesis formulation, and modeling capabilities linked together via the Data Services Network. It provides observation requests to the Control Services Network and receives observational data from the Data Services Network. It also interacts with human actors through analysis and visualization activities.

The Control Services Network establishes standard models for the management of computation resources. It provides the semantics to monitor and control the operating state of a computation. The Control Services Network configures resources to accomplish a task, usually within the context of an ongoing laboratory or classroom activity. It receives observation requests from the Modeling Services Network, and provides observation plans to the Processing and Instrument Services Networks. It also provides command and control instructions and resource allocations to the Instrument node, and receives data, status information, and resource requests from the instrument node.

The Processing Services Network provides immediate-mode scheduling of processes at specified locations within the integrated network based on explicit time requirements and/or event triggers. It provides process execution planning and control, and it couples processes to the streaming environment of the Data Services Network.

The scale node, laboratory, and classroom are instances (which are instantiated dynamically and may operate simultaneously) of the external facility model that utilize
different classes of resources subject to distinct policy constraints to accomplish diverse goals.

5.6 Cyberinfrastructure Domain Model Overview

Figure 9 shows a high-level overview of the main structural elements of the OOI CI and their relationships; detailed models for these main elements are presented in the architectural document OV-7. Dotted boxes identify the subsystems responsible for the functionality provided by the contained elements and relations. As relations can cross the boundaries of one subsystem, the figure captures the dependencies between them.

![OOI Domain Model Overview](image)

**Figure 9**: OOI Domain Overview

The main entities in the Process Network are the Computation Scheduler, the Execution Engine, the Process Instance, and the Process Definition. The Computation Scheduler is in charge of mediating the instantiation of Execution Engines on Computation Nodes and of setting up the Process Instances by having Execution
Engines loading Process Definitions. Each Execution Engine understands one language in which the Process Definition is encoded. It is also the responsibility of the Computation Scheduler to connect the created process instances to the right Communication Facilities.

The Instrument Network is responsible for deploying and providing access to the various scientific Instruments that are used to perform measurements and experiments. Each instrument will be connected to an Instrument Proxy. This proxy is a Process Instance in the CI and is in charge of making the data collected by the instrument available to the rest of OOI and of relaying commands received by other parts of the system to the instrument. Because it is the mediator between the physical network the instrument is connected to and the rest of the OOI CI, the Instrument Proxy has full control over the instrument and the enforcement of policies defined by the instrument owner. The Instrument Planner participates in OOI system-wide interactions to enforce policies over the usage of the various instruments. For example, it participates together with the Computation Scheduler and the Resource Planner in the Resource Setup Protocol, which enables scientists to obtain resources that allow them to perform observations and experiments leveraging the OOI system.

The main elements of the Control Services Network are the Resource Planner and the Observation Plan. The Resource Planner receives an Observation Request from the Modeling Services Network and reaches a Service Agreement with the Process and Instrument Services Networks to use the resources needed to perform such observation. Once the agreement is reached (exchanging Service Agreement Proposals with the other participants in the Resource Setup Protocol), an Observation Plan is created. This plan describes an interaction of technical entities in the OOI that allows execution of the observation goal of the scientist. The differences between an Observation Request and an Observation Plan are twofold. First, the Observation Request is expressed in the language of the scientists, using the vocabulary provided by a Science Ontology, whereas the Observation Plan is expressed in terms of Processes and Communication Facilities that need to be instantiated and interconnected. Second, the Observation Plan is bound to physical resources that have been negotiated and obtained according to the policies defined by OOI.

The Data Services Network is responsible for providing the physical data storage services and the internal format of data. Various message type definitions for transporting information in the OOI system are a core element of the Data Services Network.

Finally, the COI-Core is responsible for the communication, routing, and all mediation facilities of OOI. Figure 9 presents the main entities of this subsystem. An Interaction Specification captures the communication patterns between Interaction Roles. Roles communicate over Communication Channels via Messages. The
Interaction is the realization of a specification and is defined by the sequence of messages over the various communication channels of the system.

5.7 Interface Technologies

The COI provides the technologies and services to play the role of a unifying information conduit, which enables data and control streams to be published and consumed by all of the subsystems. Secondly the COI is a platform to execute the core elements of the activity model by allowing the subsystem services to be combined as workflows. Enabled by the COI, the management of state, execution scheduling and orchestration of taskable resources can be provisioned as state management and orchestration/process execution plug-ins of the chosen Enterprise Service Bus (ESB) technology platform, which can be described by the concept of the CI Capability Container as mentioned above. An ESB brings together three fundamental capabilities, which are central to addressing the requirements of OOI CI: (a) flexible data distribution via an underlying messaging infrastructure; (b) message interception/routing allowing injection of behaviors that process messages for policy management, governance, failure management, identity federation, authorization and authentication, among others; (c) an abundance of built-in connectors to a variety of ingest-data formats and transport protocols, enabling out-of-the-box connectivity to a variety of existing and emerging data sources and formats.

Figure 10 shows a schematic overview graphic of Capability Containers and its rich set of infrastructure services. The pervasive provisioning of these infrastructure services across the deployment architecture constitutes the core of the Common Operating Infrastructure (COI). A Capability Container provides access to the resource networks via service interfaces. Each Capability Container also has a presentation capability to project its services to its environment in various forms.
Because of their pervasive nature, the Capability Containers are ideally suited to addressing crosscutting infrastructure concerns, including security, reliability, governance, and scalability. Capability Containers enable an easy deployment of the OOI collaboration and policy framework.
In the initial deployment (Figure 11), the capability blocks will be populated as follows: the messaging component will be instantiated to ActiveMQ/AMQP and the router/interceptor and service/data interfaces will be instantiated to Mule. Mule’s dependency injection mechanism provides immediate access to persistence, application/transaction, workflow, configuration and monitoring frameworks that will be instantiated to Hibernate, Spring, Groovy, and JMX, respectively. Furthermore, the COI will leverage the successful CI software stacks of BIRN/TeleScience with their web-service-based ATOMIC interfaces to the national Grid computing and security infrastructure. All of these web services can easily be configured as capability block plug-ins. The flexibility of this ESB-based approach allows the development team to rapidly integrate new capabilities as they become available.

The transport-transparent messaging component of the ESB will be exploited to implement data and control streams among CI subsystems, and provision and broker any service, data source, data transport and delivery mechanism, as well as any policy that is injected into the routing/interceptor facility of the ESB. Such messaging systems supports secure, durable, fault tolerant and high availability connections.

5.8 Cyberinfrastructure Summary

To understand processes at all oceanographic scales requires the complete set of observing and computational assets envisioned for OOI. Many assets must be capable of finding and following transient and localized phenomena, wherever they occur, while other platforms must provide stable reference points over time and space. The short-term nature of many processes demands reactive control of high-speed measurements, while large-scale phenomena must be measured consistently over
months, years, or decades. Further, measurements must be taken across disciplines, as physical forces induce biological and chemical effects, which in turn mediate biological changes. Comprehensive sensing systems must be collocated and interoperable to enable studies across different science domains and observing regimes. The use of large numbers of interconnected, space- and time-indexed, remote, interactive, fixed, and mobile assets by a global user community, collaborating through the Internet and Internet-enabled software, represents the most fundamental shift in oceanic investigative infrastructure. OOI's on-demand abilities to interconnect sensor systems to make measurements, and combine data systems to analyze measurements, will yield many scientific opportunities for the entire oceanographic, atmospheric, and geoscience communities.

The design of the CI enables the following “ilities” from the OOI System Requirements Document:

Futurecasting -- CI functionality and performance significantly beyond that required to support current use scenarios shall be provide [CI-PI-1]

Upgradeability -- The CI shall accommodate software and hardware evolution [CI-PI-2]

Scalability -- The CI architecture shall be scalable to accommodate a wide range of actors, resources, and services [CI-PI-3]

Extensibility -- The CI architecture and components shall be extensible so that new services and/or resources can be added, and existing services and/or resources can be augmented, throughout the lifetime of the OOI [CI-PI-4]

Reliability -- Resources, services, and the CI architecture shall be fault-tolerant [CI-PI-5]

Interoperability -- The CI shall be interoperable with cooperating systems inside and outside the marine community that manage environmental data, especially IOOS and Neptune Canada [CI-PI-6]

Availability -- The CI shall be available on a 24/7/365 basis with no more than xx downtime [CI-PI-7]

Serviceability -- The CI shall facilitate debugging and root cause analysis [CI-PI-8]

Usability -- The CI shall make all user interfaces human friendly and web accessible [CI-PI-9]
Accessibility -- Public access for data from all core sensors shall be available: all information is open by default. The CI shall limit proprietary periods to one year for non-core sensors: all data will be publicly accessible after the expiration of a proprietary period [CI-PI-10]

6 Coastal and Global Scale Nodes Preliminary Design

6.1. Overall Design Approach

The CGSN Preliminary Network Design is guided by the OOI Science User Requirements and OOI System Requirements. The OOI System Requirements in particular define the top-level requirements for the CGSN elements. These map back to the OOI Science User Requirements and together ensure that the infrastructure developed meets the scientific needs for which it will be deployed. Specifically, the CGSN comprises three sets of equipment: Global Sites, the Pioneer Array, and the Pacific Northwest (PNW) Endurance Array. Each set of equipment contains common features (e.g., mooring control, power generation, telemetry) and unique features – PNW Endurance has cabled elements, Pioneer Array is designed to be relocatable, and Global Sites are designed for extreme, high latitude conditions.

The following order of precedence has been used to develop the PND outlined below.

1. Design, build, and installation must costs not exceed the OOI funding allocation for CGSN
2. Design must meet the OOI Science User Requirements and OOI System Requirements
3. Site prioritization was based on the CGSN Ad Hoc Team Summary Report

6.1.1 Engineering Design Approach

The CGSN engineering design aggressively defines common system components across the CSN and GSN that will reduce development and construction costs and simplify maintenance. The primary areas where significant levels of commonality have been achieved are: buoy and mooring design, power generation, buoy controller, and data logging and telemetry. An exception to the commonality strategy is the PNW 25-m mooring, which differs from other coastal moorings due to their near-shore location.

The surface buoys to be employed will be two close variants of a new design. The global and coastal buoy will share design of the main structure, with the global buoys having greater buoyancy, and a taller tower to mount instruments up to 5 m above the water line. This design is intended to enhance the global buoy’s performance and survivability over that of current buoy designs in rough seas and potential icing conditions at high latitudes. It is also aimed at improving the quality of meteorological
measurements by increasing the stability and height of the sensor platform, while reducing buoy-induced flow disturbance. The basic mooring design we will use for the CSN and GSN is also similar and builds on experience with the Nootka project, as well as moorings developed for other programs in both coastal and open-ocean settings.

Power on all surface buoys will include active power generation by photovoltaic arrays (PVA) and wind turbines, with higher power provided where needed by a methanol fuel cell system. A backup alkaline battery pack will provide emergency power to maintain vital system functionality in the event the rechargeable system is compromised. Power will be stored in a bank of Absorbed Glass Mat (AGM) lead acid batteries. Alternative battery systems were investigated (NiCd and Lithium) but found to be prohibitively costly. The power system will include a microprocessor that monitors voltage, current consumption and ground faults, and controls primary power switching. The fuel cell system will provide high power for the Southern Ocean site and for AUV dock and Multi-Function Node (MFN) moorings in the Pioneer Array.

System control, data telemetry, and logging on both the coastal and global buoys will be provided by a buoy controller based on a commercial off-the-shelf, low-power, single-board computer running a variant of the Linux operating system, a satellite modem (Iridium), radio modem (FreeWave), acoustic modem and sensor interface. Two controllers will be installed on each buoy to provide operational redundancy and ports to support both core and user-supplied sensors. Either of the units can assume control of the system, reducing the risk from failures of any of the major components. Using a proven buoy control approach has the dual advantage of reducing non-recurring engineering (NRE) development costs and reducing risk.

Five types of communication from the moorings to shore are envisioned for the coastal and global buoys: (1) Iridium will be the primary buoy-to-shore communication system for the Pioneer Array, the global surface moorings and winched profilers, the Endurance Array surface moorings, gliders, and AUVs. Alternative air-side communication will include FreeWave radio modem and radio LAN Ethernet (WiFi); (2) acoustic modems will be used to relay data and commands between subsurface equipment and adjacent Iridium-capable buoys; (3) the subsurface winched profilers will communicate inductively within the mooring and telemeter their data via Iridium when the upper profiler has surfaced. There is also an inductive link to a controller that has a (lower capacity) acoustic link to the surface buoy; (4) direct, cabled communications will be used from the Endurance (Oregon) line to the RSN shore station; (5) surface moorings equipped with fuel cell systems will be capable of using active-antenna satellite systems such as Ku-band. For the uncabled systems, practical constraints govern design decisions for communications. It should be noted that the available bandwidth of practical satellite communication systems is low (e.g., a few Mbytes/day for Iridium) with the consequence that the bandwidth of an optical link is wasted. If it were possible to occasionally offload a large amount of data from a coastal mooring buoy (e.g., via
FreeWave at 10 Mbytes/hr or WiFi at 300 Mbytes/hr), there would be sufficient time to forward it from seabed to buoy over a slower copper link.

All autonomous instrument platforms will possess a finite bandwidth for transmitting data to shore that will depend on both power availability and budgetary constraints. The need for very high sampling rates together with increased complexity and number of core sensors and user provided instruments may at times create the condition where it will not be possible to telemeter all data to shore. In order to achieve the maximum scientific benefit from all platforms, it will be necessary to prioritize and manage the amount of data streaming from any given sensor. The constraint of transferring only a percentage of total data will require all data to be stored on the platform and to sub-sample the data stream with the capability of requesting the smaller samples of full rate data on demand.

Basic connectivity to shore will be achieved using Iridium satellite modems. Iridium is a proven technology in the oceanographic field, is available all over the world and has already been implemented on all of the instrument platform types including surface buoys, gliders and AUVs. The Iridium links supports bi-directional communications at 2400 bits/second. The maximum power efficiency for data transferred via Iridium is 40 bytes/Joule. Diving platforms such as sub-surface profiles, AUVs, and gliders will be limited by their total power budget and the time spent at the surface.

Global and coastal buoys with fuel cell power generation will use both Iridium and a higher speed satellite link to provide a scalable solution that can be tailored to meet bandwidth requirements. The inclusion of Iridium on all instrument platforms will provide a common technology for communicating with shore. Several emerging satellite solutions are potentially viable on the high power surface buoys, including Inmarsat Fleet33, Iridium Next and Inmarsat BGAN. A single Iridium unit constantly transmitting data has a maximum daily capacity of 20 MB per day, but the current operational cost is prohibitive. Selection of a high-speed satellite solution will be a milestone early in the surface buoy design process.

6.1.2 CGSN / CI Interface

Currently operating mooring systems and operations software which form the basis of the CGSN design include sensor control, data collection, and mission planning as integral components. The overall OOI system design calls for the responsibility of these functions to reside with the CI IO, implying a CI control presence within the mooring system itself. This significant departure from present mooring design, development, and deployment procedures has required careful consideration.

The CGSN / CI interface agreement maintains the proven reliability and survivability features of WHOI's current mooring system and operations design, while incorporating the transformative elements represented by the use of mooring-resident and shore-
station-resident OOI CyberPOP software that will in due course pass responsibility for implementing all instrument control, data collection, etc to the CI IO. The interface design will provide for automated control and data delivery from observatory instrumentation, with implementation in place by the end of a 5-year period. Automated CyberPop instrument control and data delivery instrument drivers will be tested and incorporated in concert with the CI IO. Initially, observing elements, especially complex systems like AUVS, will be deployed with vendor-supplied control and data delivery systems. Work with CI is directed at evolving toward automation without compromising performance and reliability. The interim design incorporates Human-in-the-Loop (HIL) support for use during instrument driver development and during periods when software needs to be updated to reflect vendor-supplied firmware updates, and for some mission-critical mooring operations.

With the exception of the cabled Endurance Array assets, all OOI service requests for CGSN resources that are delivered via the Internet are accepted by the CGSN shore station software. CGSN resource destinations include CGSN Buoy Control and Communications Systems, commercially supplied platform systems (gliders, AUVs, profilers) and the oceanographic instrumentation attached to each of them. Upon intercepting the OOI service request, the CGSN shore station software either passes the service directly to the destination platform/instrument for execution by buoy-resident CyberPop software or hands the service request off to shore station-resident HIL software. The CGSN-provided HIL software elements, resident on the shore station, processes OOI service requests and conform to the OOI SOA.

6.1.3 CGSN Sensors

Sensors and sensor platforms (gliders, moored profilers and winched profilers) were standardized across the CGSN by specifying identical COTS equipment to the extent possible within the unique deployment constraints of individual sites. Sensor standardization reduces O&M cost and complexity by minimizing the number of unique sensor interfaces, allowing common procedures at the engineering and technical levels, and providing for efficient use of spare sensor pools. However, not all specified sensors are COTS since the OOI Science User Requirements and Traceability Matrices from the OOI Science Prospectus specify observations such as CO$_2$ flux, direct covariance momentum and buoyancy flux, and horizontal electric field-pressure-inverted echo sounder measurements for which suitable COTS systems do not presently exist.

The CGSN Ad Hoc Team developed a list of proposed core sensors that was used to develop the specific instrument suites described below. (In the sensor tables in Section 6, references to specific manufacturers do not necessarily represent final choices.) They also agreed on a second list of sensors, called Type 2, that they anticipated the community would want to add in the future. This list of Type 2 sensors was used to examine the future power and bandwidth needs that the CGSN infrastructure would be designed to meet.
In some cases (e.g., bio-optical sensors) sensors may not provide high-quality data during the full duration (six months to one year) of unattended deployment due to calibration drift biofouling, or other factors. Sensor degradation will be mitigated using five principal strategies: 1) profilers and AUVs will be "parked" below the euphotic zone whenever possible, 2) newly deployed mobile platforms will be directly to pass by mooring locations to provide a baseline for adjustment of sensor drift, 3) twice per year coastal mooring service cruises will be timed so that phenomena of particular interest (e.g., spring bloom, fall mixing) are observed with fresh sensors, 4) sensors on certain platforms (e.g., winched profilers, gliders, AUVs) will be serviceable in-situ using ships of opportunity, allowing re-establishment of measurement quality with minimal O&M impact, 5) all sensors will be post-calibrated upon recovery.

6.2 Global Scale Nodes

6.2.1 Locations

There are two global mooring sites with acoustically linked surface and subsurface moorings, one in the North Atlantic and one in the South Pacific. A third site, at Ocean Station Papa in the North Pacific, will be occupied with subsurface moorings. Each site utilizes a mix of fixed (mooring) and mobile (gliders, profilers) assets as summarized in Figure 12 to sample across space and time scales.

Southern Ocean, SW of Chile

Location: 55°S, 90°W; Water Depth: 4800 meters

Mooring Type: Acoustically Linked Surface Mooring with Subsurface Profiler Mooring and Mesoscale Flanking Mooring Pair

Description of Infrastructure:
- One acoustically-linked Global Surface Mooring, with high-power (fuel cell) buoy and high-bandwidth (active antenna) satellite telemetry
- One Global Hybrid Profiler mooring with one wire-crawler profiler and one winched profiler
- Two subsurface Mesoscale Flanking Moorings with fixed sensors and acoustic communications to gliders
- Acoustic telemetry link with transducer 10m below the surface buoy
- Inductive telemetry link within upper 1000m of the Surface Mooring and throughout the Profiler Mooring
- Five gliders with extended endurance and acoustic communications to the Mesoscale Flanking Moorings

Irminger Sea, SE of Greenland
Location: 60°N, 39°W; Water Depth: 2800 meters
Mooring Type: Acoustically Linked Surface Mooring with Subsurface Profiler Mooring and Mesoscale Flanking Mooring Pair

Description of Infrastructure:
- One acoustically-linked Global Surface Mooring, with powered (wind and solar) buoy and Iridium satellite telemetry
- One Global Hybrid Profiler mooring with one wire-crawler profiler and one winched profiler
- Two subsurface Mesoscale Flanking Moorings with fixed sensors and acoustic communications to gliders
- Acoustic telemetry link with transducer 10m below the surface buoy
- Inductive telemetry link within upper 1000m of the Surface Mooring and throughout the Profiler Mooring
- Five gliders with extended endurance and acoustic communications to the Mesoscale Flanking Moorings

Figure 12: Schematic of a global site, showing surface mooring, profiler mooring, flanking moorings, gliders.
Station PAPA, North Pacific

Location: 50°N, 145°W; Water Depth: 4250 meters
Mooring Type: Subsurface Profiler Mooring with Mesoscale Flanking Mooring Pair

Description of Infrastructure:
- One Global Hybrid Profiler mooring with one wire-crawler profiler and one winched profiler
- Two subsurface Mesoscale Flanking Moorings with fixed sensors and acoustic communications to gliders
- Five gliders with extended endurance and acoustic communications to the Mesoscale Flanking Moorings
- Inductive telemetry link throughout the Profiler Mooring

6.2.2 Core Sensors

The proposed global surface and subsurface moorings will support the suite of core sensors listed in Table 1, as well as the addition of science user sensors in the future. A variety of options will be available for adding sensors and instrument packages, including: clamping inductively-linked sensors to the upper 1000 m of surface mooring wire, mounting instrument packages in-line on the surface mooring with an acoustic link to the surface buoy, deploying a nearby instrument package with an acoustic link to the surface buoy, adding sensors to the profilers, adding fixed sensors to the mesoscale flanking moorings, and adding mobile platforms.
**Table 1: Core sensors, Global sites**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Example Sensor</th>
<th>Platform</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Cov Flux</td>
<td>WHOI HP-DCFS</td>
<td>Surface Buoy (55S, Irminger Sea)</td>
<td>on buoy motion sensors in buoy hull</td>
</tr>
<tr>
<td>surface wave</td>
<td>PSI/Neptune</td>
<td>Surface Buoy (55S, Irminger Sea)</td>
<td>on buoy</td>
</tr>
<tr>
<td>spectra</td>
<td>PMEL/Sabine</td>
<td>Surface Buoy (55S, Irminger Sea)</td>
<td></td>
</tr>
<tr>
<td>delta pCO2 (air/sea)</td>
<td>RDI Longranger</td>
<td>Surface Buoy (55S, Irminger Sea), mesoscale flanking moorings</td>
<td></td>
</tr>
<tr>
<td>Current profiles</td>
<td>RDI Longranger</td>
<td>Surface Buoy (55S, Irminger Sea)</td>
<td></td>
</tr>
<tr>
<td>temperature/salinity</td>
<td>Seabird</td>
<td>surface buoy (55S, Irminger Sea)</td>
<td>1m below the surface</td>
</tr>
<tr>
<td></td>
<td></td>
<td>surface moorings (55S, Irminger Sea)</td>
<td>12 depths from surface to 1500m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mesoscale flanking mooring</td>
<td>12 depths from surface to 1500m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>deep profiler</td>
<td>200m to bottom</td>
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<tr>
<td></td>
<td></td>
<td>winched profiler</td>
<td>surface to 150m</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>surface to 1000m</td>
</tr>
<tr>
<td>dissolved oxygen</td>
<td>Seabird</td>
<td>mesoscale flanking moorings</td>
<td>approx. 20m</td>
</tr>
<tr>
<td></td>
<td>McLane/Seabird</td>
<td>profiling</td>
<td>200m to bottom</td>
</tr>
<tr>
<td></td>
<td>McLane/Seabird</td>
<td>winched profiler</td>
<td>surface to 150m</td>
</tr>
<tr>
<td></td>
<td>Aandeeraa</td>
<td>gliders</td>
<td>surface to 1000m</td>
</tr>
<tr>
<td>pH</td>
<td>Seabird</td>
<td>mesoscale flanking mooring</td>
<td>approx. 20m</td>
</tr>
<tr>
<td></td>
<td>Seabird</td>
<td>profiling</td>
<td>200m to bottom</td>
</tr>
<tr>
<td></td>
<td>Seabird</td>
<td>winched profiler</td>
<td>surface to 150m</td>
</tr>
<tr>
<td>Chl-a and CDOM</td>
<td>Wetlabs</td>
<td>mesoscale flanking mooring</td>
<td>approx. 20m</td>
</tr>
<tr>
<td>fluorescense, optical</td>
<td></td>
<td>profiling</td>
<td>200m to bottom</td>
</tr>
<tr>
<td>backscatter</td>
<td></td>
<td>winched profiler</td>
<td>surface to 150m</td>
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<tr>
<td></td>
<td></td>
<td>gliders</td>
<td>surface to 1000m</td>
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<tr>
<td>bottom pressure</td>
<td>Seabird</td>
<td>55S seafloor</td>
<td>seafloor</td>
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<td>OBS</td>
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<td>55S seafloor</td>
<td>seafloor</td>
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<td>optical attenuation</td>
<td>Wetlabs</td>
<td>winched profiler</td>
<td>surface to 150m</td>
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<td>and absorption</td>
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<td></td>
</tr>
<tr>
<td>spectral irradiance</td>
<td>Satlantic</td>
<td>winched profiler</td>
<td>surface to 150m</td>
</tr>
<tr>
<td>nitrate</td>
<td>Satlantic</td>
<td>winched profiler</td>
<td>surface to 150m</td>
</tr>
</tbody>
</table>
6.2.3 Technical Approach

**Surface Buoy.** A new design with a tall, low-drag tower and deep keel is used for the surface buoy (Figure 13). The tower is a monopole and provides for instrument mounting at 5 m above the waterline. A circular crash bar below the instrument mounting area helps to prevent damage to instruments from impact. For power generation, two vertical-axis wind generators are mounted at about 3 m heights on the tower, and solar panels are mounted near the buoy deck. Solar panels will be hardened with clear acrylic or polycarbonate shields. Where possible, tower items will be painted white to minimize buoy “heat island” effects.

The buoy will be approximately 8-9 m in overall height with a foam flotation section about 2.8 m in diameter. It will have an air weight not to exceed about 4000 kg loaded with batteries, and a net buoyancy of approximately 8000 kg. Unlike typical surface buoy designs that are “bi-stable,” or capable of floating upside-down, this buoy is designed to self-right by placement of heavy batteries low in the buoy’s extended keel. Sufficient room for electronics and, when so equipped, the fuel cell power system, will be provided in the main well housing. In buoys equipped with fuel cell systems, the ethanol/water fuel mixture will be stored in bladders housed in flooded compartments below the buoy hull.
Figure 13: Schematic drawing of the surface buoy design to be used for the global sites. Two wind-driven power generators and solar panels are shown, along with the meteorological sensor mast and buoy hull with flotation and storage for batteries and electronics.
Surface Mooring. The global moorings will utilize a design similar to that used for the Nootka project (Figure 14). This is a low-scope inverse catenary style mooring consisting of (proceeding from the surface down) the surface buoy, electromechanical universal, 10-m electro-optical-mechanical (EOM) section, acoustic transducer/instrument frame, special wire rope termination for inductive link, approximately 1000m of wire rope, a plafted nylon section, a buoyant polypropylene section, glass spheres mounted to mooring chain for backup recovery, dual acoustic releases, and a deadweight anchor. The largest components, the buoy and anchor, are designed to remain below 10,000 lb air weight, in order to be readily handled by UNOLS vessels.
An alternate hybrid mooring design was considered for the Southern Ocean site, which is expected to have the most severe environmental conditions of all the global sites. This configuration was expected to provide high mooring compliance for large waves, but led to risk associated with high static loads. In contrast, the Nootka-style inverse catenary mooring provides more compliance and overall much lower drag, resulting in static mooring loads of only about 4,000 lb for the same conditions, and good dynamic performance when this current profile is combined with significant wave heights of up to 14 m expected at this site. As this mooring configuration is known to work well under difficult conditions (such as at the Nootka site, off Vancouver Island) as well as in more benign conditions (e.g., the Stratus site in the eastern Pacific off northern Chile which has been occupied continuously since October 2000), the decision was made to use this design for all the global surface moorings.

**Subsurface Mooring.** The subsurface mooring is, at its core, a conventional design with a subsurface buoy at approximately 250 m depth. A single uninterrupted shot of wire rope runs from the subsurface buoy to the sea floor, or up to the maximum manufactured length of wire (about 4500 m) in deep water. A wire-crawler profiler will operate along this section of the mooring. At the top of the subsurface buoy, an electromechanical universal joint and electro-mechanical (EM) chain will be connected to the lower tether of a two-body winched profiler consisting of a separate winch and profiler. The winch body moves down as the profiler moves up, and operates in a depth range of 150-230 m. The profiler body operates in a depth range of 150 m to the surface.

**Buoy Control and Communication System.** As described above, system control, subsurface acoustic communications, inductive communication, surface telemetry and data logging for the global buoys will be accomplished with an embedded computer that is compatible with CI cyberpop software. This controller will be selected through combined effort between the marine and cyber IOs. This effort will identify a development system that can be used by several aspects of the OOI effort while allowing the use of common software across the network. Global buoys are expected to see power conditions ranging from 20 to 200 Watts. The system controllers are designed to support multiple power states where high power consumers such as telemetry links and specific sensors are duty cycled to operate within the available power budget.

**Mooring power generation and storage.** Two configurations of the mooring power generation and storage system will be used on the Global and Coastal moorings. Both versions will utilize power generated by solar panels and wind turbines to charge a storage battery. A high-power version will supplement the solar and wind power with methanol-based fuel cells. Both versions will take advantage of the same highly efficient power management system. The moderate-power system will take inputs from Photo-Voltaic (PV) panels and wind turbines to produce upwards of 50 W continuous power. In the high-power version, a bank of fuel cell modules, capable of generating up
to 250W each from a stored methanol-water mixture will supply continuous power in the range of 200-500W. Both systems should be capable of supplying intermittent peak power of 1KW when needed.

The individual PV panels are connected to separate input ports on the Buoy Power Manager (BPM), providing greater collection efficiency when the sun’s angle of incidence supports power generation from more than one cell. This redundancy also permits the BPM to disable one or more damaged PV panels, while making full use of the remaining panels. One or two wind turbines are used by the system. For redundancy, provisions for two separate wind turbines are provided on the BPM. The fuel cells are connected to the BPM via independent power connections, and are also linked by a control channel. This permits the BPM to start and stop the two fuel cells independently, both to optimize on-demand power generation, and to maximize total system life by varying individual fuel cell duty cycle based on fuel cell system health and environmental conditions. Both the moderate and high-power system uses a large bank of AGM lead-acid batteries for energy storage with high peaking capacity. In order to maximize peak power delivery capacity in both the high and moderate power systems, this battery bank will be made as large as possible, within the constraints imposed by total buoy weight concerns.

**Acoustic links.** Several acoustic communications systems are under consideration for use as the primary link for the global nodes. The system will be selected based on criteria including demonstrated acoustical performance, power efficiency, life cycle cost and integration with existing controllers and sensors. Acoustic modems are located 10 meters below the surface buoy and will use directional transducers with 60° beams. The use of directional transducers will provide high efficiency at modest power levels and support communications with sensors located in the mooring or on the seafloor up to one water depth away from the buoy. Depending on geometry and acoustic conditions, link efficiencies for vertical configurations of 50-100 Bytes/Joule have been demonstrated.

Link protocol is simple time-division, multiple-access (TDMA) that will be controlled by the surface buoy. A reliable transport layer will be implemented which supports the management of all acoustical sensors and the addition of instruments after the buoy is deployed. Acoustic modems integrated directly with simple sensors will be required to buffer data in low power mode until polled by the surface acoustic modem. Data compression or sub-sampling will be the responsibility of the sensor.

**Inductive links.** Inductive modems will be used to communicate with sensors located on surface moorings in the upper 30-1000m and throughout the profiler moorings. These modems use the mooring cable as the communication link to provide 1200 bit per second communications with sensors. Several of the core instruments can be purchased with inductive modems from the manufacturer.
**Profilers.** Upper ocean and deep-ocean profiling capability at global sites will be implemented with two distinctly different technologies. Deep ocean “wire-crawler” profilers are available commercially. These profilers use a drive wheel to move up and down a mooring wire over several thousand meters. They are battery powered and able to carry a modest (in terms of size, mass, and power consumption) sensor payload. The systems allow deployment of CTD, current meters, and small optical sensors over a large range of the water column, have the required endurance, and can telemeter their data inductively along the mooring wire, or acoustically up/down the mooring or to a nearby mooring.

In the upper layer, a different approach is needed. The main interest here is the biologically productive euphotic zone, i.e. the top 100-150m of the ocean where a large and diverse suite of measurements needs to be enabled, including physical, chemical, biological, and ecosystem observations. Fixed-point sensors at single depths are less desirable since the vertical distribution of nutrients or plankton species is usually of interest, and individual sensors can be large and expensive (prohibiting deployment of a large number at fixed depths). Therefore profiling systems are sought which can raise/lower a package with a sizeable set of sensors through the upper 150m or so. This can best be implemented with underwater winch systems.

Currently there are no commercial, off-the-shelf upper-ocean profiler systems that can satisfy the scientific requirements, which are: (1) size and mass of payload to allow large and heavy sensors (e.g., wet chemical systems, acoustic zooplankton sonars, optical imaging systems); (2) buoyancy of sensor package and wire length large enough to overcome current drag to reach the surface; (3) ability to profile at least once per day from 150m to surface during an autonomous (battery-powered) 1-year deployment; and (4) ability to survive knockdown to 1000m due to drag on the subsurface mooring in strong currents. We propose to use a profiler system (the SeaCycler winch) that is being developed to meet these goals by a consortium project funded by NSF and the European Commission. A prototype is expected to be available at SIO for testing and demonstration in early 2008. Once ready for production, one of the consortium partners (BOT/Halifax) will sell it commercially. While this is the system currently planned, other options will be reviewed and considered as they become available.

**Gliders.** In order to provide a spatial (horizontal) footprint of the nodes, 5 gliders will be provided at each global site. Current gliders have insufficient endurance for the 1-year service interval planned for the global nodes, if they are to carry out useful science missions and carry a worthwhile science payload. Therefore an engineering effort is planned to modify and equip one brand of gliders with novel power systems. Two new battery technologies are expected to be commercially available within a year, offer energy that is increased by a factor of three or more.

The gliders will require substantial modifications to accommodate this new technology, which will allow both increased endurance and incorporation of more comprehensive
science payloads. Gliders will ultimately carry a CTD, optical sensors (e.g. for dissolved oxygen), chlorophyll fluorescence, CDOM, nutrients, and acoustic sensors for zooplankton sampling.

The gliders will be used in conjunction with the central and the flanking mesoscale moorings at each global location. They will horizontally extend the sampling domain horizontally beyond the central mooring. In particular will they resolve temporal versus spatial variability, determine the representativity of the mooring sampling, and estimate spatial scales and gradients. More important, gliders can sample both the horizontal and vertical dimension, which is essential for biological variables and processes. For example, the depth or inventory of chlorophyll or nutrients may be missed or misjudged if sampled at fixed depths on moorings or from satellites. Gliders can thus be used to observe also the depth variations or column integrals of biogeochemical quantities over horizontal distances, and relate these to processes or simply obtain volume integrals. In addition, the gliders will be used as two-way data communication relays to provide access to data from the flanking moorings and to be able to command sampling on these moorings, which have no surface expression to allow direct connectivity.

6.2.4 Installation and Servicing

The Southern Ocean mooring group will be deployed at Station W off the New England coast in 2010 for a test deployment. The deployment will be for a minimum of three months in the late fall/early winter when there is a high probability of a Nor'Easter. This deployment will test all mechanical, electrical and communication systems prior to the first yearlong deployment at the high latitude site.

The surface and subsurface mooring will be designed for turnaround on a one-year cycle. Turnaround will consist of recovery of the moorings and deployment of replacement systems that have been refurbished. Operations and Maintenance funding will be used to acquire system equipment in sufficient quantity to support this maintenance strategy. Due to the limited number of Global Sites, 100% redundant material will be purchased so downtime can be limited. Durable items such as the surface buoy, instrument frames, and acoustic releases are refurbished ashore and are expected to last in excess of 10 years. EM chains will be replaced yearly, but may eventually be used for two years or more. Mechanical wire rope, nylon, polypropylene, and chain mooring elements as well as all mooring hardware such as shackles and links will be replaced with new material at each turnaround.

Planning and occupation of the Irminger Sea site will be coordinated with European colleagues through the OceanSites program, which plans for some observations off southeast Greenland. In addition, the occupation of Ocean Station Papa will be based on cooperation with NOAA and Canadian agencies engaged in ongoing sampling at and around the site. The CGSN IO will work with the program office to coordinate long-lead time planning to schedule ship time needed to visit these remote sites and to include
sufficient weather days to maximize the probability of weather windows that allow mooring operations.

6.3 Coastal Scale Nodes - The Pioneer Array

6.3.1 Location

Location, Central Mooring: 40° 03’N, 70°45’W (Middle Atlantic Bight)
Water Depth: 150 meters
Cross-shelf mooring line extent: +/- 20 km from central mooring
Upstream moorings: 10-15 km from cross-shelf line
AUV sampling area (approximate): 100 by 80 km box centered on moored array
Glider sampling area (approximate): 150 x 150 km box over outer shelf and slope sea
Platform Types: EOM surface moorings, surface-piercing winched profilers, subsurface wire-crawler profiler moorings, AUVs and gliders

Description of Infrastructure:
- Three EOM surface moorings
- Three Multi-Function Nodes at the base of EOM surface moorings (two supporting AUV docks)
- Five coastal profiler moorings with subsurface, wire-crawler profilers
- Two coastal winched profilers
- Two AUV docking stations
- Three AUVs
- Six gliders

The backbone of the Pioneer Array will be a frontal-scale moored array with three electro-mechanical (EOM) surface moorings, two coastal-winched profilers and five coastal profiler moorings. Each EOM mooring will incorporate a surface buoy with high power generation (fuel cells) and multiple communications systems as described earlier. Each EOM mooring will incorporate a Multi-Function Node (MFN) at its base. Two of the MFNs will incorporate docking stations at their base for AUVs, while the third will be designed to support integration of science user instrumentation. All three MFNs will be capable of supporting multiple onboard (e.g., frame-mounted) sensors as well as external sensor packages connected to the MFN frame by ROV wet-mateable connectors. The coastal-winched profilers will provide a buoyant sensor body capable of profiling from a few meters above the bottom through the air-sea interface. The coastal profiler moorings will support wire-crawler type profiling packages with a multi-disciplinary sensor suite, and will have surface expressions for data telemetry. In order to provide synoptic, multi-scale observations of the outer shelf, shelf break frontal region, and slope sea, the moored array will be supplemented by nine mobile platforms – six gliders and three AUVs. The anticipated operational modes for mobile platforms are described in more detail below. Massachusetts State funds, provided through WHOI by
the John Adams Innovation Institute (JAII), will be used to acquire one of the EOM surface moorings with docking station as well as one of the AUVs.

The approximate geographic locations for the Pioneer moored array elements are given in Table 2 below and shown schematically in Figure 15. The moored array is aligned perpendicular to isobaths and spans the shelf break (Figure 16). The inshore and central sites contain EOM surface moorings paired with coastal-winched profilers (Figure 17), while the offshore site contains an EOM surface mooring and coastal profiler mooring and the intermediate and upstream sites contain only coastal profiler moorings. The central site is at the climatological center of the shelf break jet. The inshore and offshore sites span the typical inshore and offshore variability in the T/S front location, and will also capture the typical meanders of the jet. The two “intermediate” profiler moorings ensure that the horizontal section provided by the moored array samples the frontal system coherently. The upstream moorings will provide along-front gradients to aid in determination of advective fluxes.

Table 2: Summary of the platforms, platform locations, and depths of the sites occupied in the Pioneer Array.

<table>
<thead>
<tr>
<th>Platform</th>
<th>Site</th>
<th>Location</th>
<th>Depth</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOM mooring, AUV dock,</td>
<td>inshore</td>
<td>40° 14' N</td>
<td>110 m</td>
<td>Typical inshore extent of shelf break front and jet</td>
</tr>
<tr>
<td>coastal winched profiler</td>
<td></td>
<td>70° 45' W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>coastal profiler mooring</td>
<td>intermediate</td>
<td>40° 08' N</td>
<td>130 m</td>
<td>10 km horizontal separation, resolves frontal correlation scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70° 45' W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOM mooring, MFN,</td>
<td>central</td>
<td>40° 03' N</td>
<td>150 m</td>
<td>At climatological shelf break front, MFN for science-user instruments</td>
</tr>
<tr>
<td>coastal winched profiler</td>
<td></td>
<td>70° 45' W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>coastal profiler mooring</td>
<td>intermediate</td>
<td>39° 57' N</td>
<td>300 m</td>
<td>10 km horizontal separation, resolves frontal correlation scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70° 45' W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOM mooring, AUV dock,</td>
<td>offshore</td>
<td>39° 52' N</td>
<td>500 m</td>
<td>Typical offshore extent of shelf break front and jet</td>
</tr>
<tr>
<td>coastal profiler mooring</td>
<td></td>
<td>70° 45' W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>upstream</td>
<td>inshore</td>
<td>40° 14' N</td>
<td>110 m</td>
<td>15 km horizontal separation, resolves frontal correlation scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70° 38' W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>coastal profiler mooring</td>
<td>offshore</td>
<td>39° 52' N</td>
<td>500 m</td>
<td>15 km horizontal separation, resolves frontal correlation scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70° 38' W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUVs</td>
<td>shelfbreak region</td>
<td>various</td>
<td>various</td>
<td>~80 km transects along and across shelf, centered on shelf break</td>
</tr>
<tr>
<td>gliders</td>
<td>outer shelf</td>
<td>various</td>
<td>various</td>
<td>~150 km transects from outer shelf to slope sea</td>
</tr>
<tr>
<td></td>
<td>&amp; slope sea</td>
<td></td>
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</tbody>
</table>
Figure 15: Plan view schematic map of the multi-scale Pioneer Array in the context of other regional observing elements. A moored array will be centered at the shelf break front and jet south of Cape Cod, Massachusetts, AUVs will sample the frontal region in the vicinity of the moored array, and gliders will resolve mesoscale features on the outer shelf and the slope sea between the shelf break front and the Gulf Stream.
Table 3: Pioneer Array core measurement and sensor summary, identifying the deployment platforms for the sensors.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Example Sensor</th>
<th>Platform</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>surface fluxes (direct covariance)</td>
<td>LP-DCFS</td>
<td>central, inshore and offshore EOM buoys</td>
<td>direct measurement of momentum and buoyancy fluxes</td>
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<td>CO2 flux</td>
<td>PMEL/Sabine</td>
<td>central EOM buoy</td>
<td>simultaneous measurement of air-side and water-side pCO2</td>
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<td>surface wave spectra</td>
<td>PSI/Neptune</td>
<td>central EOM buoy</td>
<td>motion sensors in buoy hull</td>
</tr>
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<td>temperature and conductivity</td>
<td>Seabird</td>
<td>central, inshore and offshore EOMs</td>
<td>5 m below surface</td>
</tr>
<tr>
<td></td>
<td></td>
<td>central, inshore and offshore MFNs</td>
<td>2 m above bottom</td>
</tr>
<tr>
<td></td>
<td></td>
<td>winched profilers</td>
<td>2 m above bottom to surface</td>
</tr>
<tr>
<td></td>
<td></td>
<td>moored profilers</td>
<td>near bottom to 15 m below surface</td>
</tr>
<tr>
<td></td>
<td></td>
<td>gliders</td>
<td>saw-tooth transects to 1500 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AUVs</td>
<td>saw-tooth transects to 500 m</td>
</tr>
<tr>
<td>high-precision pressure</td>
<td>Seabird</td>
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<td>winched profilers</td>
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<td></td>
<td>moored profilers</td>
<td>near bottom to 15 m below surface</td>
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<td></td>
<td>gliders</td>
<td>saw-tooth transects to 1500 m</td>
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<td></td>
<td>AUVs</td>
<td>saw-tooth transects to 500 m</td>
</tr>
<tr>
<td>mean currents</td>
<td>Nortek</td>
<td>central, inshore and offshore EOMs</td>
<td>5 m below surface</td>
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<td></td>
<td>central, inshore and offshore MFNs</td>
<td>2 m above bottom near bottom to near surface</td>
</tr>
<tr>
<td></td>
<td>ADCP</td>
<td>winched profiler base</td>
<td>near bottom to near surface</td>
</tr>
<tr>
<td></td>
<td>ADCP</td>
<td>moored profiler base</td>
<td>near bottom to near surface</td>
</tr>
<tr>
<td>Parameter</td>
<td>Platform/Device</td>
<td>Measurement Range</td>
<td></td>
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<td>----------------------------</td>
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<tr>
<td>Nortek gliders</td>
<td>ADCP AUVs</td>
<td>saw-tooth transects to 1500 m, saw-tooth transects to 500 m</td>
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</tr>
<tr>
<td>Turbulent velocities</td>
<td>3D ACM winched profilers</td>
<td>2 m above bottom to surface, near bottom to 15 m below surface</td>
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</tr>
<tr>
<td>Dissolved oxygen</td>
<td>Seabird central, inshore and offshore EOMs</td>
<td>5 m below surface</td>
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<td></td>
<td>Seabird central, inshore and offshore MFNs</td>
<td>2 m above bottom to surface</td>
<td></td>
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<tr>
<td></td>
<td>Seabird winched profilers</td>
<td>near bottom to 15 m below surface</td>
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<td>Seabird moored profilers</td>
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<td>Seabird gliders</td>
<td>saw-tooth transects to 500 m</td>
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<tr>
<td></td>
<td>Aanderaa AUVs</td>
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<tr>
<td>pH</td>
<td>Seabird central, inshore and offshore EOMs</td>
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<td></td>
<td>Seabird winched profilers</td>
<td>2 m above bottom to surface</td>
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<td></td>
<td>Seabird moored profilers</td>
<td>near bottom to 15 m below surface</td>
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<td>Optical attenuation and absorption</td>
<td>Wetlabs central, inshore and offshore EOMs</td>
<td>5 m below surface, 2 m above bottom to surface</td>
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<td></td>
<td>Wetlabs AC-9 central, inshore and offshore EOMs</td>
<td>2 m above bottom to surface</td>
<td></td>
</tr>
<tr>
<td>Chl-a and CDOM fluorescense, optical backscatter</td>
<td>Wetlabs winched profilers</td>
<td>2 m above bottom to surface, near bottom to 15 m below surface, saw-tooth transects to 1500 m, saw-tooth transects to 500 m</td>
<td></td>
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<td>Eco-Puck central, inshore and offshore EOMs</td>
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<td></td>
<td>Wetlabs moored profilers</td>
<td>near bottom to 15 m below surface</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wetlabs gliders</td>
<td>saw-tooth transects to 1500 m</td>
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<td>Wetlabs AUVs</td>
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<td>Spectral irradiance</td>
<td>Satlantic central, inshore and offshore EOMs</td>
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<td>Satlantic winched profilers</td>
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<td>Nitrate</td>
<td>Satlantic central, inshore and offshore EOMs</td>
<td>5 m below surface, 2 m above bottom to surface</td>
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<tr>
<td>Nutrients (NO₂, NO₃, PO₄, SiO₄)</td>
<td>SubChem AUVs</td>
<td>saw-tooth transects to 1500 m</td>
<td></td>
</tr>
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</table>
6.3.2  Pioneer Core Sensors and Platforms

The Pioneer Array core sensors and their locations are listed in Table 3. A combination of standard meteorological sensors for estimation of bulk fluxes and specialized sensors for direct (covariance-based) estimates of momentum and buoyancy flux will be deployed on the EOM surface moorings. This allows for investigation of air-sea interaction on the frontal scale and provides characterization of surface meteorology on so-called meso-beta and meso-gamma scales (20 to 200 km and 2 to 20 km, respectively). Nearby NOAA buoys (Figure 15), upgraded with a full meteorological
sensor suite using funds from the JAII, will provide regional scale meteorology. The two types of profilers and co-located bottom-mounted ADCPs are the primary tools for time-series monitoring of the water column, providing interdisciplinary observations resolving the semi-diurnally tidal band and lower frequencies. These observations will be supplemented by discrete sensors on the EOM surface moorings (5 m depth) and on the MFN frames to resolve higher frequency variability and to observe

**Figure 17**: Schematic diagrams of Pioneer Array moorings (not to scale). EOM moorings with Multi-Function Nodes (MFNs) supporting AUV docks (left panel) will be at the inshore and offshore sites. An EOM mooring with MFN supporting science user instrumentation (second from left) will be at the central site. Surface-piercing winched profilers with ADCPs at their base (second from right) will be at the inshore and central sites. Profiler moorings with wire-crawler type profilers and an ADCPs (right) will be at the intermediate sites along the inshore/offshore line, and at the upstream corners. Pioneer Core Sensors (Table 3) will be distributed among the surface buoys, EOM moorings, MFNs and profilers. Buoys, moorings and MFNs will also accommodate science user instrumentation, and acoustic modems on the EOM moorings will allow data transfer from science-user instrumentation deployed nearby.

The near-surface and near-bottom parts of the water column inaccessible to ADCPs and wire-crawler profilers. The two AUVs are the primary tools for resolving cross- and along-front “eddy fluxes” due to frontal instabilities, wind forcing, and mesoscale variability. In addition to carrying an interdisciplinary sensor suite similar to that of the gliders, each AUV will be outfitted with a novel, reagent-based nutrient sensor, providing
nitrate, nitrate, phosphate, and silicate measurements. The role of the gliders will be to monitor the mesoscale field of the slope sea and outer shelf, resolving rings, eddies and meanders from the Gulf Stream as they impinge on the shelf break front.

6.3.3 Technical Approach

**EOM Surface Moorings.** The Pioneer EOM moorings will share much of their surface buoy and subsurface mechanical design with the Global moorings. The Coastal buoy will be similar in construction Global buoy but with a smaller buoyancy module and lower tower, allowing it to be deployed by smaller regional-scale UNOLS vessels. Mooring elements just below the buoy accommodate an acoustic modem transducer, sensor frame, and electro-mechanical connections. The enabling technology for the Coastal mooring, which distinguishes the mooring design from the Global moorings, is the incorporation of a 30m stretch hose section. This design is optimal for shallow water applications where it is necessary to provide electrical and/or optical paths to seabed equipment while minimizing the risk of cable hockling by maintaining positive tension on the entire EOM section. The design can be tuned for water depths from 50 to 500 m using the WHOI CABLE mooring modeling software as a function of expected environmental conditions, hose and EOM cable length.

At the seafloor, an MFN terminates the bottom of the mooring and provides data and power ports for benthic instrumentation. The moorings will be terminated either at an MFN with AUV dock or at an unpopulated MFN. The MFN houses a rechargeable battery pack to provide high power for intermittent seafloor needs such as AUV battery recharging. The MFN also provides the weight necessary to anchor the mooring. The weight is provided by a cast steel anchor that can be acoustically released for recovery of the mooring. An anchor recovery line pack in the MFN allows the steel anchor to be hauled back once the MFN is recovered. The MFN will also be fitted with sufficient flotation to provide slight positive buoyancy when released. The latter attribute will facilitate recovery with standard deck equipment. An ROV will not be required, reducing installation and O&M costs. As stated above, the Coastal moorings will be designed for deployment and recovery by regional-class UNOLS vessels.

Control and data signals to and from sensors on the mooring flow along copper and optical conductors integrated with the various elements of the mooring strength member. These strength member elements include steel armored electro/optical/mechanical (EOM) cable, EOM molded chain bending strain relief members approximately 5 m in length, and, depending on water depth, one or two EOM mooring stretch hoses that can stretch from an original length of 30 m to upwards of 70 m while maintaining electrical and optical continuity. Within the water column, frames for sensors are provided for the mounting and protection of instruments at the junctions between the various mooring elements. Electrical breakouts near the surface buoy provide the instruments with connections for power and telemetry between the instrument frames and the buoy. The EOM mooring’s optical link allows for high-speed
communication between the surface buoy controller and the MFN. This direct link is available for the AUV in its dock and can be broken out for instrumentation on the MFN frame or near the bottom of the mooring.

**Power Generation and Distribution.** Due to the high power requirements imposed on the Pioneer Coastal moorings, in support of AUV recharging and a relatively high power directional satellite antenna, the surface buoy is equipped with the same high-power system as the Southern Ocean buoy, with a methanol fuel cell supplementing wind and solar power generators.

Power storage onboard the buoy will consist of a bank of Absorbed Glass Mat (AGM) lead acid batteries, similar to those in the global buoys. A backup alkaline battery pack aboard the buoy will offer limited operability (Iridium satellite communications and non-MFN sensor systems) for several months if power generation systems fail. Power requirements for the two AUV docks, and for science user instrumentation on the third MFN, are expected to be significant relative to short-term power generating capability. Thus, a battery reservoir is needed on the MFN that can be charged at an appropriate rate from the surface buoy. The power controller on the Coastal mooring buoy will manage the distribution of power to the MFN reservoir after stepping up the voltage to reduce losses in the mooring conductors. The power controller will monitor voltage, current, estimated “fuel gauge” levels and ground fault leakage of surface and seabed reservoirs, and report to the surface buoy controller. PVA or wind power subsystems that fail will be isolated. Ongoing attention will be paid to alternate power generation solutions, initial costs associated with developing fuel cell for the buoy power systems have been found to be high.

**Buoy Control and Communication System.** System control, subsurface acoustic communications, surface telemetry and data logging for the Pioneer Coastal moorings will be accomplished with the same dual-controller system proposed for the global buoys (Exhibit B-2). The principal differences are that a higher data throughput (4 Mbyte/day) has been budgeted for each Coastal mooring and that FreeWave and WiFi buoy-to-ship data offload will be used more extensively to obtain records from high data rate sensors such as AUVs and science-user instrumentation on the MFN.

**Multi-Function Node (MFN).** The Pioneer MFN is a benthic platform to supply communications and power for “clients” that include AUV docks and unspecified science-user instrumentation. The MFN power system is geared towards clients with large, episodic power requirements such as an AUV, but will also support multiple, low power sensors with regular sample intervals. All three MFNs will be capable of supporting multiple onboard (e.g. frame-mounted) sensors as well as external sensor packages connected to the MFN frame by ROV wet-mate connectors. Power available for science-user instrumentation will be limited at the inshore and offshore sites due to the demands of the AUVs, but the MFN at the central site will be dedicated to science-
users, allowing sensors and instrument packages to be placed at the climatological location of the shelf break front and jet.

The MFN acts as a power and telemetry breakout between the mooring EOM cable and the science users. The user interface consists of 8-12 dry-mate, electrical connectors, which provide DC power and a 10/100BaseT Ethernet connection. An ROV pluggable, wet-mate connector on the MFN frame will provide the same Ethernet data interface and a high voltage DC power supply to allow for a long cable run. The MFN as presently designed will act as a simple data pass thru with no local storage capability. Data coming into an MFN user port is immediately transmitted up to the surface buoy. The fiber optic telemetry system is always powered and active so there is no need to store data at the MFN. Any data logging required will be provided by the science user or by a remote DCL (data concentrator/_logger).

The surface buoy power system will be capable of delivering up to 1kW peak power to the MFN. The cable voltage will be stepped up to 300-500 VAC in order to reduce power loss in the cable and then transformed back down at the MFN. To satisfy the needs of high power/low duty cycle users, the MFN will include an onboard lithium ion battery reservoir capable of supplying up to 600 W at 28 VDC, consistent with known AUV charging requirements. A battery controller will manage the charge/discharge process and report reservoir status and state of charge. An MFN controller board will convert, switch and monitor power to all users and also negotiate power usage requests in the context of total power available from the surface and local batteries. If the power drawn by users exceeds power available, the MFN controller will scale back users based on a predetermined schedule to avoid system damage or an ungraceful shutdown. The MFN controller will also monitor voltage buses for over-current, out-of-range voltage or fault to seawater.

**Coastal Winched Profilers.** The Coastal Winched Profiler consists of an aluminum bottom frame (1.7 m diameter, 1.4 m high) which has mounting points for sensors and contains an anchor weight and release mechanism. For the Pioneer Array application, the frame will include a battery pack to re-charge the profiling package and an upward looking ADCP. A buoyant profiling package uses the bottom frame as its base and winches itself up and down through the water column. The profiler includes flotation material, a winch system, battery pack, controller, scientific sensors, and an iridium satellite telemetry system. The profiler is designed to pierce the surface, providing observations through the surface layer and allowing satellite communications. The profiler seats in the bottom frame when at the bottom of its travel, allowing onboard batteries to be recharged and data from the ADCP to be uploaded via an inductive link. Advantages of the winched profiler relative to a wire-crawler are full water column profiling and the ability to house a more complete set of sensors. Limitations are higher cost and a maximum expected operating depth of 200 m. These limitations led to a combination of winched and wire-crawler profilers for the Pioneer Array.
Coastal Profiler Mooring. The Profiler Mooring (Figure 17) will be of conventional design from the anchor to the subsurface flotation sphere, but will also include a surface expression. An electromechanical (EM) stretch mooring hose will connect a small surface buoy to the subsurface flotation sphere, providing compliance in the upper 15-20 m of the mooring (to accommodate tidal excursions and wave motion) while allowing the flotation sphere to maintain vertical tension in the wire-rope portion of the mooring on which the profiler rides. The March 2007 CND promoted profiler moorings with acoustic transmission of data to the Coastal surface moorings. However, the long (5 km) horizontal acoustic channels in shallow water (defined as depth much less than the horizontal path distance) required for the intermediate Profiler Moorings represent significant expense and risk compared to the proposed mooring design where data will be sent directly to shore via Iridium. Profiler moorings will be equipped with a wire-crawler type profiler that will translate all but the upper 15 m of the water column and an ADCP situated near the bottom. Both will transmit data inductively using COTS inductive modems over the jacketed steel cable with seawater return, through conductors in the flotation sphere and stretch hose, to a receiver in the surface buoy.

The profiler mooring surface buoy will be a small (~1 m diameter) foam disk containing a telemetry controller, Iridium modem and antenna. The design will be based on an existing, power-efficient controller used for long-term Arctic deployments with similar instrumentation (www.whoi.edu/itp). An inexpensive alkaline battery pack on the buoy will power both satellite and inductive communications for a year while permitting command and control from shore as part of any data transmissions via the Iridium link. The profiler and ADCP will be powered from internal battery packs. The candidate profiler is available from the factory with an integrated inductive modem and controller, while the ADCP will require an external inductive modem and controller. The profiler is capable of approximately one million meters of travel, allowing six profiles per day for a year in 500 m water. The ADCP, with external battery packs, will be capable of at least one profile per hour for a year.

Autonomous Underwater Vehicles. Two AUVs will operate from the EOM Surface Mooring docking stations, running synchronized, synoptic sampling missions of ~100 km along- and across-shelf. The baseline AUV missions will be 200 – 250 km of total track length within a region of about 100 by 80 km centered on the moored array (see schematic example in Figure 15 and plan view of the AUV “box” in Figure 16). The interval between missions will be 5-10 days, determined by the rate of power generation by the surface buoys. The two AUV docking stations will be integrated with an MFN at the base of the inshore and offshore EOM moorings (Figure 17). The AUV missions will be user-controllable via satellite link directly to the vehicle (while on the surface) or through the Coastal Mooring/MFN (when docked).

The third AUV will be operated via day-trips of a small (~60 ft) coastal vessel and will have three purposes: 1) to provide adaptive sampling and event-response capability without interrupting the baseline AUV missions, 2) to serve as a replacement vehicle if
the baseline missions cannot be accomplished due to malfunction, and 3) to provide regular comparisons of moored bio-optical sensors with freshly calibrated sensors (on the vehicle) as a means of mitigating sensor degradation during long-term deployment. Twelve days per year for a coastal vessel (some to be combined with glider servicing) are planned, providing four three-day trips. Including AUV operations conducted during mooring service cruises (twice per year) yields a baseline of six deployments per year for the third AUV.

The attributes of the REMUS-600 AUV (described in detail at www.hydroidinc.com/remus600.html) satisfy the use requirements, and this vehicle is budgeted as a prototypical example. For use in the Pioneer Array, the vehicle will be specially modified to enable sub-sea docking (including a special nose assembly and ultra-short baseline acoustic navigation), and to allow integration of core sensors and a 4-channel nutrient analyzer. Two 5 kWh Li-ion battery packs will be used to increase endurance. Demonstrated endurance with two battery packs and a basic sensor suite is 500 km at 3.5 kt. Demonstrated navigational accuracy with inertial navigation (standard) and ADCP bottom track is less than 0.2% of distance traveled, without the use of navigational beacons. Maximum operating depth is 600 m.

Gliders. An array of six gliders will survey the outer shelf and the slope waters offshore of the moored array. Six cross-shore lines of ~150 km with 25-30 km spacing between lines (Figure 15) will be simultaneously occupied. The lines will be repeated at intervals of approximately 2 weeks and individual gliders would remain in the field for several months before being recovered for refurbishment. The attributes of the Spray glider (described in detail at http://spray.ucsd.edu) satisfy the use requirements and this glider is budgeted as a prototypical example. For use in the Pioneer Array, the gliders will carry a multi-disciplinary sensor payload, including bio-optical sensors with copper shutters for mitigation of biofouling. Demonstrated endurance with a basic sensor suite is about six months. Maximum operating depth is 1500 m.

6.3.4 Installation and Servicing

While all of the platforms and sensors are based on demonstrated capability, the Pioneer Array pushes the limits of current technical development in many areas. As a result, multiple engineering field tests will be necessary prior to commissioning Pioneer Array sites for routine operation. These test deployments are expected to mimic the actual operational environment, but in more benign conditions (e.g., summer rather than winter) and for a shorter duration. Engineering field tests for Pioneer Array elements are scheduled to begin in year three, with two four-day cruises on R/V Oceanus for mooring deployment, testing and recovery and two two-day trips on R/V Tioga for AUV and glider deployment, testing and recovery of. One five-day Oceanus cruise and one two-day R/V Tioga cruise in year four (October 2010) will lead to the partial commissioning of the Pioneer Array (a subset of complete sites or a subset of platforms at all sites) later in the fiscal year (May 2011). Because a full set of mooring-component
and sensor spares are not available, partial commissioning is desirable in order to stagger the time-in-service of array elements. Commissioning of the full Pioneer Array is expected early in year five.

There would be three principal installation phases: gliders first, profiling moorings second, winched profilers, and then EOM surface moorings/MFNs and AUVs.

Once the full Pioneer Array is in place, servicing will consist of two cruises, one on an intermediate-class vessel (Oceanus is assumed) and one on a coastal vessel (Tioga is assumed) twice per year. The Oceanus cruises would be for mooring service, glider recovery and re-deployment, and AUV recovery, while the Tioga cruises would be for AUV re-deployment. Due to the desire to operate in hospitable weather, as well as the need to mitigate degradation of sensors due to biofouling, the cruises will be in May and October. Recovered mooring elements and instrumentation will be returned to WHOI for service, with priority given to the AUVs. These will be refurbished within a few weeks, returned to sea on the Tioga, and deployed in proximity of the Array such that they are able to re-acquire the AUV docks and continue their sampling mission. The second service operation of the year would be analogous to the first, but the array elements with the longest time-in-service will have changed. After the second set of cruises all array elements would have been serviced or replaced, and the cycle would begin again.

Durable mechanical elements such as surface buoys, instrument frames, and acoustic releases would be refurbished ashore and are expected to last in excess of 10 years. EOM molded chain, EOM cable and stretch hose elements will initially be replaced annually. However as performance becomes fully characterized, the life cycle of these components may be extendable. Wire rope and mooring hardware such as shackles and links will be replaced with new material at each turnaround. Buoy and Core Sensor primary battery packs will be sized to last for at least 1 year, and changed out regardless on the annual service cycle. Rechargeable batteries in the Coastal mooring, MFN and AUV are expected to operate for 5 years. Short of physical damage from wave impact or vandalism, PVA panels are expected to have a five-year lifetime. The lifetime of wind turbines, particularly the aircrew (propeller) driven style, is less well known and we expect that these units may have to be changed out on an annual basis. Fuel cell generator modules have a lifetime proportional to their hours of use, and are expected to be replaced yearly.

6.4 Coastal Scale Nodes - The Endurance Array

6.4.1 Location

Endurance Line (Central Oregon-Newport Line)

Location: 44° 39’N, 126°W to coast; Water Depth: 500-25 m
Platform Types: three seafloor nodes at 25, 80, and 500 m water depth (two cabled and one un-cabled) supporting profilers and benthic boundary layer sensors, three fixed surface moorings, and adaptive sampling using gliders

Description of Infrastructure:
• Two surface MET moorings (80, 500 m) with wind and photovoltaic power generation, iridium communications, and meteorological sensors
• One EM surface mooring (25 m) with battery power and Iridium communications
• Two winched profiler moorings (25, 80 m)
• One combination mooring with subsurface profiler and winched profiler (500 m)
• One LV benthic node with electrical communications to surface buoy and supplementary battery power provided by the surface buoy (25 m)
• Two LV benthic nodes with fiber optic communications and power provided by MV benthic nodes attached to the RSN (80 m, 500 m)
• Six gliders

The backbone of the Endurance Array will be three fixed sites spanning the slope (500 m), mid-shelf (80 m) and inner-shelf (25 m). The most transformative design element of the 500 m and 80 m sites will be the cabled infrastructure that integrates the Endurance Array with the RSN cable through an extension off N1 as described in the Regional Scale Nodes Secondary Interface White Paper (25). This CGSN-RSN partnership will extend the reach and capability of the RSN infrastructure into the coastal environment and allow the OOI to support synoptic experiments across this range of scales. Cabled infrastructure of the Endurance Array will be provided under agreement with the RSN and will use the same physical interfaces, command control and data transport mechanisms as other RSN components to minimize duplicated design work by RSN, CI or CGSN. The cabled infrastructure will support an extensive suite of core sensors deployed on winched profilers and at benthic boundary layer nodes. Equally important, the cabled infrastructure will also provide access for the science user community enabling experiments requiring high power, high bandwidth sensors. Surface moorings will also be present at the 500 m and 80 m sites. These moorings will provide continuous meteorological and surface boundary layer measurements.

As the conduit between the shelf and the near-shore zone, the 25 m site is both scientifically important and logistically challenging. Breaking waves and sediment transport driven by winter storms make relatively delicate surface buoy towers, MET sensors, and buried bottom cabling impractical. Instead we will install a surface buoy hardened to overtopping by waves. The buoy will support surface water column measurements, two-way communications with the seafloor, and will provide power to benthic boundary layer sensors via a battery pack. A standalone winched profiler will also be deployed at this site, communicating through iridium.

The three fixed sites are correlated in the cross-shelf direction along the historical Newport Hydroline, but are each associated with unique physical, geological, and
biological processes. To bridge the distances between the fixed sites and allow adaptive sampling, we will use six autonomous gliders. These gliders will support sensors similar to those on the winched profilers. The 6 gliders planned for the PNW Endurance Array will operate along four cross-margin lines along 43.5, 44.6, 47.0 and 48.0 N latitude, from approximately the 20-m isobath out to approximately 126W. The gliders will also run north-south along approximately 126 W. The northernmost glider track will not enter the Canadian EEZ but will allow some continuity with the VENUS and NEPTUNE Canada arrays as well as RSN, GSN, and NOAA assets.

Together, the gliders, surface buoys, profilers, and benthic nodes will provide near real time data from the air-sea interface, through the water column and to the sea-sediment interface. This full water column coverage at several sites with bottom cabled infrastructure provides experimental capabilities that are unique within the OOI.

6.4.2 Endurance Array Platforms and Core Sensors

The geographic locations of the cross-shelf Endurance array moorings are given in Table 5 and are shown schematically in Figure 18. The moored array is aligned perpendicular to isobaths and spans from the inner-shelf to the mid-shelf and on to the slope. The mid-shelf and slope sites combine fully instrumented surface platforms with cabled profilers and benthic boundary layer sensors. The inner-shelf site combines a surface platform electromechanically linked to benthic boundary layer sensors and a stand-alone winched profiler. The three environments are linked physically, biologically, and geologically, yet represent distinctly different processes. As an example, wave forcing is especially important at the 25 m site, while local and remote wind forcing is dominant at the mid-shelf site and slope currents and offshore mesoscale variability is important at the slope site.

The core science sensors for the PNW Endurance Line are listed in Table 4.

**Table 4:** Core science sensors for the PNW Endurance Line.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Example Sensor</th>
<th>Platform</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>Surface wave spectra</td>
<td>PSI/Neptune</td>
<td>80m and 500m Surface Buoy</td>
<td>motion sensors in buoy hull</td>
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<td>delta pCO2 (air/sea)</td>
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<td>water-side pCO2</td>
<td>SAMI-15000</td>
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<td>25m, 80m and 500m Moorings</td>
<td>5m or 10m below the surface</td>
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<td>Seabird</td>
<td>benthic experiment nodes</td>
<td>Near Bottom</td>
</tr>
<tr>
<td>Mean Currents</td>
<td>Nortek</td>
<td>25m, 80m and 500m Moorings</td>
<td>surface</td>
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<td></td>
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<td>25m, 80m, 500m winched profiler</td>
<td>2m above bottom (except</td>
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<td>Parameter</td>
<td>Instrument/Device</td>
<td>Location Details</td>
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<tr>
<td>Mean velocity (profile)</td>
<td>RDI</td>
<td>25m, 80m and 500m Moorings near surface to near bottom</td>
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<td>RDI</td>
<td>winched profiler base near bottom to near surface</td>
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<td></td>
<td>Nortek</td>
<td>saw-tooth transects to the seafloor or 1000 m</td>
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<tr>
<td>Dissolved oxygen</td>
<td>Nortek</td>
<td>25m, 80m and 500m Moorings 5m or 10m below the surface</td>
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<td>Aanderaa</td>
<td>saw-tooth transects to the seafloor or 1000 m</td>
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<td>Aanderaa</td>
<td>2m above bottom (500m site: starts at 200m) to surface</td>
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<td>Aanderaa</td>
<td>2m above bottom (500m site: starts at 200m) to surface</td>
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<td>2m above bottom (500m site: starts at 200m) to surface</td>
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<td>Aanderaa</td>
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<td>near Bottom near bottom to 200 m below surface</td>
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<td>WET Labs</td>
<td>near Bottom 2m above bottom (500m site: starts at 200m) to surface</td>
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<td>Spectral irradiance</td>
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<tr>
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<td>WHOI micromodem</td>
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<td></td>
<td>WHOI micromodem</td>
<td>benthic experiment nodes Near Bottom</td>
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<td>Seabird</td>
<td>25m, 80m and 500m benthic experiment node Near Bottom</td>
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<td>Profiler Details</td>
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<td>FSI</td>
<td>McLane profiler at 500m site</td>
<td>near bottom to 200 m below surface</td>
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<td>25m, 80m, 500m winched profiler</td>
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<td></td>
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<tr>
<td>Camera</td>
<td>Deep Sea Power and Light</td>
<td>25m, 80m and 500m benthic experiment node</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2m above bottom (500m site: starts at 200m) to surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horiz electrical field pressure inverted echosounder</td>
<td>HPIES</td>
<td>500m benthic experiment node</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2m above bottom (500m site: starts at 200m) to surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTD</td>
<td>Seabird McLane profiler at 500m site</td>
<td>near bottom to 200 m below surface</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2m above bottom (500m site: starts at 200m) to surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25m, 80m, 500m winched profiler</td>
<td>saw-tooth transects to the seafloor or 1000 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seabird gliders</td>
<td>2m above bottom (500m site: starts at 200m) to surface</td>
<td></td>
</tr>
<tr>
<td>Chl-a and CDOM fluorescense, optical backscatter</td>
<td>WET Labs McLane profiler at 500m site</td>
<td>near bottom to 200 m below surface</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WET Labs 25m, 80m, 500m winched profiler</td>
<td>2m above bottom (500m site: starts at 200m) to surface</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WET Labs gliders</td>
<td>saw-tooth transects to the seafloor or 1000 m</td>
<td></td>
</tr>
<tr>
<td>PAR</td>
<td>Biospherical Instruments 25m, 80m, 500m winched profiler</td>
<td>2m above bottom (500m site: starts at 200m) to surface</td>
<td></td>
</tr>
</tbody>
</table>

To allow comparison across the OOI, sensors are quite similar to those selected for the Pioneer array and the global scale nodes. Meteorological sensors and near-surface ocean sensors are deployed at the slope and mid-shelf sites. Meteorological sensors are deployed to resolve first order cross-shelf gradients in surface heat and momentum fluxes (including wind stress curl and cross-shelf diurnal wind variability). Surface sensors will be deployed at these buoys and at the inner-shelf site to resolve cross-shelf gradients in water properties including nutrients and ocean color. The in-situ measurements provided by these buoys will be an important source of ongoing improvement of algorithms for satellite estimation of wind stress and ocean color near the sea-land boundary. The moored profilers and bottom-mounted ADCPs are the primary tools for time-series monitoring of the water column, providing interdisciplinary observations resolving the semi-diurnal tidal band and below. The gliders will carry an interdisciplinary sensor suite as described in the Pioneer Array description and Table 3. They will monitor shelf and slope water column variability at mesoscale and lower frequencies. The gliders will be crucial to monitoring processes such as upwelling frontal instability, riverine buoyant plumes, and the along-shelf extent of blooms and hypoxic events. Their datasets will overlap directly with the higher frequency fixed node observations along 46.65° N.
### Table 5: Endurance location table

<table>
<thead>
<tr>
<th>Location description</th>
<th>Approximate latitude, °N</th>
<th>Approximate longitude, °W</th>
<th>Depth, m</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP2 (OR 500)</td>
<td>44.65</td>
<td>124.90</td>
<td>500</td>
<td>Slope site, cabled, shared infrastructure with RSN</td>
</tr>
<tr>
<td>NP3 (OR 150)</td>
<td>44.71</td>
<td>124.51</td>
<td>150</td>
<td>MV node only, future infrastructure possible upscope</td>
</tr>
<tr>
<td>OR 80</td>
<td>44.64</td>
<td>124.30</td>
<td>80</td>
<td>Mid-shelf site, cabled, powered from NP3</td>
</tr>
<tr>
<td>OR 25</td>
<td>44.65</td>
<td>124.10</td>
<td>25</td>
<td>Inner-shelf site, uncabled</td>
</tr>
</tbody>
</table>

**Figure 18:** Map of the location of the Endurance Array off Oregon. The Endurance sites are at the 25 m, 80 m, and 500 m sites along the line off Newport. The cables of the RSN are also shown.
6.4.3 Technical Approach

**Benthic Nodes.** The OR-80 and OR-500 m sites will have a LV benthic junction box attached to the medium voltage (MV) junction box that links to the RSN. This LV benthic junction box will provide power and communications with the subsurface profilers at these locations as well as user specified science instrumentation.

The OR-25m site will have a multi-function node (MFN) below the EM surface buoy. This MFN will provide power and control similar to the LV junction box. It will be powered internally and also receive power from the surface buoy. It will communicate with the surface buoy via an EM communication link. The MFN will provide power and real time communication core sensors and future user experiments on the benthic node. Surface meteorological sensors and wind/solar power generation have been dropped from the 25-m moorings since they are unlikely to survive 10-m waves in winter storms when the buoy is likely to be submerged.

**Winched Profilers.** Each mooring site will also have an associated profiling mooring (Figure 18). The profiler moorings will be of two types: standalone (at OR-25) or connected to the RSN (OR-80 and OR-500). The stand-alone profiler moorings are internally powered and will communicate acoustically with the surface moorings located less than 2 km away. Those profiler moorings connected to the RSN will receive power and communicate via the secondary cabled infrastructure. The OR-80 and OR-500
profilers will still be paired with nearby surface moorings and retain the capability to communicate acoustically with them. Winched profiler moorings consist of an aluminum bottom frame that is approximately 1.7 m diameter and 1.4 m high, with mounting points for an ADCP and other near bottom sensors, anchor weight, an anchor release mechanism, and a profiling package that includes flotation material, a winch system, a sealed lead acid battery pack (12 AH at 18-42 volts), controller, scientific sensors, and a radio and iridium satellite telemetry system. The profiler package will be extend 2 m or less above the top of the base. The connection between the bottom frame and profiling package is a synthetic line approximately 8 mm in diameter. When the profiling package is at the bottom of its travel it seats in the bottom frame and can communicate with and download data from the ADCP via an inductive link. These profiler systems can operate in depths approaching 200 meters depending on current conditions.

The bottom frame can be used in two modes, as a standalone battery-powered base, or as a cabled connection to low voltage node. The standalone base will contain a set of lithium ion battery packs (72 AH at 25-42 volts) providing a power reservoir for the winched profiler. It will have the capability to communicate engineering data to a nearby (less than 1 km distant) surface buoy via an acoustic modem. In the cabled mode, the base will be cabled to the low voltage node via a wet mateable connector. The connection will be made and broken using an ROV. In this mode, the low voltage node will provide power and the primary two way data link to both the base and the profiler (via the inductive link).

Hybrid Profilers. The profiler mooring at 500m will follow the design of the RSN water column mooring as described in Section 7. This hybrid profiling mooring consists of an electrical/optical/mechanical (EOM) cable that is connected to a LVN and anchored to the seafloor. The cable rises 300m to a buoyant platform 200 meters below the sea surface. The platform keeps the EOM cable taut. From the platform, a winched profiler samples from the platform to the sea surface; the winch system will be ROV-serviceable. At the platform, an inductive data and power coupler allows the Profiler to transmit data to the 200-meter J-Box and to recharge the Profiler batteries. Real-time communication with the Profiler is accomplished using a low data-rate inductive modem for command and control and data transfer. The Profiler can be installed and removed using an ROV to facilitate service. The winched profiler will be designed such that sensors can be serviced from a small boat when the profiler is at the surface.

Coastal Surface Moorings. The surface mooring would provide any meteorological observations, power to surface and subsurface instruments, and real time data transmission. The Endurance moorings will be similar in design to the Coastal mooring type developed for the Pioneer array, but without power transmission below a near surface sensor attachment point at 5 m. Like the Coastal mooring buoys, power will be generated using a combination of wind turbines and photo-voltaic panels. Due to the lower power requirements of the Endurance coastal mooring, it would not include the methanol fuel cells described for the Pioneer coastal mooring. Wind and solar power will
be used to charge storage batteries in the buoy, and ultimately will be delivered to meteorological and near surface instrumentation. The buoy control and communication system will be as proposed for the Pioneer and global scale buoys. The surface buoys will provide Ethernet (twisted pair) and acoustic communication with subsurface sensors, as well as three different types of air-side communication systems (Iridium, FreeWave, and WiFi). In addition to the core instrumentation, the surface buoys will provide power and communications to two user-specified near surface sensors. There will be provision for one near surface sensor at the base of the buoy and one sensor at 5 m beneath the buoy in a load bearing cage.

Near-shore surface mooring. The near-shore mooring(s) will comprise a surface buoy with mooring control, battery power, telemetry and scientific sensors, an EM mooring strength member running to the bottom, and a multifunction node (MFN, described in the section on coastal moorings) with power and data distribution capabilities. The MFN also provides the weight necessary to moor the system. The surface buoy has a welded aluminum core structure and yellow closed-cell polyethylene foam buoyancy module about 1.5 m in diameter. It has a welded aluminum tower structure approximately 2 m high to support antennas, a radar reflector, and amber flashing light. It is hardened for submergence by breaking waves.

The buoy contains an electronics controller consisting of a microcomputer running code designed to control power supplied to sensors, acquire and log data, and transmit recorded data to shore via satellite and/or radio links. Power is stored in absorbed glass mat (AGM) sealed lead/acid batteries housed in a chamber within the buoy hull structure. An alkaline battery pack may be used for backup power supply in the event of a power system failure. Telemetry to and from the mooring is via satellite and/or radio links including Iridium, Freewave, WiFi, etc.

The near-shore buoy is designed to support sensors on the buoy base and 5 m beneath the surface. Control and data signals to and from sensors below the buoy flow along copper conductors built into the mooring strength member elements. These include steel armored electro/optical/mechanical (EOM) cable approximately 15 mm in diameter, EOM urethane molded chains approximately 75 mm in diameter and 5 m in length, and, depending on water depth, one or two EOM mooring stretch hoses that are approximately 100 mm in diameter and can stretch from an original length of 15 m to upwards of 32 m, and serve to reduce shock loading in the mooring for increased longevity. Frames for sensors are provided for the mounting of instruments at the junctions between the various mooring elements. Electrical breakouts provide the instruments with connections for power and telemetry. The optical link allows for high-speed communication between the surface buoy controller and the MFN instrumentation.

Gliders. An array of gliders will survey the outer shelf and provide high resolution transects of the moored cross-shelf Endurance lines. Repeat missions of several
hundred km will be run over a period of several months until the gliders are recovered for servicing and replacement. The purpose of these missions will be to characterize the mesoscale field, upwelling fronts, and buoyant plume fronts over the shelves and provide spatially rich data in which to embed the moored Endurance time series data.

6.4.4 Installation and Servicing

The installation of cabled and non-cabled components elements of the Endurance Array are independent of one another. That is, installation of uncabled components (surface moorings and the 25 m site) does not depend on cabled infrastructure and vice versa. Similarly, glider deployment does not depend on the deployment of fixed assets.

Since many of the uncabled Endurance Array components are the same as Pioneer array components, testing will occur when the Pioneer components are tested. Winched profilers will be developed and tested with deployments of increasing duration off the Oregon coast in Years 2 and 3. The near-shore buoy will also best tested in Years 2 and 3. The initial operational deployment of the near-shore buoy would occur in spring with a recovery and thorough examination of the components in fall. Redeployment of the buoy over the more severe winter conditions would occur only after the mooring performance and wear on mooring components during the summer deployment was verified.

Cabled Endurance array components will be developed and tested by the RSN. The buried fiber optic cable will be laid in concert with the RSN cable after site surveys are completed. Deployments of cabled infrastructure (MV and LV nodes, junction boxes, benthic sensor packages, the hybrid profiler, and winched profilers) will be coordinated with RSN, using the same ship and ROV.

Experience indicates that twice-per-year servicing in the coastal environment is a minimum requirement because of biofouling. Both surface moorings and stand alone subsurface profilers can be serviced using an intermediate class UNOLS ship such as the R/V Wecoma. At each turnaround, sensors and mooring hardware would be cleaned and checked. Most sensors will need a once per year recalibration, as budgeted for this in operations and maintenance planning. Experience shows that many mooring components (e.g., molded chain and compliant hose) will last at least two years. A 15% per year attrition rate on sensors and long-lasting mooring hardware (e.g., surface buoys and bottom sleds) is assumed in operations and maintenance planning.

For Endurance Array components that are connected to the RSN, a once per year turnaround is planned. Servicing would be done using a ship with ROV support capabilities, which will likely be coordinated with the RSN. For replacement of cabled infrastructure, attrition rates similar to those for other moored components are assumed, except for the winched profilers, which would be serviced twice per year when uncabled Endurance Array components are turned around.
For gliders, installation and servicing will occur through small boat operations. Operations and maintenance requirements are based on experience with small numbers of gliders operated to date. These include small boat time, iridium-based communications, sensor recalibration, and other maintenance. A 20% attrition/replacement rate is also assumed.

Potential enhancements to the Endurance PND fall into two categories: restoring scope reductions made to remain within budget, and addition of seabed and benthic sensors to the Endurance Array. Up-scope paths include: 1) a cabled benthic node and winched profiler at the OR 150 m site and/or 2) instrumentation of Washington line moorings (beginning with a minimum of two sites at 80 m and 25 m). We also recommend several sensors be added to the proposed infrastructure. The highest priority sensors are: water column bioacoustics and seabed optical sensors at the LV benthic nodes. The addition of these sensors will allow a much more complete assessment of biological and biogeochemical properties and dynamics at the water-sediment interface and in the water column above.
6.5 Coastal and Global Sale Nodes: Up-Scope and Down-Scope Options

The CGSN Ad Hoc Team (17) developed a prioritized list for the design of each infrastructure element, which guided the development of the CGSN PND. At the same time, potential up-scoping and down-scoping scenarios were discussed. The potential scope options are based on several perspectives: improving observing capability, improving reliability and redundancy, and building back reductions made to meet the cost guidelines.

A CGSN-wide view that would restore scope eliminated from the PND baseline leads to these up-scope options, not listed in order of priority:

- add a fourth global site (Mid-Atlantic or other)
- add the OR 150m mooring to Endurance
- add elements of the Washington Endurance line (25m, 80m, 150m)
- deploy the Extended Draft Platform
- add site P2 (an upstream EOM mooring with MFN) back to Pioneer
- add EOM cabling to an MFN at 55°S
- add the surface mooring to Ocean Station Papa

Improving observing capabilities and reliability of observations leads to selection of:

- improved redundancy in observing, such as by including dual sets of meteorological sensors;
- increased provision of spare buoy and mooring hardware to maintain continuous operations at all sites

If further reductions from the PND baseline became necessary, the CGSN strategy would include examining the science impact of the following options:

- Dropping the power augmentation on the global and Pioneer surface moorings
- Cable only the 500m site on the OR Endurance line
- Drop the third Pioneer AUV
- Drop Ocean Station Papa
7 Regional Scale Nodes Preliminary Design

7.1 Introduction

The Preliminary Network Design for the Regional Scale Nodes is based on the revised Conceptual Network Design (13). The current design is more fully described in the RSN Preliminary Design Document Version 2.0 (26). The RSN design incorporates the findings of two trade-off studies completed by the RSN IO to investigate optimal configuration of the cabled backbone infrastructure and shore station location(s). These studies include the Regional Scale Nodes Wet Plant Primary Infrastructure White Paper (27) and the Regional Scale Nodes Shore Station Options White Paper (28). Further definition of the RSN design is developed in the RSN Secondary Infrastructure White Paper (25).

As discussed further in (27), a STAR configuration (Figure 20) now replaces the previous RING configuration as the working design of the Primary Infrastructure. As discussed further in (28), this design incorporates two shore stations at Pacific City, Oregon and at Warrenton, Oregon. A high level block diagram of the RSN is shown in Figure 21. More detailed RSN block diagrams are given in Appendices 4-13.

In this and all future documents, Primary Infrastructure refers to the backbone cable and primary nodes, Secondary Infrastructure to extension cables that come off the primary node and associated secondary nodes and low voltage nodes, and Tertiary Infrastructure to junction boxes, associated minor extension cables, moorings, and sensors. The RSN STAR configuration includes five primary nodes, designated N1-N5, each attached to nearly linear cable backbone segments linked directly to the shore stations. An exception to this configuration is the newly added mid-plate node, N5, located mid way between the Pacific City Shore Station and N3. As outlined in the Wet Plant Infrastructure White Paper, the STAR configuration offers significant advantages over the RING geometry in terms of utilizing existing technologies to achieve parity; it is a less risky approach to supporting the same node geometry served by the RING configuration, the power distribution scheme is simpler and more flexible, yet retains significant expandability, and the two shore stations result in significantly fewer cable crossings. Because it is a more conventional schema for the submarine cable industry, the STAR configuration is expected to attract more competition in the commercial procurement for the Primary Infrastructure.

The positions of the first four primary backbone nodes were revised from the CND based on a Desktop Study of the Regional Scale Cabled Nodes prepared by Fugro Seafloor Surveys, Inc. completed in April 2007. The study suggests adjustments for node locations based on assessment of bathymetry and seafloor roughness, hazards (ordinance and waste dumps) and obstructions, the location of commercial fisheries, and other cable installations in the proposed area of study. Subsequently, the position of Node 3 at Axial Seamount was further revised based on safety considerations and
was moved ~ 40 km to the northwest, adjacent to the northeastern flank. This new position results in a shorter run of armored extension cable (~ 30 km less) to the low voltage node near the summit of the volcano and places the cable out of the active zone of spreading and volcanism. All cable locations, and therefore cable lengths, will be reevaluated based on the results of a new Desktop Study and results from future surveying studies. The RSN PND also includes water column moorings at two of the primary nodes, with up-scope contingency for three additional profiling moorings at the other primary nodes. Each mooring contains a suite of core sensors located on a platform at 200 m, a surface winch and a profiler, and an instrument package.

Figure 20: Star configuration and location of two shore stations for the Regional Scale Node component of the OOI. Future extensions to nodes s, t, and w are not considered in this document, but these nodes are shown for completeness.
7.2 Field and Sensor Requirements

To illustrate the RSN infrastructure shown in the functional block diagrams (Appendices 4-13), preliminary illustrations of the field relationships and sensor distributions at each of the focused study sites are shown in Figures 22-25. Exceptions to this include a common suite of sensors at each primary node (Table 6) and the water column moorings and sensors (Figure 26 and Table 11), which are not included in the seafloor illustrations because their locations are straightforward. As noted above, a more complete discussion of the primary nodes, secondary nodes, low voltage nodes, junction boxes, and moorings are included in Reference (25).

A node-by-node description of the RSN preliminary design is presented below, followed by a complementary description describing the regional array that emphasizes water
column infrastructure and science. A table giving details of the various core sensors in the RSN design can be found in Appendix 2. In this appendix and the sensor tables in Section 7, references to specific manufacturers do not necessarily represent final choices.

**Table 6: Core Sensors at each Primary Node**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Example Sensor</th>
<th>Manufacturer</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global/regional seismic events, subduction earthquakes, slow quakes</td>
<td>Broadband Triaxial Seismometer</td>
<td>Guralp CMG-1T 360s-50Hz</td>
<td>Buried in caissons in sediment ~ 1 m beneath seafloor covered in silica beads</td>
</tr>
<tr>
<td>High frequency events, marine mammals</td>
<td>Hydrophone</td>
<td>Naxys Ehyd</td>
<td>Very close proximity to broadband</td>
</tr>
<tr>
<td>Local currents, background ocean temperature</td>
<td>Current Meter + Temperature</td>
<td>Nobska Mavs-3</td>
<td>On &lt;1 m mooring near hydrothermal site</td>
</tr>
<tr>
<td>Tidal and storm pressure perturbations on the seafloor</td>
<td>Pressure</td>
<td>Paroscientific Series 8000</td>
<td>Mounted on Ti-stand, pressure housing</td>
</tr>
</tbody>
</table>
7.2.1 Node 1: Hydrate Ridge

Node 1 at Hydrate Ridge (Figure 22; Table 7) is a focal point for numerous interdisciplinary studies that address process linkages associated with gas hydrate formation, the flow of carbon from the crust and from the coast to the deep sea, and the linkages among biogeochemical processes and climate change in one of the most biologically productive areas in the world’s oceans. Hydrate Ridge has also been the site of Ocean Drilling Program (ODP) Legs 146 (Site 892) and 204 (Site 1249). Proposed RSN cabled infrastructure at this site includes two secondary nodes NP-1 and NP-2 and a full water column mooring.
Figure 22: A) This image illustrates the location of the backbone cable and extension cables for Node 1 of the RSN at Hydrate Ridge and the CSN Endurance Array. A full water column mooring with profiling capabilities will be located near the primary node. The locations of the backbone and extension cables will likely be modified subsequent to completion of a new DeskTop Study, RSN and CSN share the node at 500 m. The CSN at 500 and 80 m will host moorings wired to N1 through the extension cable. B) Proposed sensor suite and approximate locations and associated tertiary infrastructure for the Hydrate Ridge site proper.
<table>
<thead>
<tr>
<th>Measurement</th>
<th>Example Sensor</th>
<th>Manufacturer</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global/regional seismic events, subduction events, slow quakes</td>
<td>Broadband Triaxial Seismometer</td>
<td>Guralp CMG-1T 360s-50Hz</td>
<td>Distal to methane seep site</td>
</tr>
<tr>
<td>Regional/local seismicity, hydrofracturing</td>
<td>Short Period Seismometer</td>
<td>MBARI/GEOSense BH1 corehole geophone connected to a MBARI/GEOSEnse LP1 data logger</td>
<td>In array distal to seep sites</td>
</tr>
<tr>
<td>Plume structure, velocity profile through water column</td>
<td>Bottom Mounted upward-looking ADCP</td>
<td>150 kHz ADCP RDI/Teledyne</td>
<td>On stand on seafloor within seep footprint</td>
</tr>
<tr>
<td>Local currents, background ocean temperature</td>
<td>Current Meter + Temperature</td>
<td>Nobska Mavs-3</td>
<td>On &lt;1 m mooring near seep</td>
</tr>
<tr>
<td>Tidal Pressure on Seafloor</td>
<td>Pressure</td>
<td>Paroscientific Series 8000</td>
<td>Mounted on Ti-stand, pressure housing</td>
</tr>
<tr>
<td>Flow through sediment-water interface (0.1 to &gt;500 m/yr)</td>
<td>Optical Injection Tracer Sensor</td>
<td>PI</td>
<td>Base is coupled to seafloor, sensors in frame in seep</td>
</tr>
<tr>
<td>Dissolved volatiles in seep fluids</td>
<td>Mass Spectrometer</td>
<td>Stanford Research Systems RGA200 quadrupole mass spectrometer</td>
<td>Intake extends from seep to TI-housing on stand</td>
</tr>
<tr>
<td>Major/Trace element chemistry of seep fluids</td>
<td>In situ Time Series Osmotic Water Sampler + temperature</td>
<td>PI</td>
<td>Seafloor frame</td>
</tr>
<tr>
<td>Digital still imagery of vents, diffuse flow, seeps, and macrofauna</td>
<td>Seafloor High Res Camera Ethernet W strobes</td>
<td>Prosiilica GE2040 (Camera) 4 Megapixel</td>
<td>On frame with pan and tile capabilities, lights</td>
</tr>
</tbody>
</table>
7.2.2 Node 2: Blanco Transform Fault

Cabled infrastructure at the Blanco Transform Fault represents the best opportunity within the RSN for capturing large earthquakes and examining linkages among geological, hydrological, chemical, and biological processes at a transform fault, one of three major plate boundaries within the plate tectonic framework (Figure 20). In addition, the Blanco Transform Fault intersects both the Juan de Fuca and Gorda spreading centers, and lies only ~200 km from the Cascadia subduction zone, making it a crucial link between three other major plate boundaries. The cable is required for this experiment because of the need to keep instrument drift to a minimum, accurate and precise timing of the instruments, and the critical need to be able to observe the impact of seismic events at the other nodes as an event is occurring so that sampling rates can be changed (e.g., “wet” chemistry).

Infrastructure at Node 2 is focused at the Blanco Ridge near the eastern portion of the Blanco Fracture Zone and includes a primary node that hosts the common sensor suite, pressure sensor, and current meter (Figure 23; Table 8). The primary node is located to the north of the area of faulting/slip in an area that is relatively benign. The small channels (deep blue) are historical turbidite channels that are no longer active. Also connected to the primary node is an array of 8 medium power junction boxes connected with 100 km of extension cable and 12 km of armored cable that allows crossing of the ridge. This array will allow connection of a suite of buried broadband seismometers that have been funded by the W.M. Keck Foundation. The specific geometry of this array will undergo some revision as infrastructure costs are refined, but the basic geometry is likely to remain similar with a series of seismometers north and south of the ridge.
Figure 23: Preliminary location of infrastructure at the Blanco Ridge. An array of extension cables will host 8 medium power junction boxes (2A-2G) that allow connection of broadband seismometers.

Table 8: Blanco Transform Fault Core Measurements, Sensors, and Locations

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Example Sensor</th>
<th>Manufacturer</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global/regional seismic events</td>
<td>Broadband Triaxial Seismometer w/an Episensor Accelerometer</td>
<td>Guralp CMG-3T</td>
<td>In Ti-housings, buried where possible just south and north of the Blanco Ridge</td>
</tr>
</tbody>
</table>
7.2.3 Node 3: Axial Seamount

Axial Seamount is the most robust volcanic system on the Juan de Fuca Ridge and it is both seismically and hydrothermally active (Figure 24). Infrastructure at Axial Seamount includes the primary node, a full water column mooring that hosts a suite of chemical and physical sensors, and a low voltage benthic node that provides communication to the common suite of geophysical instruments. Node 3 is located in a benign area roughly 40 km down slope and east of the seamount (Figure 24; Table 9). Its placement, in part, is governed by the presence of an ~ NE-SW running telecommunications cable (no longer active). At least some, if not all of this cable will be armored. A Secondary Node located on the southeast portion of the summit will provide power to a series of low voltage nodes that allow access to the Ashes vent fields and to the central portion of the caldera. As currently envisioned, the Secondary Node may also host a broadband and short-period seismometer as well as a bottom pressure recorder and tilt meter. A suite of chemical, physical oceanographic, and biological sensors will be located in and near vigorously venting chimneys and diffuse vent sites at Ashes. Additional short-period seismometers and coupled pressure sensors and tilt meters will also be placed at these sites. A ~ 5 km long extension cable extends up the center of the caldera to provide access to a low voltage node that will also host two short-period seismometers and coupled pressure sensors and tilt meters.
Figure 24: Power and communications to sensors within and proximal to the Axial caldera are provide by Secondary Node 3A. The caldera hosts three vigorously venting hydrothermal sites, which are located along bounding faults. The Ashes field will host three low voltage nodes (LV).
<table>
<thead>
<tr>
<th>Measurement</th>
<th>Example Sensor</th>
<th>Manufacturer</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global/regional seismic events, harmonic tremor</td>
<td>Broadband Triaxial Seismometer</td>
<td>Guralp CMG-1T 360s-50Hz</td>
<td>On outer south-eastern portion of summit/flank, buried in caissons in sediment</td>
</tr>
<tr>
<td>Regional/local seismicity, hydrofracturing</td>
<td>Short Period Seismometer</td>
<td>MBARI/GEOSense BH1 corehole geophone connected to a MBARI/GEOSEnse LP1 data logger</td>
<td>In arrays within 250 m to ~3 km from hydrothermal fields, placed in coreholes in basalt or in cement seismonuments</td>
</tr>
<tr>
<td>Temperatures of diffuse flow across seafloor</td>
<td>Thermistor Array</td>
<td>PI</td>
<td>Linear array across seafloor</td>
</tr>
<tr>
<td>Local currents, background ocean temperature</td>
<td>Current Meter + Temperature Pressure</td>
<td>Nobska Mavs-3</td>
<td>On &lt;1 m mooring near hydrothermal site</td>
</tr>
<tr>
<td>Tidal Pressure on Seafloor</td>
<td></td>
<td>Paroscientific Series 8000 PI</td>
<td>Mounted on Ti-stand, pressure housing</td>
</tr>
<tr>
<td>Dissolved volatiles vent fluids</td>
<td>Mass Spectrometer</td>
<td>Stanford Research Systems RGA200 quadrupole mass spectrometer</td>
<td>Intake extends from venting site to Ti-housing on stand</td>
</tr>
<tr>
<td>Major/Trace element chemistry of diffuse flow fluids</td>
<td>In situ Time Series Osmotic Water Sampler + temperature</td>
<td>PI</td>
<td>Seafloor frame with intake extending into diffuse flow site</td>
</tr>
<tr>
<td>Digital still imagery of vents and macrofauna</td>
<td>Seafloor High Res Camera Ethernet W strobes</td>
<td>Prosilica GE2040 (Camera) 4 Megapixel</td>
<td>On frame with pan and tile capabilities, lights</td>
</tr>
<tr>
<td>Black smoker fluid temperature, hydrogen, hydrogen sulfide, and pH</td>
<td>Temperature Resistivity-H₂</td>
<td>PI</td>
<td>Sensor tip placed within black smoker orifice, logger in Ti-housing on stand</td>
</tr>
<tr>
<td>Black smoker fluid temperature, hydrogen, hydrogen sulfide, and pH</td>
<td>pH-Hydrogen Sulfide-Temperature-hydrogen</td>
<td>PI</td>
<td>Sensor tip placed within black smoker orifice, logger in Ti-housing on stand</td>
</tr>
<tr>
<td>Digital still imagery of vents, diffuse flow, and macrofauna, flow velocity calculations</td>
<td>High Definition Camera</td>
<td>Insite Pacific Zueess Plus PI</td>
<td>On frame with pan and tile capabilities, lights</td>
</tr>
<tr>
<td>Inflation and deflation of seafloor due to magmatic processes</td>
<td>Bottom Pressure Tilt Recorder</td>
<td>Paroscientific Digiquartz pressure transducer, tilt meter Applied Geomechanics (LILY) Pi</td>
<td>Ti-housing, stand, leveled</td>
</tr>
<tr>
<td>Major/trace element chemistry of diffuse flow fluids, co-registered</td>
<td>Remote Access Fluid Sampler</td>
<td>McLane Water Transfer Sampler w/pH, H₂S, temperature sensor</td>
<td>Mooring with extension to vent</td>
</tr>
</tbody>
</table>
7.2.4 Node 4: Subduction Zone

This node is located seaward of the Cascadia deformation front and is focused on earthquake and tsunami generation and plate scale strain (Figure 25; Table 10). In this design, Node 4 is connected to a shore station in Warrenton, Oregon (Figure 20). The Cascadia Subduction zone is known historically to have generated great ($M_w$ 9+) earthquakes and associated large tsunamis. Recently reported correlations between forearc basin structure and the slip history of large earthquakes in other subduction zones provide a framework for designing a combined seismic-geodetic network at this site that will lead to a better understanding of subduction zone dynamics (such as slow earthquakes/tremor) and earthquake/tsunami hazards in the Pacific Northwest. This site, along with Node 1, provides strong linkages to the Plate Boundary Observatory component of EarthScope.
Figure 25: Preliminary location of infrastructure at the Subduction Zone site, Node 4. A 40 km extension cable will connect the backbone to a low voltage node (LV 4C) hosting a small geophysical experiment. The mid-plate node (N5) is important to studying intraplate deformation, the flow of carbon offshore, and mesoscale oceanographic processes.
<table>
<thead>
<tr>
<th>Measurement</th>
<th>Example Sensor</th>
<th>Manufacturer</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global/regional seismic events, subduction earthquakes, slow quakes</td>
<td>Broadband Triaxial Seismometer</td>
<td>Guralp CMG-1T 360s-50Hz</td>
<td>Buried in caissons in sediment</td>
</tr>
<tr>
<td>Regional/local seismicity,</td>
<td>Short Period Seismometer</td>
<td>MBARI/GEOSense BH1 corehole geophone connected to a MBARI/GEOSense LP1 data logger</td>
<td>In array placed in cement seismonuments</td>
</tr>
<tr>
<td>Local currents, background ocean temperature</td>
<td>Current Meter + Temperature Pressure</td>
<td>Nobska Mavs-3</td>
<td>On &lt;1 m mooring near hydrothermal site</td>
</tr>
<tr>
<td>Tidal Pressure on Seafloor</td>
<td></td>
<td>Paroscientific Series 8000</td>
<td>Mounted on Ti-stand, pressure housing</td>
</tr>
</tbody>
</table>
7.2.5 Node 5: Mid-Plate

The mid-plate node (Figure 26) located between Axial Seamount and the Pacific City Shore Station is important because it provides one of the few mid-plate sites that allows study of stress propagation through the plate as well as intraplate deformation and is related to plate boundary failure. This site also allows study of the subtropical gyre and will provide insights into seasonal to interannual and interdecadal climate change and the impact of these changes on regional physics and ecology. The mid-plate node also will serve as an important site for studying the flux of carbon from the shelf across the slope to deep water. If funding allows, this site will host a full water column mooring with profiling capabilities and a suite of core chemical and physical sensors. The site presently hosts the common geophysical suite (Table 6).
7.3 Water Column Array

The RSN sites fill the continuum of oceanographic scales between the Coastal PNW Endurance sites and NE Pacific Global site Papa, and other non-OOI assets such as NEPTUNE Canada. For many of the water column science themes (as well as geophysical), a spatial array is formed, made up of the elements at the individual sites. With a multi-element spatial array one can form a control volume, measure boundary conditions, determine gradients and higher-order terms in the various governing equations, and image the interior using remote sensing methods. With this capability one can address the interaction and dynamics between the different scales and processes.

The cabled mooring systems with abundant power and communications will be able to support the instrumentation needed to conduct the dramatic and transformational science that addresses issues at the heart of the carbon cycle and climate change (for example); see Figure 26 and Table 11.

The RSN node sites (along with CSN Endurance Array sites) provide meridional shelf, slope, open ocean/basin contrast, as well as north-south along-coast contrast. In this context, it should primarily be considered an array, and secondarily as a collection of individual sites with specific topics. The region includes the California current eastern boundary current system, and is affected by the west wind drift, the bifurcation of the latter, as well as ENSO and PDO.

- **N1**, Hydrate Ridge, at the base of the continental slope forms the seaward extension of the historical Newport hydrographic line, lies within the California Current system and anchors the cabled Coastal nodes. With the coastal nodes, and the more seaward N2 and N3, the east-west/shelf-abyss gradients, offshore-onshore transports, up- and down-welling, and shelf-slope interactions can be measured, and form the southern boundary of a control volume. The N1 mooring described here will provide more detailed site-specific oceanographic context necessary for the local work at Hydrate Ridge.
- **N2**, Blanco, in addition, will have strong abyssal tidal mixing over the transform fault.
- **N3**, Axial Seamount, will anchor the seaward, open-ocean extent of the RSN array. It will be able to measure flow associated with the ridge as well as the hydrothermal/chemical/biological effects of the volcano on the flow.
- **N4**, Subduction Zone, is at the base of the continental slope, forming the seaward extension of the Coastal Gray's Harbor line of moorings across the continental shelf and slope. As with N1 and associated coastal elements, N4 will be used to measure east-west/shelf-abyss gradients, offshore-onshore transports, and shelf-slope interactions, forming the northern boundary of a control volume. These two E-W lines will be able to address the N-S gradients as a function of distance from shore.
• N5, Mid Plate, as mentioned above will improve the spatial resolving power of the overall array, and provides east-west contrast to N1 and the inshore coastal array along the Newport line.

In the future, additional bottom instrument packages and mobile platforms such as gliders and AUVs and integrating acoustic measurements between fixed and mobile nodes will extend the spatial footprint of the water column measurements beyond each node, and serve to more directly connect the various scales, from coastal to basin.

From a seismic perspective, the presence of an array will greatly improve the spatial resolution of the plate structure, and form the natural seaward extension of EarthScope’s Plate Boundary Observatory (another on-going MREFC project). A great “hole” in the regional seismic imaging comes from lack of measurements on the ocean side of the subduction zone.
Figure 26: Illustration of full water column mooring hosting a profiler, 200 m platform and sensors. Moorings will be located ~ 4.5 km from the Primary Nodes at Hydrate Ridge (N1) and Axial Seamount (N3). Also shown is the location of the low voltage node that connects to a seafloor package hosting an array of sensors as shown in Table 11. Additional moorings and seafloor packages at the other primary nodes are up-scope options.
<table>
<thead>
<tr>
<th>Measurement</th>
<th>Example Sensor</th>
<th>Manufacturer</th>
<th>Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>Current Meter-Acoustic</td>
<td>Falmouth 3D-MP</td>
<td>Winch and McLane profilers</td>
</tr>
<tr>
<td>Temperature,</td>
<td>CTDO</td>
<td>Seabird 52MP/43F</td>
<td>Profiler, 200 m platform, winch, bottom package</td>
</tr>
<tr>
<td>conductivity,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dissolved oxygen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectral backscatter</td>
<td>Fluorometer-OB</td>
<td>WetLabs ECO-BB2F</td>
<td>Profiler, 200 m platform, winch, bottom package</td>
</tr>
<tr>
<td>and chlorophyll</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fluorometer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>pH</td>
<td>Seabird 18</td>
<td>Profiler, 200 m platform, winch, bottom package</td>
</tr>
<tr>
<td>Profiles of turbulence</td>
<td>VADCP</td>
<td>300kHz 5 beam VADCP</td>
<td>200 m Platform</td>
</tr>
<tr>
<td>pCO₂</td>
<td>pCO₂</td>
<td>Sunburst SAMI-15000</td>
<td>200 m Platform</td>
</tr>
<tr>
<td>Fish and engineering</td>
<td>Camera &amp; LED Lights</td>
<td>DSP&amp;L LED Multi</td>
<td>200 m Platform</td>
</tr>
<tr>
<td>Communication with</td>
<td>Acoustic Modem</td>
<td>WHOI micromodem</td>
<td>200 m Platform and seafloor package</td>
</tr>
<tr>
<td>surrounding sensors, extend the spatial footprint</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorophyll-a, CDOM, and fluorescence,</td>
<td>Fluorometer-3W</td>
<td>Wet Labs Triplet</td>
<td>200 m Platform</td>
</tr>
<tr>
<td>optical backscatter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine mammal and</td>
<td>Hydrophone-Broadband</td>
<td>Naxys eHyd</td>
<td>200 m Platform and bottom</td>
</tr>
<tr>
<td>fish, wind rain,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seismic T-phases</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Long range velocity profiles</td>
<td>ADCP</td>
<td>ADCP RDI 75kHz</td>
<td>200 m Platform</td>
</tr>
<tr>
<td>Horizontal electric</td>
<td>HPIES Horizontal electric field &amp; Pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>fields, seafloor to sea</td>
<td></td>
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<tr>
<td>surface acoustic</td>
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<td>travel time, and</td>
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<tr>
<td>pressure</td>
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</tbody>
</table>
7.4 Regional Scale Nodes: Up-Scope and Down-Scope Options

A list of scope options has been developed by the RSN group. Incorporated in the following options is the goal to preserve as much of the science and especially the transformative potential of the RSN and its relationship with OOI.

Up-scope:
- Add Vertical Moorings – The current PND includes two vertical moorings, significantly less than earlier designs. The coupling of vertical moorings with the power and bandwidth available from the RSN infrastructure provides significant improvement in water column science capabilities and links coastal and global scales. Providing these capabilities at all RSN nodes is judged to be high priority.
- Provide Event Response Capability with AUV(s) – Another early design concept has been the ability to react, in near term, to significant events within the region. The ability to deploy AUVs with sensors during events for data acquisition enhances the in situ observations in ways never before possible.
- Add Ecogenomic Sensors – The development of new eco-genomic sensors is being watched carefully and is expected to add another layer of transformational science capability to OOI and the RSN.
- Add Water Column Bottom Mounted Sensors – At less cost than some of the other up-scope options, water column science, especially where vertical moorings do not currently exist, can be enhanced with the addition of bottom mounted sensors.
- The current MREFC sparing budget will require ongoing evaluation against the ability to provide sustainable and recurring spares budget within the future O&M funds. This further evaluation may indicate a more prudent course of action to procure additional spares as a component of the MREFC project.

Down-scope:
- Eliminate Core Sensors at N5 (mid-plate) – The elimination of the core sensor suite at the Mid-plate Node (N5) has the least impact on science and allows for future replacement. It does not significantly affect the plate scale aspect of RSN.
- Eliminate 40km Extension Cable and Sensors From N4 – Similarly the elimination of these elements reduces costs yet preserves the ability to recover the capabilities in future. The science impact is more significant at this location as this subduction zone provides unique observations related to the Juan de Fuca plate.
- Eliminate Sensors From One Vertical Mooring – In the same way, elimination of sensors from one of the two vertical moorings provides some cost savings and allows for recovery in future as the infrastructure would remain in place and ready.
- Reconfigure N2 as a Mid-span Node – While more significant in terms of cost savings, this option raises the level of technical risk and limits the ultimate capacity and power available to these two locations.
8 Education and Public Awareness Infrastructure

8.1 Introduction

Technological advances in computing, cyberinfrastructure, and communications are revolutionizing both scientific research and science education. In the ocean sciences, the advent of the OOI promises to reshape the way ocean science is conducted by providing ocean researchers with access to near real-time data, the ability to control/configure sensors and mobile assets, high-bandwidth infrastructure for images, powerful cyberinfrastructure, and data visualization and modeling tools to conduct their research. In a parallel trend, recent advances in the delivery of web-based education, and use of visualization technology and data visualization tools in educational contexts, have lead to development of on-line platforms for instruction that engages students in active scientific inquiry (29), incorporates computer simulations of real-world phenomena (30,31), and involves collecting and analyzing data (32,33). Capitalizing on the burgeoning fields of information and visualization technology and the increasing power of the Internet, OOI education and public awareness (EPA) programs will use technology to advance ocean science education and outreach in much the same way that the OOI will advance ocean research. By investing in education infrastructure for the OOI, the ocean research and education community will be positioned to establish an ocean science education and public awareness (EPA) program of unprecedented technical sophistication.

8.2 Background

NSF/OCE has advised that $5M of the projected $331M of capital investment for the OOI be used to develop infrastructure specifically focused on an education and public awareness effort, “within the restrictions on the use of MREFC funds.” Although NSF’s Large Facilities Manual does not define or address “education infrastructure” and these restrictions, NSF has offered guidance that education infrastructure for OOI would be something that depreciates over time and needs to be bought, developed, and/or maintained. As with the rest of the MREFC funds, human resources to plan, manage, and implement the education infrastructure are also an appropriate expenditure. However, specific use of the education infrastructure beyond its design, implementation, and testing would not be funded from the MREFC account; these efforts would be funded by an external program, or in some cases by operations and maintenance as consistent with the Large Facilities Manual. In addition to the MREFC funding, NSF/OCE Education Program Officers anticipate that significant support for competitive education awards using knowledge, data, and products from the OOI network will be available.

It is also expected that the education infrastructure associated with the OOI will:

- Have an impact on a nation-wide scale;
• Enhance the size, intellectual scope, diversity and sophistication of the ocean education user community;
• Emphasize the creative opportunities enabled by the novel aspects of the OOI (e.g. near real-time data, the ability to control/configure sensors and mobile assets, high-bandwidth infrastructure for images, powerful cyberinfrastructure and links to the scientific community);
• Develop partnerships between scientists, formal and informal science educators, and technology specialists (and their organizations and networks) in ways that will extend the impact of OOI accomplishments most effectively; and
• Promote a culture of open access to OOI assets for the broadest set of audiences and partnerships so that the most creative ideas on using OOI assets come forward and are fully developed.

All strategies and activities need to involve the open sharing of data, images, and other assets with the broader community.

Mindful of these expectations and the constraints on when and how MREFC funds can be spent, this education and public awareness plan articulates the overarching vision, central goals, and key strategies that will be addressed by OOI EPA programs during the construction phase, outlines common EPA infrastructure essential to reaching these goals, and establishes a framework for use of the MREFC education investment.

8.3 Vision and Goals

8.3.1 Vision

The OOI has the potential to spark widespread public appreciation of the oceans and ocean science and technology. By engaging in a comprehensive OOI EPA campaign, the ocean sciences community will engender national support for OOI, the innovative technology it employs, and the science it enables. Broad backing for OOI from the science community, educators, the public, and policy makers is critical to healthy funding for long-term observatory operations, research, and education. EPA infrastructure and programs will make OOI accessible, compelling, and important to these audiences. Such an investment will pay dividends to the scientific community in the form of increased recognition of OOI as technologically innovative, scientifically transformative, and essential to the future of ocean sciences. The vision statement can be summarized as “The Ocean Observatories Initiative education and public awareness program connects people to 21st century ocean science and technology.”

8.3.2 Goals

Two broad goals have been established to attain the OOI vision. These are to:
• Increase public awareness, appreciation, and understanding of the oceans’ role in the Earth system.
- Increase participation and diversity in science, engineering, and technology careers, particularly those related to ocean sciences.

In support of EPA goals, the OOI will design, construct, test, and deploy Common Educational Infrastructure (i.e., infrastructure that is universally accessible) that will constitute the foundation for long-term OOI EPA efforts. Common educational infrastructure for the OOI includes a suite of data visualization tools, products, and audience appropriate user interfaces produced at the cutting edge of cyberinfrastructure, visualization technology, and education. This suite of tools, and in some cases hardware, constitute essential infrastructure needed to build the capacity for engaging non-scientist users and provide open access to educational and scientific content and services.

These EPA goals stem directly from the community consensus established at the first ORION Workshop in Puerto Rico (3) and in the ORION Education and Public Awareness Committee (EPAC; 34). They are well aligned with National Science Board (NSB) priority recommendations for an NSF Science, Technology, Engineering, and Mathematics (STEM) education roadmap (35; see box below), directly addressing priorities two and three and providing support for investigations into the efficacy of cyber-enabled teaching and learning.

The NSF STEM education road map and strategic priorities should reflect the Foundation’s responsibilities to:
(1) Support research on learning and educational practices and the development of instructional materials.
(2) Develop human capital (e.g. STEM workforce development).
(3) Increase public appreciation for and understanding of science, technology, engineering, and mathematics.


Strategies for achieving these OOI EPA goals are discussed in detail below, including a more specific description of how each is aligned with the National STEM Education Action Plan (34) and examples of the types of infrastructure components that can be constructed to reach the target EPA users. Subsequent sections describe 1) an implementation plan that includes a national competition for an OOI Education Infrastructure Facility focused on the two goals/strategies; 2) a management plan with community advisory input for OOI EPA; 3) near-term (e.g. 12-month) strategies for the OOI EPA, and 4) a framework for future EPA planning.
8.4 Strategies

Recognizing that it is beyond the scope of the MREFC phase of the OOI EPA activities to reach all possible audiences or to engage in the full range of strategies that can be envisioned for achieving EPA goals, the strategies presented here have been selected based on the following criteria. Each strategy will: 1) directly support one of the goals articulated above; 2) complement and leverage, rather than duplicate, existing ocean education activities and programs; 3) allow for the creation of infrastructure that is inherently flexible and that can be adopted and adapted for different audiences and/or future OOI education initiatives and programs; 4) leverage and build on the OOI cyberinfrastructure; and 5) align with national strategies for the future of STEM education at NSF to ensure a solid funding base for future OOI-based educational products and programs.

With these criteria in mind, the initial OOI EPA strategies for the MREFC phase of the OOI are to build educational infrastructure that will:

- Support “free choice” learning in a variety of both physical and virtual settings with a focus on raising public awareness about ocean science and enabling technology (e.g., Goal #1).
- Support online post-secondary career, technical and educator training programs, with a focus on increasing participation and diversity in ocean science and technical careers (e.g., Goal #2).

The former is envisioned to include infrastructure essential to interactive exhibits at science centers, online learning environments such as simulation-based virtual worlds (e.g., Whyville; http://www.whyville.net/smmk/nice), and Internet and broadcast media venues. The latter is envisioned to include infrastructure required for using OOI data, services and collaborative tools in online vocational training courses for community college students, virtual learning environments for graduate and undergraduate science programs, online teacher professional development, and future oceanographer certification programs. These strategies represent only a subset of possible approaches, and long-term planning will expand upon these strategies.

Essential to both are enabling common educational infrastructure including user/audience appropriate interfaces, either physical (as in a science center setting) or online, and the underlying and embedded tools and services appropriate for each group of EPA users. Building the education infrastructure required for both of these strategies will require an Education Infrastructure Facility (EIF) comprising partners (institutions and/or individuals) with expertise in ocean science, education, cyberinfrastructure, visualization technology, and online learning environments. The facility personnel will be responsible for all phases of planning (including coordinating community input), designing, developing and testing the infrastructure components. This facility and the allocation of MREFC funds to support educational infrastructure development are discussed in Section 8.5, Implementation.
Example strategies and activities given here are intended to illustrate the potential of common educational infrastructure for supporting widespread EPA programs, rather than as a prescription for what should be undertaken. These strategies are not intended as a comprehensive list, but to serve as guidelines that demonstrate the breadth and scope of potential activities for future OOI EPA contributors.

8.4.1 Free Choice Learning Environments

Strategy 1 is to support “free choice” learning environments as venues for OOI education. Free choice learning environments are those in which individuals are unconstrained in when, how, and for how long they engage in a learning activity. The pervasiveness of technology and media, coupled with an explosion of informal education initiatives, has dramatically influenced where and how individuals learn; a recent study indicated that only 3-7% of what people learn takes place in schools (36). Through science center exhibits, broadcast media, web sites, virtual worlds, and other internet-based venues, individuals can now obtain 24/7 learning on demand. The OOI Education Infrastructure Facility for free choice learning will support the construction of infrastructure for informal and online learning environments that capitalize on the strengths of the OOI, the cyberinfrastructure backbone, and emerging patterns of learning among students and the public. By virtue of its strong cyberinfrastructure component and the emphasis on near real-time data streams, data visualization, and interactivity, the OOI is in an excellent position to create data visualization products tied to effective pedagogical practice in these learning venues. Furthermore, by engaging in this approach, the OOI EPA plan is closely aligned with NSB guidance for future NSF STEM education investments (see box below).

As NSF is developing a road map for its public outreach efforts, it should consider directing resources toward several areas. These include:

- STEM programming in broadcast media. Television and movies are both important sources of information for the public on STEM fields.
- Web-based resources and facilities.
- Museums and informal STEM education learning environments.


Examples of how OOI common educational infrastructure can be deployed in free choice learning environments are discussed briefly below.

Science Centers. The explosion of digital media-based interactive exhibits and Internet connectivity at science centers, aquariums, and museums is leading to increasing sophistication in how information is presented and consumed in these settings (Figure 27). Informal science education institutions are investing in powerful tools to illustrate
complex, often real-time data for public audiences, and are creating networked exhibit kiosks that allow widespread dissemination of exhibit content from a single location. OOI common educational infrastructure can leverage these advances by creating interfaces and software that allow OOI data, visualizations, animations, and simulations to be integrated into visual display systems and interactive exhibits that transcend traditional science center boundaries through high-speed internet connectivity.

Figure 27. A) Internal projection globes can be programmed with animations that translate vast amounts of data into an interactive interface where it can be easily viewed and analyzed. Visitors can choose what they want to explore, zoom in for a closer look using picture-in-picture technology, and run animations forward and backward in time. Capabilities to interact with researchers in real time in a “picture-in-picture” format are in development; B) Geowall2 is an interactive display system that consists of 15 LCD panels tiled in a 5x3 array comprising a total resolution of 8000x3600 pixels. GeoWall2 can be used to visualize large 3-D data sets, view animations and simulations, and for other applications that require a large collaborative screen area; C) The CAVE is an immersive virtual reality facility designed for the exploration of and interaction with spatially engaging environments. 3-D virtual environments such as the CAVE allow people to interact with data in ways that are only just beginning to be explored.

Simulation-based Virtual Worlds. Virtual worlds represent a powerful new media for instruction and education. These simulation-based, multi-user environments provide a foundation for serious games, instruct and illuminate in highly informal and collaborative settings and in some cases provide support for simulation-based instruction, increasingly recognized as a powerful, new computer enabled approach to learning (29, 30). OOI educational infrastructure including data visualizations, animations, video footage, and simulations can be used on existing virtual world platforms (e.g., Whyville; see Figure 28). Additional educational infrastructure could include programming for more sophisticated user interfaces, additional games and cyber-based learning activities (Figure 29), as well as portals to OOI virtual field trips. Collaboration with experts in the pedagogy of these environments (e.g. Y. Kafai, UCLA) would allow for pedagogically informed educational infrastructure built on the virtual world platforms, as well as a basis for (separately funded) investigations into cyber-learning (see A Playground for Millions Project; [http://www.gseis.ucla.edu/faculty/kafai/projects/whyville.htm](http://www.gseis.ucla.edu/faculty/kafai/projects/whyville.htm))
Figure 28: Whyville is an educational simulation based virtual world geared toward preteens and teenagers. Its goal is to engage its users in learning about a broad range of topics from science and business to art and geography. Woods Hole Oceanographic Institution has established a presence in Whyville, and is exploring its efficacy for engaging students in ocean science.

Internet and Broadcast Media. Blogging, video podcasts, TV documentaries, GoogleEarth – all represent the plethora of free choice learning environments available via the internet and TV. OOI common educational infrastructure can be tailored to provide essential components for:

- Documentaries
- Video podcasts

Emerging communications technologies, especially web-based, present new opportunities for providing multi-media “pieces” including visualizations, animations, and video to a wide variety of media outlets that can potentially package and tell the OOI story. OOI data visualization infrastructure and products can be used in online, universally accessible visualization environments such as Google Earth, an interface that allows access to layers of ever more detailed information, visualizations and imagery through the user friendly and familiar Google interface. Mass broadcast media reaches millions of viewers through popular science documentaries such as the National Geographic Channel’s *Naked Science* and Discovery’s Science Channel. OOI common educational infrastructure can include video, animations, and visualizations that are essential components of this documentary-style programming.

A key element for the success of OOI EPA endeavors in any or all of these free choice
learning environments will be building on existing platforms and programs. For example, the new Smithsonian Ocean Hall has established a collaboration with NOAA to create an internet connected network of ocean focused interactive learning kiosks at science centers nationwide. The kiosk infrastructure and digital content is being designed to allow for continuous updating and improvements, providing an opportunity for partnership over the life cycle of the exhibit. OOI EPA can position itself to work closely with the Smithsonian lead team and capitalize on the 25 million people that will be reached through this Smithsonian network with science centers nationwide. Similar opportunities to build on and leverage existing infrastructure exist for a wide range of other free choice learning venues.

8.4.2 Support for Post-Secondary Training Programs

Strategy 2 is to support post-secondary career, technical, and educator training programs. Increasingly powerful information, computation, and communication technologies have transformed science and education. Advances in sensor technology, remote real-time data acquisition, data simulation and modeling, and the availability of affordable mass data storage devices are enabling the collection, creation, and federation of large, complex datasets. Moreover, extensive networking capabilities, sophisticated middleware applications, and new collaboration platforms are simultaneously providing and improving interactive access to and analysis of these data. In addition to advancing research, these technological tools and services are also creating transformational opportunities in education by promoting ubiquitous cyber-based learning environments and making sophisticated analytical, modeling, and visualization tools available to students at all levels in a wide variety of settings. Importantly, the Education Infrastructure Facility will be in an excellent position to compete for the rapidly expanding funding-base for education and discovery enabled by cyberinfrastructure (e.g. Cyber-enabled Discovery and Innovation). This investment in education infrastructure can potentially have long ranging impact on how ocean science is taught in the future, and is directly aligned with NSB recommendations for NSF investment in cyber-enabled education (see box below).

A specific area in which NSF could make significant contributions is in the development of cyberinfrastructure, including computer gaming and simulations, to bolster STEM teaching and learning. Cyber-enabled technologies could also allow:

- The development, collection, distribution, and curation of digital content such as animations, simulations, text, video, data sets, lesson plans, and curricula.
- Access to virtual laboratory facilities that can bring general and specialized laboratory experiences into nearly any classroom, regardless of geographical location, via the internet
- Collaborations among STEM students, teachers, researchers, and those designing and developing digital teaching and learning resources
- Student acquisition of knowledge and skills essential to success in the technology-rich future
Active engagement of the current, internet-acccustomed pre-K-12 student population in STEM

The OOI community needs to build capacity to use the OOI among stakeholder groups, starting with the research community, but extending those efforts to key audiences for workforce development, including graduate and undergraduate science and engineering students, community college students in technical training programs, and teachers in online teacher professional development courses (a pathway to pre-college students). The enabling OOI cyberinfrastructure provides an avenue to develop online teaching/training environments, courses and/or learning modules using OOI data, tools and resources that capitalize on the powerful OOI cyberinfrastructure, building capacity to engage both scientific and non-scientific users in the OOI. This endeavor is a natural and welcome addition to the IO based efforts to support scientist training in the use of OOI data, tools and services and is a natural bridge between the research and education components of the OOI.

Examples of the opportunities to use OOI common educational infrastructure in online learning environments is discussed briefly below.

**Online Learning Modules and Courses.** Online course enrollment has shown consistent growth over the last 5 years, topping 3 million in 2005, and the proportion of academic leaders reporting online as part of their long-term strategy continues to grow (37). In addition, the integration of web-based modules and tools is increasingly common in what are referred to as web-facilitated or hybrid courses, with tools like Moodle (Figure 29) and Blackboard in common use on college campuses as faculty begin to utilize the power of the internet to combine online and face-to-face instructional strategies. In a parallel development, teacher professional development is also being offered in online environments, expanding the reach of the courses and allowing those who deliver the courses to share resources and establish collaborative learning environments that transcend geographic barriers (for example, the Earth System Science Education Alliance (ESSEA), which through the NSF GEO-Teach program delivers a student-centered teaching model for pre-service and in-service middle-high school teachers). These virtual learning environments are at the heart of so-called e-learning, a trend that is rapidly changing the way we teach. Developments in internet and multimedia technologies are the basic enabler of e-learning, with content, technologies, and services being identified as the three key sectors of the e-learning industry (38). The OOI content, tools, and services can be tailored for specific audiences (common educational infrastructure) and integrated into online learning modules for both web-facilitated and online community college, undergraduate and graduate level course work in ocean science and engineering, as well as teacher professional development. Working in close collaboration with the CI IO Design team, the Education Infrastructure
Facility will be the entity responsible for creating the software, middleware, online visualization tools, and prototype online learning tools appropriate for the non-scientist or novice scientist user audience.

Figure 29: Moodle is an example of a Virtual Learning Environment, an online platform for delivery and sharing of content. Moodle is designed to help educators create online courses with opportunities for rich interaction. Its open source license and modular design allows development of additional functionality. Moodle has over 10,000 sites and over 1,000,000 users.

A growing body of research exists to inform the design and development of prototype online learning tools and programs (39,40). Moreover, the OOI can be used to create a test bed for research on teaching and learning science in cyber-enabled environments.

8.5 Implementation

8.5.1 Constructing a Common Educational Infrastructure

Implementation of the strategies described above will require design, development, construction, and application of a full suite of data visualization tools, products, and audience appropriate user interfaces produced at the cutting edge of cyberinfrastructure and visualization technology. This suite of tools, and in some cases hardware, constitute essential infrastructure needed to build capacity for engaging non-scientist users and provide open access to educational and scientific content and services. The data delivery and services associated with the OOI are delivered via the CI backbone of the network. Similarly, the educational components of the OOI will be built on the cyberinfrastructure backbone and delivered to the EPA audience through portals analogous to those for the science users - essentially “learning laboratories” or “classrooms” tailored to non-science user groups.

The construction of the common educational infrastructure will take place in the Education Infrastructure Facility (EIF). The EIF will comprise a group of partners (institutions and/or individuals) with the requisite knowledge, skill, and experience to
create the robust, pedagogically sound infrastructure for their own prototype educational products and importantly future education programs affiliated with the OOI (e.g., EHR funded projects, broader impact components to research proposals that propose to use the OOI and OOI data products and services, and other sources of education funding). Design and development of infrastructure components should include the following steps:

- Assess existing software tools for data access, handling, and visualization that are currently in use by educators.
- Develop an understanding of data types, format, and handling tools that the CI will deliver.
- Hold user requirements workshops with target audiences to identify specific needs and barriers.
- Develop a System Engineering Plan based on the outcome of the user requirements workshops and an understanding of the CI deliverables.
- Develop “bridge” system(s) (also known as middleware) that will bridge the gap between what the Cyberinfrastructure IO will deliver and what EPA audiences require.
- Beta-test these prototypes (which will include middleware software, tools for using the data, and data visualization prototypes) with target audiences; revise System Engineering Plan for education.
- Work with partners to transition prototypes into final products (Operational Phase).

The EIF will work closely with the OOI CI Design and Education teams. All software, middleware, and interface development will be based on the spiral development management model that is widely used for software intensive systems (i.e., design – develop – iterate – deploy; Figure 30).

![Figure 30: Simplified illustration of the spiral lifecycle design model. For a more detailed explanation see Section 5, Cyberinfrastructure Preliminary Design.](image)

8.5.2 Proposed OOI EPA Competition

MREFC funds to develop/construct the essential infrastructure needed to build the capacity for engaging non-scientist users will be competitively awarded to an OOI Education Infrastructure Facility arranged and monitored through the OOI Project Office. The successful awardee will develop the management structure and staffing necessary for a coordinated and coherent Education Infrastructure Facility that is aligned with the
OOI science and technology research objectives, is collaborative with the IOs, and proactively seeks external science and EPA partners and funding. External partnerships are essential to the success of the EPA program. Key partnerships include EPA programs associated with other NSF near real-time data projects (e.g. EarthScope, NEON); “free choice” learning organizations (e.g. the Smithsonian Institution Ocean Hall; Whyville); NSF-funded Earth and ocean science initiatives (e.g. GEO Teach, COSEE), and cyber-based education organizations or programs (e.g. those funded through the Office of Cyberinfrastructure CI-Team and/or Cyber-enabled Discovery and Innovation awards).

8.6 Leveraging EPA Investments at the IOs

The OOI comprises three IOs under the central management of the OOI Project Office. Each IO has an EPA team and has made a commitment to support OOI EPA through a combination of institutional matching funds, in-kind contributions, and personnel time, as well as through existing EPA partnerships. Once the Education Infrastructure Facility is identified, it will become part of the OOI EPA community. Table 12 summarizes the institutional contribution areas for each IO and the OOI Project Office during the construction phase.

Table 12. Example EPA activities at IOs during the construction phase.

<table>
<thead>
<tr>
<th>CI IO</th>
<th>RSN IO</th>
<th>C/GSN IO</th>
<th>Project Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientist training</td>
<td>Education oriented research cruise(s)</td>
<td>Visualizations and animations</td>
<td>EPA Program Management and Coordination</td>
</tr>
<tr>
<td>Visualizations and animations</td>
<td>Partnerships for education modules</td>
<td>Outreach to Policy Community</td>
<td>Media Coordination</td>
</tr>
<tr>
<td>Educational Prototypes</td>
<td>Partnerships for TV documentaries</td>
<td>K-12 Online learning environments</td>
<td>Outreach to Lawmakers</td>
</tr>
<tr>
<td>OOI CI Education Web Portal</td>
<td>Science center and museum partnerships</td>
<td>Science center and museum partnerships</td>
<td>Synergy with other ocean education and diversity activities</td>
</tr>
</tbody>
</table>

Each IO partner has strong connections within the ocean education community (e.g. Centers for Ocean Sciences Education Excellence (COSEEs); science centers or aquarium affiliations and partnerships) and with groups or initiatives that already have audiences in the tens of millions (e.g., university, regional, and national cable TV channels; virtual world web sites, multi-use geographic tools such as Google Earth). Similarly, the Consortium for Ocean Leadership has long affiliations with other large geoscience programs and is well-poised to connect with activities within its 90+ member institutions, within the national policy making framework, and within the NSF and other federal agencies. A new COSEE, COSEE Networked Ocean World, has been funded and part of its initial work will be to perform a needs assessment of educational products from ocean observing systems, which could be taken directly as input for the OOI. All of these
assets and partnerships can be brought to bear on OOI EPA. For example, near-term activities that can begin prior to MREFC funding with institutional contributions include:

- Begin establishing a virtual community (list) of OOI educators: seek names from COSEEs, Sea Grant Educators network, NOAA, NERRS, NEON, EarthScope, JOI Learning, etc.
- Begin design of a unified web site as a common outlet for project products, such as animations and visualizations currently being developed by the IOs. (Note that a unified web site in tandem with other cyberinfrastructure activities is already under discussion within the wider project.)
- To the extent possible within current timeframes and budgets, each IO will meet with and informally poll their various education partners about what would be the most useful education “tools” or “infrastructure” associated with the specific elements or data provided by that IO (CI, GSN, RSN, or CSN).
- Establish regular meetings or telconferences to align efforts among the IO education group and set common short-term milestones, working with the program’s advisory structure to include appropriate expertise from the stakeholder community, and including representatives from related efforts as appropriate.
9 Summary

At its roots the OOI will transform the way scientists observe the ocean. No longer will a small subset of the science world travel by ship to collect a limited data set using an expeditionary model. Instead, a broad science community will have to access large volumes of data collected over sustained time periods in near-real time from a large number of sites at varying scales. This ability, combined with a robust cyberinfrastructure, will enhance collaborations on resolving the key science questions outlined in the OOI Science User Requirements. Many of these questions require the collection of data from multiple sources over very large spatial scales. Recommendations from the Blue Ribbon Panel and the Interim Observatory Steering Committee (iOSC) were incorporated into the Preliminary Network Design. This guidance resulted in selecting sites for the Global platforms that concentrate on high-latitude locations with the addition of more mobile assets and flanking moorings to improve the context of the data being measured. In the coastal zone, an increase in sensors and mobile assets with a broad footprint was applied to the Pioneer Array.

OOI is designed from the start to provide these key features for ocean science:

- Persistence: Designed for long-term (greater than 25-year) operation, support, and data access
- Geographic Range: Consistently occupying larger volumes of multiple oceans to adaptively observe ocean processes on multiple scales
- Mobility/Portability: Able to go where the action is and the science demands
- Control/Adaptability: Responsive to commands addressing real-time needs
- System Interoperability: Common ways to exchange information and do science
- Intercommunication: Connected systems
- High Power/Bandwidth: Experiments and observations freed from traditional limits
- Sensor Capability: Increased spatial, temporal, and measurement resolution
- Community: Building sharing and interactions across all scientific endeavors

The use of large numbers of interconnected, space-indexed, time-indexed, remote, interactive, fixed, and mobile assets by a global user community, collaborating through the Internet and Internet-enabled software, represents the most fundamental shift in oceanic investigative infrastructure since the arrival of satellites. It will induce major changes in funding strategies, our community structure, the nature of our collaborations, the style of modeling and data assimilation, the approach of educators to environmental sciences, the manner in which the scientific community relates to the public, and the recruitment of young scientists. The discoveries, insights, and new technologies of the OOI effort will continuously transfer to more operationally oriented ocean-sensing systems operated by other agencies and countries. These characteristics are central to addressing the premier, and critical, ocean and environmental science questions of our time. Individually they are novel or state-of-the-art in ocean science; in combination they provide capabilities previously impossible in any environmental science domain.
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Appendix 1: Extended Draft Platform Design

Mid-Atlantic Site (Extended Draft Platform (EDP)): This buoy incorporates an evolutionary design based on the Scripps FLIP (Floating Instrument Platform) as well as years of experience and engineering based on the FLIP concept in energy company deployments in increasingly deep water. The EDP is designed to provide high power (>500W at the seafloor and KW on the platform) and broadband communications (minimum 64kbps, nominal 1 Mbps) between surface and subsurface instruments and science users. The EDP has been proposed for deployment at the mid-Atlantic site (23°N, 43.5°W, water depth 4459 m) to provide a large, stable, power-and-bandwidth platform to address science questions involving interior structure of the Earth, global seismology, air-sea exchange, atmospheric transport of aerosols, hurricane generation, global climate, and near-surface oceanography. Studies are also underway for possible deployment at Ocean Station Papa at 50°N, 145°W.

The CGSN IO's industry partner, Technip, has developed the Extended Draft Platform (EDP) design in response to a need for an easily deployable drilling/recovery vehicle in deep water. Technip is leading a consortium of offshore oilfield operators to fund the development, construction, and testing of a scaled prototype that will also be well suited for additional deployments at the EDP scale to understand the impact of a changing climate on energy company operations. Upon completion of their testing (an including test to verify conformance with design criteria), the EDP will be turned over to the OOI program for scientific outfitting and deployment at the mid-Atlantic site.
Figure 31. The EDP is tri-moored on a combination steel wire/polyester mooring designed to hold the platform on station while a separate EOM cable is used for power and data transmission to the seafloor. As at the other global sits, a nearby profiler-equipped subsurface mooring and gliders will be deployed. Diesel power generation of ~20 kW DC on the platform with an electro-optical (EO) cable.
will deliver >500 W and two-way communication to a seafloor junction box for benthic and borehole sensors and experiments.

The design basis for the EDP was developed this past February (2007). Important constraints included:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design life</td>
<td>1 yr for servicing&lt;br&gt;5 yr for refurbishment&lt;br&gt;10 yr for complete replacement</td>
</tr>
<tr>
<td>Telemetry</td>
<td>VSAT: continuous at &gt;64kbps</td>
</tr>
<tr>
<td>Power</td>
<td>10 kW at buoy; 500W at seafloor</td>
</tr>
<tr>
<td>Payload</td>
<td>33.5 metric tons</td>
</tr>
<tr>
<td>Target heave</td>
<td>Measured in ft/ft, the target heave at all frequencies to be encountered should be &lt;0.5 for waves at the peak spectral period for survival wave energy and &lt;0.3 for operational waves.</td>
</tr>
<tr>
<td>Target pitch</td>
<td>Same as above, but for deg/deg</td>
</tr>
<tr>
<td>Survival conditions</td>
<td>Survive a 50-yr storm</td>
</tr>
<tr>
<td>Operational conditions</td>
<td>Operate through a 5-yr storm</td>
</tr>
</tbody>
</table>

Table 13: Design parameters

The wave and wind conditions, obtained through OceanWeather for representative global sites are shown in Figure 32.

Because the revised Conceptual Network Design (March 2007) included a siting for a spar (EDP) in the Mid-Atlantic, subsequent EDP design used the conditions at this site for sizing and costing. Further research on currents in the area led to the use of upper-ocean current of 1.4kt to a depth of 30m and tapering to zero at a depth of 1km during a 50 yr storm.
Figure 32. Weather and waves for four global sites at 5 and 50-year extremes. (The vertical axis is in m/s, m, or seconds as appropriate.) The platforms should be designed to operate in the 5-year extremes and survive the 50-year extremes. The measures are derived from the Ocean Weather data.
at each of the sites. The wave dominant period of the extreme waves are an essential design specification for both EDP and discus designs. Note that the extreme weather at the Irminger site is nearly identical to that in the Southern Ocean except that the peak wave periods are shorter at Irminger. Further except for the mid-Atlantic site, there is not a great reduction in the extremes values for 5 and 50 years.

Figure 33 illustrates the advanced design for the EDP as well as important dimensions for orientation.

Figure 33. The platform has evolved beyond the illustration shown in Figure 23; the rectangular deck sections have become 8’ square cylinders to reduce platform torsional flexure. Several important dimensions are shown with large arrows. While the IO has worked closely with Technip in developing the design, a Scripps contract to Glosten Marine supported the development of mooring and anchor plans, a concept of operations for deployment and servicing, physical layout and other issues intrinsic
to its use as an oceanographic platform. Glosten has designed the bulk of the new UNOLS vessels in the past decade and constructed FLIP in the 60's.

Figure 34 illustrates the current tested design for the Extended Draft Platform. The dimensions correspond to the dimensions in Figure 33. The mooring lines for the EDP comprise (top to bottom) chain, sheathed strand (shark bite protection), polyester line, and chain. The characteristics are given in Table 14.

<table>
<thead>
<tr>
<th>Type</th>
<th>Diameter (mm)</th>
<th>Length (m)</th>
<th>Wet Wgt (kg/m)</th>
<th>Dry Wgt (kg/m)</th>
<th>Breaking Strength (Mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chain</td>
<td>50.8</td>
<td>27.4</td>
<td>49.30</td>
<td>53.69</td>
<td>161.4</td>
</tr>
<tr>
<td>Sheathed strand</td>
<td>35.0</td>
<td>1615.4</td>
<td>4.74</td>
<td>5.92</td>
<td>121.4</td>
</tr>
<tr>
<td>Polyester</td>
<td>69.8</td>
<td>4876.8</td>
<td>0.73</td>
<td>2.79</td>
<td>113.6</td>
</tr>
<tr>
<td>Chain</td>
<td>50.8</td>
<td>91.4</td>
<td>49.30</td>
<td>56.67</td>
<td>161.4</td>
</tr>
</tbody>
</table>

*Table 14: Anchor line parameters from top to bottom. The sheathed strand is designed to resist “shark bite” to a depth of approximately 1km. The breaking strengths are given in Mg or kg/1000. Note that the chain strengths assume 0.8mm/yr of corrosion and a lifetime of a decade.*

The current design includes a GM distance of 1.44m with the three cylinders sealed to seawater after the structure is erected. GM is the metacentric height and is the distance between the center of gravity of the structure and the metacenter about which the platform center of buoyancy (below the center of gravity) rotates when rolling or pitching in seas. Generally the larger the GM distance, the “stiffer” the ship and the less comfortable; the smaller the GM the more “tender” the ship. Normally naval architects design 1m<GM<2m. This choice of GM is a good choice for the Mid-Atlantic location.

Computer modeling was used to estimate EDP motions. In equilibrium in a calm ocean, the platform natural periods in seconds are given in Table 15.

<table>
<thead>
<tr>
<th>GM (m)</th>
<th>Surge</th>
<th>Heave</th>
<th>Sway</th>
<th>Roll</th>
<th>Yaw</th>
<th>Pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.44</td>
<td>604</td>
<td>16.5</td>
<td>603</td>
<td>26.6</td>
<td>80.9</td>
<td>25.1</td>
</tr>
</tbody>
</table>

*Table 15: EDP characteristics at equilibrium in a calm ocean. Note the heave period of 16.5s is greater than the wave period (11.9s) during a 50-year storm. All other periods exceed the wave period by very large margins leading to good platform stability even during extreme storms; in this case an incident hurricane in the region.*
Figure 34. A current rendering of the EDP design including the on-board crane, a C-Band antenna, and two met towers for mounting equipment that needs to be away from distortions of the airflow around the elevated EDP structure.

The platform was subsequently subjected to a 50-yr storm assuming the wind, current and waves were all aligned in the same direction (worst case). Two cases were considered – the weather vector was aligned between two moorings in the first case (0°) and in the other the vector was in the opposite direction (180°) placing all stress on a single mooring cable. The modeling results for the two cases are shown in Table 16.
<table>
<thead>
<tr>
<th>Conditions</th>
<th>Weather vector = 0°</th>
<th>Weather vector = 180°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waves (ft/m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>0.0/0.0</td>
<td>29.3/8.9</td>
</tr>
<tr>
<td>Hs</td>
<td>-28.8/-8.8</td>
<td>27.7/8.4</td>
</tr>
<tr>
<td>min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>max</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Vel (kt)</td>
<td></td>
<td>53.4</td>
</tr>
<tr>
<td>mean</td>
<td></td>
<td>6.4</td>
</tr>
<tr>
<td>stdev</td>
<td></td>
<td>27.5</td>
</tr>
<tr>
<td>min</td>
<td></td>
<td>72.5</td>
</tr>
<tr>
<td>max</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Env load (kips) min</td>
<td>49.3</td>
<td>49.0</td>
</tr>
<tr>
<td>max</td>
<td>54.6</td>
<td>57.2</td>
</tr>
<tr>
<td>Surge (ft/m)</td>
<td>1,779/542</td>
<td>-1,076/-328</td>
</tr>
<tr>
<td>mean</td>
<td>25/7.62</td>
<td>22/6.71</td>
</tr>
<tr>
<td>stdev</td>
<td>1,709/521</td>
<td>-1,158/-353</td>
</tr>
<tr>
<td>min</td>
<td>1,862/568</td>
<td>-1,009/-308</td>
</tr>
<tr>
<td>max</td>
<td>25/7.62</td>
<td></td>
</tr>
<tr>
<td>Heave (ft/m)</td>
<td>-1.7/0.52</td>
<td>-1.1/-0.34</td>
</tr>
<tr>
<td>mean</td>
<td>4.2/1.28</td>
<td>4.2/1.28</td>
</tr>
<tr>
<td>stdev</td>
<td>-13.9/-4.24</td>
<td>-13.7/-4.18</td>
</tr>
<tr>
<td>min</td>
<td>11.2/3.41</td>
<td>11.3/3.44</td>
</tr>
<tr>
<td>max</td>
<td>-17.7</td>
<td>-9.3</td>
</tr>
<tr>
<td>Pitch (°)</td>
<td>-3.1</td>
<td>2.0</td>
</tr>
<tr>
<td>mean</td>
<td>3.3</td>
<td>2.8</td>
</tr>
<tr>
<td>stdev</td>
<td>-17.7</td>
<td>-9.3</td>
</tr>
<tr>
<td>min</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>max</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension (most loaded) (kips)</td>
<td>77.3</td>
<td>89.8</td>
</tr>
<tr>
<td>mean</td>
<td>1.6</td>
<td>2.6</td>
</tr>
<tr>
<td>stdev</td>
<td>72.8</td>
<td>81.5</td>
</tr>
<tr>
<td>min</td>
<td>82.5</td>
<td>100.0</td>
</tr>
<tr>
<td>max</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anchor loads (kips)</td>
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<tr>
<td>Tension</td>
<td>57.5</td>
<td>75.0</td>
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<tr>
<td>Tv</td>
<td>28.0</td>
<td>39.4</td>
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<tr>
<td>Th</td>
<td>50.2</td>
<td>63.8</td>
</tr>
<tr>
<td>Wet Wgt (kips)</td>
<td>max 128</td>
<td>167</td>
</tr>
<tr>
<td>Dry Wgt</td>
<td>max 163</td>
<td>212</td>
</tr>
</tbody>
</table>

Table 16: Modeling results for EDP during 50-year storm with current, wind and waves aligned between a pair of mooring lines (0°) and the opposing case in which the environment opposes a single mooring line (180°). Because the American shipbuilding industry continues to use English units, these have been preserved in this table. (Kips = kilopounds.)
The worst case pitch is encountered for the 0° environmental load (between two mooring lines) and is <18°. The maximum heave is significant: 25.1’ or 7.65m. However, the 40’ clearance between the ocean and platform will prevent wetting the deck with green water even when tilted 17°. In contrast, a discus buoy is a wave follower and hence its heave would be about 56’ (17.2m) and the pitch equal to the wave slope or nearly 90°. The likelihood of the worst-case scenario in 50 years with current, wind and waves aligned is very small. The required anchor weight is shown in the last row. The dry weight is 212,000 pounds (>100 short tons) (each) dry on deck or 167,000 pounds in water. No UNOLS ship is capable of carrying or launching anchors of this size. Our installation scenario uses a cheaper offshore supply vessel to carry and deploy the anchors and a small ocean tug to tow the platform (see below). When fully loaded, the tension on the mooring lines never exceeds 37% of the breaking strength – the safety factor is 2.7. In the final design the pretension on all the legs was increased by 3,000 pounds to ensure the polypropylene line never lies on the seafloor. The watch circle radius in the extreme 50 yr storm was 475m.

With the EDP design complete and tested, a scale model (1:128) of the platform was constructed and tested in at the Ocean Engineering Center tank in Vancouver, B.C. in May, 2007 under the supervision of Glosten Marine and John Halkyard. Tests addressed calm water resistance at both light (10.37ft) and deep (75ft) drafts. The light draft towing condition was tested both with the stem of the ‘Y’ forward and using a bridle with the stem of the ‘Y’ trailing. Towing tests were also conducted in irregular waves in order to gain insight into added resistance and also to observe towing behavior.

Transient oscillation tests were carried out for both the unmoored and moored platform. The model mooring was devised to approximate the forces and stiffness of the design mooring. Platform motion tests of the moored platform were carried out in a selection of regular waves, moderate irregular seas, and also in a nominal $H_s=5.8m$, $T_p=11.25s$ sea represented the upper limit of waves that could confidently be generated in this test basin at the 1:28 scale. Several photos taken during the test are included below in Figure 35.
In addition to towing tests to calibrate model calculations, tests were conducted with the moored platform with a self-propelled, radio-controlled, tug model intended to represent a resupply/servicing vessel. The types of activities that were simulated were representative of the types of operations necessary for personnel and material transfer when servicing the platform. Most of the tests were performed in either sea state 3 (nominal $H_s = 0.88m$, $T_p=7.5s$) or mean sea state 4 (nominal $H_s=1.88m$, $T_p=8.8s$). Based on the observations during the tests, sea state 4 represents the limiting condition for transfer of personnel and slung loads utilizing the EDP’s supply davit or the ship’s crane.
Based on tank tests, a decision was made to tow the EDP to the site in the Mid-Atlantic after lowering the buoyant cylinders in protected waters. During the tank tests, this was termed the Deep Towout configuration. The tug and tow speed was determined from the results of the tank tests.

The results from the towing tests were scaled back to the full EDP to determine the expected towing speed and are plotted in Figure 36. The estimates in the figure are for towing in calm water and in sea state 4 with 20 kt of ambient wind. The net towrope pull for 3,800; 5,000; 10,800 and 16,000 BHP tugs are typical values for generic tugs. Based on these results a mean speed-made-good of about 3.5 kt is estimated for the deep tow out condition towed by a 5,000 HP tug in conditions that average about Sea State 4 and U=20kt. A large UNOLS vessel with 10,000 BHP can tow the system although costs are higher than that for a moderate-sized ocean-going tug. The tow speed and current commercial tug costs were used in budgeting for installation.

An Anchor Handling and Towing System (AHTS) was chosen to be the second vessel at the site to manage the large weight of the anchors. The AHTS prepares for controlled lowering of the anchor by attaching its 3” main winch wire to the anchor with a swivel and an acoustic release. The tug passes the prepared end of the polyester to the AHTS for connection to the bottom chain attached to the anchor. The tug moves several hundred meters away from the AHTS, maintaining a slight strain on the polyester with its traction winch.

The AHTS overboards the anchor using its stern roller or a custom-manufactured tripping beam. The AHTS pays out the 3” wire rope to a predetermined termination at about the 2,500-meter mark. The downline is stopped off on deck and the bitter end connected to the AHTS’s 4” wire from its traction winch. During this operation, the tug stands off, paying out the polyester mooring line with a slight strain on it to prevent the anchor from spinning as the lowering wire tries to unlay (see Figure 37).
Figure 37. The tug, which brought the EDP to the Mid-Atlantic, is joined by a large AHTS for the anchoring operations. The figure shows the lowering of the 167,000-pound anchor by a 4" wire rope from the AHTS while the tug manages the polyester mooring line and chain connected to the anchor. The AHTS sets the anchor on the seafloor so the tug never assumes the full load of the anchor.

Once the anchor has touched bottom, the acoustic release is triggered and the down line is retrieved. The bitter end of the polyester is attached to a buoy on the tug, which is then overboarded. The procedure is repeated for installing the second and third anchors.
Figure 38. The completion of the EDP deployment using the tug and AHTS in concert. The tug pulls the EDP with two attached mooring lines toward the third anchor and mooring line.

Attaching the third leg requires that the tug be used to pull the EDP in the direction of the third anchor until it is close enough for the top chain to be passed. Approximately 5 MT (metric tons) of force is required to bring the EDP to its neutral position. The AHTS may use its working wire to assist with this maneuver, so that the period during which the tug and AHTS must work in close proximity is minimized. Once the final leg is made up, the tug and AHTS are free to leave.
**Figure 39:** The tank tests provided an opportunity for testing the service mode for the EDP. It was found that a manually controlled, twin-screw vessel equipped with a bow thruster could hold station with its stern to weather between the columns in sea state 4. The maneuver was easier when aided by soft stern lines passed around the columns to port and starboard. The *R/V Roger Revelle* is shown with the platform.

The crane on the EDP is rated at 5,000 at a 35 feet radius. If the servicing visit requires larger loads or longer reaches, the supply vessel will have to provide the larger lift capacity. Relative motions associated with a crane fixed to the servicing vessel may demand more benign conditions than those attending sea state 4. Transfer of liquids (e.g., fuel) will be accomplished by pumping, which is generally more tolerant of relative motions between the vessels.
## Appendix 2

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Name</th>
<th>State of Readiness</th>
<th>Deployment Platform</th>
<th>Avg Pwr(W)</th>
<th>Avg data rate (b/s)</th>
<th>Hydrate Mooring</th>
<th>Biorec</th>
<th>Axial Mooring</th>
<th>Subduction Zone</th>
<th>Total</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Global/regional seismic events, harmonic tremor</td>
<td>Broadband Triaxial Seismometer</td>
<td>High</td>
<td>Buried in seafloor</td>
<td>1</td>
<td>1000</td>
<td>2</td>
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<td>1</td>
<td>8</td>
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<tr>
<td>Global/regional seismic events, harmonic tremor</td>
<td>Broadband Triaxial Seismometer w/ a Episensor Accelerometer</td>
<td>High</td>
<td>Buried in seafloor</td>
<td>1</td>
<td>1000</td>
<td>8</td>
<td>8</td>
<td>Currenty 10 Keck Seismometers w/Scripps hydrophone (differential pressure guage, tuned for long periods) $30,000 for each sensor added to transition a donated sensor onto cable</td>
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<td>Tidal Pressure on Seafloor</td>
<td>Pressure</td>
<td>High</td>
<td>Ti-housing, stand</td>
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<td>1000</td>
<td>2</td>
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<td>1</td>
<td>1</td>
<td>6</td>
<td>Sensors have been deployed for &gt;1 year at Endeavour in Ti-housing, oil compensated</td>
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<tr>
<td>Tidal Pressure on Seafloor</td>
<td>Hydrophone</td>
<td>High</td>
<td>Coupled to broadband</td>
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<td>5</td>
<td>Routine in marine environments</td>
</tr>
<tr>
<td>Tidal Pressure on Seafloor</td>
<td>Current Meter + Temperature</td>
<td>High</td>
<td>~1 m mooring</td>
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<td>1000</td>
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<td>Medium-high (due to fouling)</td>
<td>Seafloor frame</td>
<td>200</td>
<td>3200000</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>Includes camera, lens, housing cables and pan and tilt. Lights will be mounted on top of camera on extension bars. Will need to deal with biofouling. Includes</td>
<td></td>
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<tr>
<td>Plume structure, velocity profile through water column</td>
<td>Bottom Mounted upward-looking ADCP</td>
<td>High</td>
<td>Seafloor frame</td>
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<td>16000</td>
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<td>1</td>
<td>Routine in marine environments, previously deployed in balck smoker-diffuse sites to look at plumes</td>
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<tr>
<td>Flow through sediment-water interface (0.1 to &gt;500 m/yr)</td>
<td>Optical Injection Trazer Sensor</td>
<td>High</td>
<td>Seafloor frame</td>
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<td>1000</td>
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<td>1</td>
<td>Previously deployed at Nootka and Monterey Canyon</td>
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<td>1</td>
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<td>Major/trace element chemistry of low and high temperature fluids</td>
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<td>High</td>
<td>Seafloor frame</td>
<td>1</td>
<td>1000</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>Routinely used in diffuse and black smoker systems, margin environments, and CORKed ODP-IODP observatories, requires recovery for chemistry</td>
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<td>Regional/local seismicity</td>
<td>Short Period Seismometer</td>
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<td>In borehole or cement seismomournt</td>
<td>1</td>
<td>1000</td>
<td>6</td>
<td>6</td>
<td>Deployed in drill holes or in cement seismomouns, array in place for several years at Endeavour, 2 will be transitional on to Neptune Canada. Must be deployed ≤5° of horizontal ($5000 added for each donated sensor to transition)</td>
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<td>Black smoker fluid temperature, hydrogen, and chlorinity</td>
<td>Temperature Resistivity-H2</td>
<td>High</td>
<td>Ti-housing, stand</td>
<td>1</td>
<td>1000</td>
<td>1</td>
<td>1</td>
<td>Deployed in black smoker edifions in Endeavour and EPR for &gt;1 year, 2 will be transitioned on to Neptune Canada.Will require sampling with gas-tight bottles prior to installation and after recovery for calibration</td>
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<td>Black smoker fluid temperature, hydrogen, hydrogen sulfide, and pH</td>
<td>pH-Hydrogen Sulfide-Temperature-hydrogen</td>
<td>High</td>
<td>Ti-housing, stand</td>
<td>1</td>
<td>1000</td>
<td>1</td>
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<td>Used on submersible/ROV and deployed in vents at Endeavour and EPR, will require sampling with gas-tight bottles prior to installation and after recovery for calibration</td>
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<tr>
<td>Inflation and deflation of seafloor due to magmatic processes</td>
<td>Bottom Pressure Tilt Recorder</td>
<td>High</td>
<td>T-housing, stand</td>
<td>1</td>
<td>1000</td>
<td>3</td>
<td>3</td>
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<td>Temperatures of diffuse flow</td>
<td>Thermistor Array</td>
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<td>Many of these have been built and used in diffuse flow sites</td>
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<td>Major trace element chemistry of diffuse flow fluids, co-registered temperature, hydrogen sulfide, pH</td>
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<td>Used at the NOAA NEMO Observatory on Axial Seamount and at Endeavour for several years, will require recovery for sample analyses</td>
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<td>Microbial community in diffuse flow systems</td>
<td>Particulate DNA Sampler</td>
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<td>Current Meter + Temperature</td>
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<td>Flow through sediment-water interface (0.1 to &gt;500 mly)</td>
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<td>Major/Trace element chemistry of low and high temperature fluids</td>
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<td>MBARI/GEOSENSE BH1 three axis corehole geophone connected to a MBARI/GEOSENSE LP1 data logger</td>
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<td>Black smoker fluid temperature, hydrogen, and chlorinity</td>
<td>Temperature Resistivity-H2</td>
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<td>PI</td>
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<td>Black smoker fluid temperature, hydrogen, hydrogen sulfide, and pH</td>
<td>pH-Hydrogen Sulfide-Temperature-hydrogen</td>
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<td>Inflation and deflation of seafloor due to magmatic processes</td>
<td>Bottom Pressure Tilt Recorder</td>
<td>Proscientific Digiquart2 pressure transducer, tilt meter Applied Geomechanics (L3Y)*</td>
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<td>Temperatures of diffuse flow across seafloor</td>
<td>Thermistor Array</td>
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<td>PI</td>
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<td>Microbial community in diffuse flow systems</td>
<td>Particulate DNA Sampler</td>
<td>McLane Phytoplanktron*</td>
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<tr>
<td>Measurement</td>
<td>Name</td>
<td>State of Readiness</td>
<td>Deployment Platform</td>
<td>Avg Pwr(W)</td>
<td>Avg data rate (b/s)</td>
<td>Hydrate</td>
<td>Hydrate Mooring</td>
<td>Axial</td>
<td>Axial Mooring</td>
<td>Sediments</td>
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<td>Current Meter-Acoustic</td>
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<td>Temperature, conductivity, dissolved oxygen</td>
<td>CTD-O</td>
<td>High</td>
<td>Profiler, platform, winch, bottom package</td>
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<td>80</td>
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<td>Fluorometer-DB</td>
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<td>Profiler, platform, winch, bottom package</td>
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<td>pH</td>
<td>Medium</td>
<td>Profiler, platform, winch, bottom package</td>
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<td>Profiles of turbulence</td>
<td>VADCP</td>
<td>High</td>
<td>Platform</td>
<td>1.00</td>
<td>16000</td>
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<td>dissolved CO2</td>
<td>CO2</td>
<td>Medium-high</td>
<td>Platform</td>
<td>12.00</td>
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<td>2</td>
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<td>Fish and engineering</td>
<td>Camera &amp; LED Lights</td>
<td>Medium</td>
<td>Platform</td>
<td>12.00</td>
<td>3200000</td>
<td>1</td>
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<td>Communication with surrounding sensors, extend the spatial footprint</td>
<td>Acoustic Modem</td>
<td>High</td>
<td>Platform and seafloor package</td>
<td>1.00</td>
<td>6300</td>
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<td>Marine mammal and fish, wind, rain, seismic tubresses</td>
<td>Hydrophone-Broadband</td>
<td>High</td>
<td>Platform and bottom</td>
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<td>6000000</td>
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<td>Horizontal electric fields, seafloor to sea surface acoustic travel time and pressure</td>
<td>HPRES Horizontal electric field &amp; Pressure Inverted echosounder</td>
<td>Medium-high</td>
<td>Seafloor Package</td>
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<td>9600</td>
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<td>Three of these now deployed in the NE Pacific</td>
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<td>Profiles of turbulence</td>
<td>VADCP</td>
<td>300kHz, 5 beam VADCP</td>
<td>Teledyne RDI</td>
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<td>Marine mammal and fish, wind, rain, seismic T-phases</td>
<td>Hydrophone-Broadband</td>
<td>Naxys ellyd</td>
<td><a href="http://www.naxys.no">http://www.naxys.no</a></td>
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<td>Horizontal electric fields, seafloor to sea surface acoustic travel time, and pressure</td>
<td>HPIES Horizontal electric field &amp; Pressure inverted echosounder</td>
<td>PI</td>
<td><a href="http://www.parascientific.com/echosounder.htm">http://www.parascientific.com/echosounder.htm</a></td>
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</table>
Papa

TO CYBERINFRASTRUCTURE SERVICE BUS

COASTAL/GLOBAL SCALE NODES/CYBERPOPs

GLIDER 6A
GLIDER 6B
GLIDER 6C
GLIDER 6D
GLIDER 6E

PAPA GLOBAL HYBRID PROFILER
PAPA SEA SURFACE MOORING 6A
PAPA SEA FLANKING MOORING 6A
PAPA SEA FLANKING MOORING 6B
TO CYBER INFRASTRUCTURE SERVICE BUS

COASTAL/GLOBAL SCALE NODES
CYBER POP's

Appendix 16

TYPES OF CONNECTIVITY
- CABLE
- RADIUM
- C-BAND
- ACOUSTIC
TO CYBER INFRASTRUCTURE SERVICE BUS

COASTAL/GLOBAL SCALE NODES
CYBER PDOs

SOUTHERN OCEAN
GLOBAL HYBRID MONITORING BA
SOUTHERN OCEAN
SEA SURFACE MONITORING BA
SOUTHERN OCEAN
FLAMINGO MONITORING BA
MULTI-FUNCTION
NOC BA
SOUTHERN OCEAN
FLAMINGO MONITORING BA

NOT FUNDED

TYPES OF CONNECTIVITY

--- CABLE
--- HOVER
--- C-BAND
--- HOVER
55 South

TO CYBERINFRASTRUCTURE SERVICE BUS

COASTAL/GLOBAL SCALE NODES/CYBERPOPs

GLIDER 8A
GLIDER 8B
GLIDER 8C
GLIDER 8D
GLIDER 8E

55S GLOBAL HYBRID PROFILER
MOORING 8A
55S SEA SURFACE
MOORING 8A
MULTI-
FUNCTION
NODE 8A

55S FLANKING
MOORING 8A

55S FLANKING
MOORING 8B
Mid Atlantic

TO CYBERINFRASTRUCTURE SERVICE BUS

COASTAL/GLOBAL SCALE NODES/CYBERPOPs

GLIDER 9A
GLIDER 9B
GLIDER 9C
GLIDER 9D
GLIDER 9E

MID ATLANTIC GLOBAL HYBRID PROFILER
MOORING 9A
SURFACE MOORING 9A

EDP J-BOX 9A

55S FLANKING MOORING 9A
55S FLANKING MOORING 9B
Endurance Array

To Node 1

SECONDARY NODE 1B

LOW VOLTAGE NODE 12A
COASTAL WINCHED PROFILER MOORING 12A
BENTHIC NODE 12A

SECONDARY NODE 1C

LOW VOLTAGE NODE 12B
COASTAL WINCHED PROFILER MOORING 12B
BENTHIC NODE 12B

SECONDARY NODE 1B

LOW VOLTAGE NODE 12C
COASTAL WINCHED PROFILER MOORING 12C
BENTHIC NODE 12C