OCEAN OBSERVATORIES INITIATIVE

FINAL NETWORK DESIGN

Version 2-06 Public
Document Control Number 1101-00000
2010-04-22

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Document Control Sheet

Note to the Reader: This document has been edited to remove information that is considered confidential and/or sensitive to ongoing or future financial negotiations for OOI procurements. Information removed has been replaced by the insertion of “[redacted]”.

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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 transforming the community's focus 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, oceanographic, 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 final design from the preliminary network design incorporates the response to the OOI Preliminary Design Review (PDR), and maximizes OOI's transformational impact. The OOI will enable multiple scales of marine observations that are integrated into one observing system via common design elements and an overarching, interactive cyberinfrastructure. The coastal-scale assets of the OOI will expand existing observations off both U.S. coasts, 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 high power grid. The global component addresses planetary-scale changes 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, Integrated Ocean Observing System - IOOS).

Through a unifying cyberinfrastructure, researchers will control sampling strategies of experiments deployed on one part of the system in response to remote detection of events by other parts of the system. Distributed research groups will form virtual organizations to analyze and respond to ocean events collectively, adding to the globally accessible environmental signal that digitally represents our planet. A specialized infrastructure designed for education and public engagement will interface closely with the cyberinfrastructure to expand the OOI's tools and discoveries more widely to the public consumer, enhancing the Nation's ocean literacy. 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, scientific collaboration, and education and public engagement. By applying the best technologies for ocean science, ocean data systems, community collaboration, and education, OOI will enable new science, make existing science more effective, publicly and interactively disseminate knowledge, and change expectations about what can be and should be achieved. This *OOI Final Network Design* presents driving motivations for this work, the requirements that have been identified, and the designs for each of the infrastructures comprising the OOI integrated observatory network.

2 Enabling a New Approach to Science and Education

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 individuals organized separate 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 in oceanography 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 irrevocably 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 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, raise our Nation’s ocean literacy within the general public, and change expectations about what can be and should be achieved.

2.1 What is Different about the OOI?

Humans have a great deal of experience with atmospheric effects and conditions on the continents, but we understand very little about how the ocean and underlying seafloor operate. The ocean, like the atmosphere, is vital to life on Earth. The fluid ocean stores and transports heat, freshwater, carbon dioxide, and nutrients around the globe. Anomalies in ocean surface temperature and heat storage influence atmospheric circulation across time scales from weather to climate, affecting surface temperature and rainfall on Earth. Even more than the atmosphere, the ocean supports diverse ecosystems vital to society. Plate tectonics cause active volcanoes, large earthquakes and tsunamis, the formation of energy resources, and may be required for the initiation of life on Earth. The OOI is about understanding how the complex interplay of atmospheric, oceanic, and tectonic processes within the ocean basins influence our quality of life. In the broadest sense, the OOI is designed to study the ocean system as driven at its two boundaries: its surface, heated by the sun and driven by winds, and its benthos, heated from below by geothermal heat and driven by plate tectonics.

Movement of the ocean’s surface is driven from above, by the atmosphere. Both the ocean and atmosphere absorb solar radiation most intensely in the tropics. The asymmetry in the heating between the equator and the poles, together with strong wind patterns, drive global-scale, 3D circulation that carries warm water pole-ward and cool water equator-ward, plunging downward into the interior of the oceans. The salinity of surface waters is an important regulator for downward mixing, which also removes carbon dioxide from the atmosphere. With increased melting of polar ice and resulting de-salinization of surface waters, the creation of dense waters at high latitudes will decrease, which could alter the global circulation patterns that define the ocean climate we know today. Growing human populations that increasingly burn fossil fuels are further loading the transport system with atmospheric carbon dioxide, which is absorbed into the ocean, altering the global carbon cycle.

Strong coastal boundary currents such as the Gulf Stream are part of this ocean climate, resulting directly from wind stresses associated with equatorial heating and the rotation of the Earth. These complex coastal flow patterns modulate the transport of nutrients critical to marine life. Nutrient richness and resulting healthy ecosystems make coastal areas regions of high economic value. Nutrients, pollutants, and other material from rivers and streams affect ecosystem health and are exchanged into the ocean interior by the boundary currents.

The ocean climate is also profoundly influenced by its bottom boundary layer, the dynamic seafloor. Earth's tectonic plates are in motion, causing new seafloor to be formed by volcanism at ocean ridges and recycled back into Earth's interior as evidenced by large earthquakes at subduction zones. Heat flow between partially molten magma chambers and the cool seafloor causes chemically laden water in the fractured seafloor aquifer to escape, supporting unique ecosystems through recently discovered chemosynthetic mechanisms. Seafloor formations of frozen methane hydrate may be both a source of energy and a threat if large-scale release of this sequestered greenhouse gas is suddenly triggered by a slow increase in ocean temperature, or if degassing of hydrates leads to mass wasting along the continental margins. The escape of methane is one explanation of global species extinctions.

Just as forecasting the weather was not possible until meteorological stations were established on oceanic (e.g., Ocean Weather Ships that operated following WWII), continental, national, and municipal scales and their observations were used collectively, a multi-scale approach is needed to study the innumerable dependencies in the ocean climate. Making the analogy with the view of Earth's surface at night, buoy arrays have done much to "light up" the tropics and mid-latitudes, de-ciphering ocean effects like El Niño. Yet, latitudes above 40°, where strong winds and vigorous atmospheric exchange establish the global circulation system, remain dark. A few key stations there would provide sustained sampling of circulation and climate change drivers, and would anchor with certainty the spatial gradients of air-sea exchange inferred from models and remote sensing. There is an occasional lamp lit along the coasts of the United States, but the current tools are insufficient to observe the strong gradients in water properties and nutrients, and understand how varying flow patterns that affect marine life. Given their importance to our sustenance and economy, a spotlight of observing capability needs to shine on our coastal regions. We have visited the seafloor with submersibles, but have not established a sustained illumination of the bottom boundary of the ocean climate.

The NSF Ocean Observatories Initiative will install the wiring to illuminate these interdependent regions. Four ocean arrays will be built in the following locations: southeast of Greenland, in the Gulf of Alaska, in the Argentine Basin, and in the poorly known Southern Ocean. A coastal Pioneer Array on the continental shelfbreak off New England, where south-flowing cool waters of the Labrador western boundary countercurrent interact with warm Gulf Stream waters flowing northward, will tie fine-scale observations of ecosystem health to the large-scale circulation and transport observations made at the Greenland station. In contrast, the coastal Endurance Array off Oregon will observe a narrower shelf with a wind-driven eastern boundary current, referenced back to high-latitude observations from the Gulf of Alaska. This array is connected to Regional Scale Nodes (RSN) spanning the seafloor of the Juan de Fuca tectonic plate, providing a continuum of scales from the coastal zone into the deep ocean while observing the main tectonic forces of rifting, volcanic building, faulting, venting, and subduction of the seafloor,. Full water column moorings on the RSN tie shallow coastal observations to the deep sea, offshore environment monitoring eastern boundary currents. Unique in the network, these nodes will be hard-wired by telecommunications cables to provide high power (10 kv) and bandwidth (10 Gb/s). These observations will be wired together and eventually networked into a multi-agency and international observing grid through cyberinfrastructure (CI). The CI provides a powerful lens to combine hundreds of thousands of individual observations into customizable views which can be "focused" on a particular science question akin to the fine-tuning control on a telescope, and the Education and Public Engagement infrastructure will extend the view to the non-specialist audience.

Answering the question, "How does the ocean function as a coherent physical, chemical and biological system at different scales of time and distance?" is vital to the future of our species. The answer will not be forthcoming using existing facilities - ships, low latitude buoys, floaters, etc. The fully integrated system envisioned by the OOI will quantitatively measure the interaction of major and minor global ocean components and processes and determine their interdependence for the first time. As with other sciences – physics, astronomy, genomics – transformational increases in the resolution of observations in time and spatial dimension lead inevitably to paradigm-shifting discoveries. Given how little we understand about Earth's ocean, this will be manifestly true upon the completion of the infrastructure planned for the 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, interactive architecture enabling a sophisticated web of sensors, analysis and modeling cyberinfrastrcture and virtual 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 revealed by data analysis and data assimilation into models
- System Interoperability: Common ways to exchange information and data 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 modifies the mineralogy of oceanic crust and sediments, leads to the formation of hydrothermal vents that support unique micro- and macro-biological communities, and concentrates 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 benthic and sub-seafloor 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 degree to which active plate boundaries influence the ocean from a physical, chemical, and biological perspective are largely unexplored.

Persistent geophysical sensors at two key tectonic boundaries - a spreading center and subduction zone - will provide critical data about plate deformation and its causes and effects. The permanence, power, and bandwidth associated with this network will provide critical data focused on processes and linkages between earthquakes, major carbon release from volcanic gases, hydrothermal flow, methane hydrate release, and seafloor biological activity 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. The OOI's impact will be further extended through its education and public education infrastructure that will be designed in response to carefully articulated user requirements and closely linked to the cyberinfrastructure.

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 readily 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 studying the ocean and the ocean's impact on many aspects of our human society.

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 Oceanographic Research and Education (CORE). This effort broadened into the Dynamics of Earth and Ocean Systems (DEOS) committee leading to the Ocean Research Interactive Observatory 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 2-1. Major milestones in the development of the Ocean Observatories Initiative.

Figure 2-1 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 (JSOST) 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, the NSF Division of Ocean Sciences (NSF/OCE) established a project office to coordinate further OOI planning through a cooperative agreement to Joint Oceanographic Institutions (JOI). JOI was one of the predecessor organizations that merged to form Consortium for Ocean Leadership in 2007. Beginning in 2005, guided by a large community advisory structure, JOI coordinated a broad community effort to arrive at a Conceptual Network Design (CND; 7-10) that was vetted with the potential user community 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. The CDR 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 (12).

The major partners in the planned OOI construction process, called Implementing Organizations (IO), were selected in 2007 by an acquisition process similar to that used in large federal acquisitions. Subawards were established to University of Washington as the IO for the Regional Scale Nodes in March 2007, University of California San Diego (UCSD) as the IO for the Cyberinfrastructure in 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 in August 2007. Ocean Leadership is providing the program management and systems integration role for the overall OOI system.

In arriving at the *OOI Preliminary Network Design* (PND; 13), Ocean Leadership depended largely on its Implementing Organization partners to reconcile the technical concepts from the CND with cost and design details done from the "bottom up" by costing over 600 individual technical work packages in the PND Work Breakdown Structure. 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* (14) and constrained by the contractual responsibility of performing to the cost, schedule, and scope baselines.

NSF convened the OOI's Preliminary Design Review in December 2007. The panel report of the PDR was very favorable (15) and advised the program to move forward with construction. The Report included 43 recommendations for NSF to consider for transmission to the implementation team. These recommendations have been considered, and in most cases implemented (16), as part of the work leading toward the OOI's Final Design Review held and passed November 2008. Modification of the network design to accommodate NSF recommended infrastructure changes lead to an additional design review held in March, 2009. On May 15, 2009, the National Science Board authorized the NSF Director to make awards toward the construction of the Ocean Observing Initiative network.

3 Requirements

A composite set of OOI Acquirer Requirements, gathered from science, programmatic, environmental, and other sources, is captured and controlled in a hierarchically organized manner. These requirements represent a distillation, reorganization, and further maturation of requirements starting from previous versions of the *OOI Science User Requirements* (14) and the *Systems Requirements* (18) developed with the *OOI Preliminary Network Design* (13).

The OOI project follows a standard systems-engineering approach for setting requirements at successive levels of detail, maintaining traceable relationships between them, and testing them appropriately. All requirements are maintained in the Dynamic Object Oriented Requirements System (DOORS) database application. The relationships between science requirements, system requirements (at all levels), and conformance tests, as well as the systems engineering and configuration management policies will be maintained and enforced using the DOORS application.

The set of OOI acquirer requirements comprises top-level requirements at Level 2 (L2), system requirements at Level 3 (L3), subsystem requirements at Level 4 (L4), and individual system elements captured in lower levels. This schema is described in Figure 3-1. Acquirer requirements are prepared, reviewed, released, controlled, and maintained in accordance with the *OOI Configuration Management Plan* (CMP; 19).

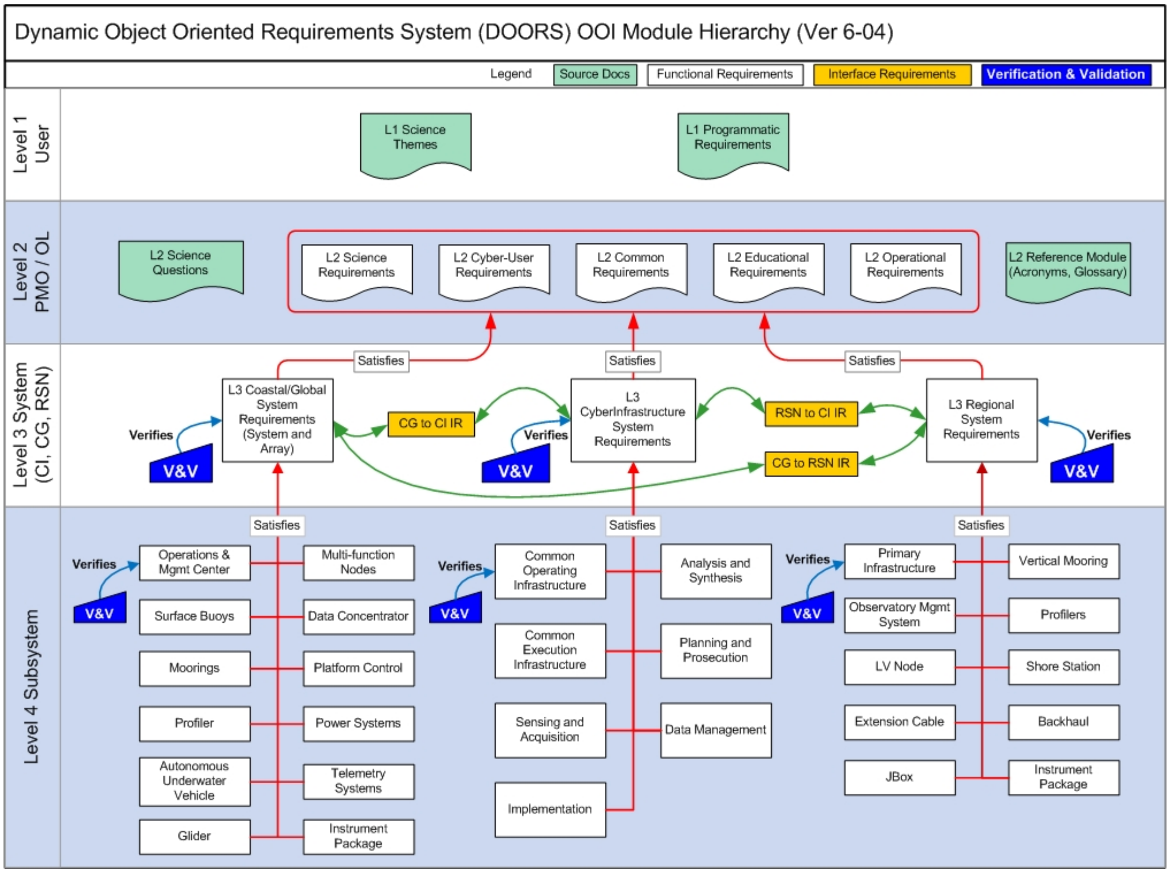

Figure 3-1. Schematic description of the OOI requirements hierarchy in DOORS.

3.1 Level 2 Requirements

The top-level of the acquirer requirements are recorded in DOORS as the following set of Level 2 Requirements modules:

- L2 Science Questions
- L2 Science Requirements
- L2 Cyber-User Requirements
- L2 Educational Requirements
- L2 Operational Requirements
- L2 Common Requirements

The Level 2 modules are grouped to facilitate traceability of requirements from the top level to any lower level of the requirements hierarchy.

3.1.1 L2 Science Questions

Multiple workshops and reports have identified OOI Level 2 Science Questions that reflect the high priority areas of ocean research that require the infrastructure envisioned in a state-of-the-art ocean observing network. These topics have been described in founding program documents, such as the *OOI Science Plan, Ocean Sciences at the New Millennium*, and *Ocean Research Interactive Observatory Networks (ORION) Workshop Report* (1,2,and 3 respectively). 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 OOI's six science themes, constituting the basis from which the OOI Level 2 Science Questions were developed, were described in Section 2.2.

3.1.2 L2 Science Requirements

Project science requirements provide the foundation of the design process, and establish the functions and performance levels the installed observatory delivers. The science requirements override all other design variables and are carefully protected throughout the development period. The science requirements have been derived from the *OOI Science Plan* and traceability matrices, and are maintained in DOORS.

As discussed in the CMP, modifications to the science requirements shall be made only based on specific authorization by the Principal Investigator (PI), and all changes shall require approval by the Change Control Board, with OOI Level 2 Science Questions driving rationalization.

3.1.3 L2 Cyber-User Requirements

The Cyber-User Requirements were initially based on the CI Conceptual Architecture, and were developed from an examination of the *OOI Science Plan* (1) and existing observatory projects (Linked Environments for Atmospheric Discovery - LEAD, Software Infrastructure and Applications for the Monterey Ocean Observing System - SIAM, Shore Side Data System - SSDS, IOOS Data Management and Communications - DMAC, and VENUS/NEPTUNE Canada) using with input from the OOI advisory structure. Further definition of the Cyber-User Requirements was achieved by a deliberate capture process based on stakeholder involvement. This process is iterative in nature, to provide immediate stakeholder feedback and requirements adjustment. The Cyber-User Requirements are divided into four major categories (functional requirements, performance requirements, design principles, and interface requirements), and then further sorted into categories that are consistent with the CI subsystems.

3.1.4 L2 Educational Requirements

OOI Educational Requirements were developed through a mission 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. The approach to developing the Educational Requirements is discussed more fully in Section 4.5.

The resulting Level 2 Educational Requirements 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 (20). They are well aligned with National Science Board (NSB) priority recommendations for an NSF Science, Technology, Engineering, and Mathematics (STEM) education roadmap (21) and the Ocean Literacy Principles by multiple sponsoring agencies in 2004.

L2 OOI Educational Requirements are cognizant of the anticipated level of MREFC funding that will be provided to construct the OOI EPE infrastructure, which NSF has defined as something that depreciates over time and needs to be bought, developed, and/or maintained.

3.1.5 L2 Operational Requirements

The OOI Level 2 (L2) Operational Requirements have engaged the OOI stakeholders in identifying requirements and the concept of operations for data product generation, ocean observing programs, education and public engagement, and integrated observatory management. The architectural specification effort for subsystems has refined system requirements and operation views, and provides system and technology views for the six subsystem: Plan and Prosecution, Analysis and Synthesis, Sensing and Acquisition, Data Management, Common Execution Infrastructure, and Common Operation Infrastructure.

3.1.6 L2 Common Requirements

OOI Common Requirements allow for a broad science community access to large volumes of data collected over sustained time periods in near-real time from a large number of sites at varying scales. As discussed in Section 2.1, these Common Requirements capture the need to provide key features for multi-scale capability of the OOI:

- 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.

3.1.7 Other Top-Level Requirements

While science requirements form the core of the design process, a host of additional requirements must also be simultaneously satisfied. OOI programmatic requirements include, but are not limited to, fulfilling international treaty obligations, compatibility with existing transportation and handling resources whenever possible, user safety, and many other aspects critical to the instrument design yet not directly tied to specific science requirements.

Many other sources of requirements exist that may require capture and management during the overall system development. Examples include compatibility with existing development tools and test equipment, safety and ergonomic provisions, need for test and repair access, and others too numerous to list here.

The requirements development process shall identify, collect, and record other stakeholder requirements that may affect development, production, test, deployment, training needs, and maintenance of OOI, and ensure that the resulting set of requirements agrees with other stakeholder needs and expectations.

3.2 Level 3 (L3) System Technical Requirements

While the Level 2 Requirements capture the primary overarching requirements of the OOI, the System Technical Requirements contain some of the more detailed specifications and constraints. Because of the wide breadth of systems, software, hardware, operations, and services required for the OOI, the OOI System Technical Requirements are defined by and within each IO’s System Requirements and maintained jointly within the OOI DOORS system.

3.2.1 L3 CG System Requirements

The Level 3 System Requirements for the Coastal and Global Scale Nodes (CGSN) are captured in the *Coastal-Global L3 Requirements* (in DOORS). These requirements describe the CGSN system architecture and explains the data measurement requirements at each of the Coastal and Global arrays, sites, and platforms. These requirements have been used to derive the subsystem requirements for the fixed and mobile assets that comprise the coastal and global arrays. The CGSN IO is responsible for the development, refinement, and maintenance of these requirements and the overall document integrity.

The CGSN Level 3 Requirements inform the design, build, and operation of an integrated network of offshore infrastructure to facilitate ocean science over the next three decades. These requirements define a system that is part of a larger network that includes the Regional Scale Nodes (RSN); a network to be fully integrated by a shared Cyberinfrastructure (CI) designed and implemented by the CI IO. CGSN Level 3 Requirements include system requirements for, but not limited to, four Global Arrays, the Pioneer Array, the Endurance Array, and Operations Management Centers.

3.2.2 L3 CI System Requirements

The Level 3 System Requirements for the OOI Cyberinfrastructure are captured and maintained in the *Cyberinfrastructure L3 System Requirements*. The CI System Requirements set, supplemented by the Interface Requirements, is used as the basis for design and qualification testing of the OOI Cyberinfrastructure.

They detail the requirements for information technology structure, capabilities, and development plans required to integrate the OOI’s CGSN and RSN marine infrastructure into a coherent system-of-systems providing an integrated observatory network and user environment management services. The CI System Requirements are derived from, and can be traced to, Level 2 requirements. The L3 CI System Requirements are the parent requirements used to derive the Level 4 requirements for each of the CI Subsystems, which are also captured and maintained in DOORS modules. Traceability is maintained from the L4 requirements to the parent L3 requirements and to the grandparent L2 requirements using inherent DOORS capabilities, which allows both bottoms-up and top-down analyses of proposed changes and potential risks.

The CI IO is responsible for the development, refinement, and maintenance of the L3 CI System Requirements and for maintaining the hierarchy of CI requirements from the top-level L2 Cyber-User Requirements to the L4 subsystem requirements in accordance with the CMP and the *OOI Systems Engineering Management Plan* (SEMP).

3.2.3 L3 RSN Requirements

The Level 3 System Requirements for the Regional Scale Nodes (RSN) are captured in the *RSN Level 3 Requirements*. These requirements describe the RSN system architecture and explains the data measurement requirements at each of the Regional Scale Nodes. These requirements shall be used to derive the subsystem requirements for the fixed and mobile assets that comprise the coastal and global arrays. The RSN IO is responsible for the development, refinement, and maintenance of these requirements and the overall document integrity.

RSN Level 3 Requirements include specific system requirements for, but not limited to, communication systems, power systems, time distribution systems, observatory control systems, land-based facilities, primary infrastructure, secondary infrastructure (e.g. vertical moorings, network interfaces, etc), core instruments, the backhaul, and shore stations. They describe general system requirements such as expandability, maintainability, security, operations, reliability and environmental consideration. This requirements document shall be used to derive the subsystem requirements for the subsystems comprising the RSN, and is in the control of the RSN IO to develop, refine, and maintain requirements and document integrity.

3.2.4 Interface Control via L3 Interface Requirements

The OOI project has established specific interface requirements between various parts of the system being developed by the different Implementing Organizations. These are also captured, monitored, and managed through DOORS as part of the System Technical Requirements. The challenge of effective interface control is significant, and interface control represents a key project risk area that must be carefully managed. The fewer, and simpler, the interfaces that are introduced, the lower the overall risks are to the project.

The four currently defined interface requirements are:

- L3 CG-CI Interface Requirements
- L3 CI-RSN Interface Requirements
- L3 RSN-CG Interface Requirements
- L3 CI-EPE Interface Requirements

The Interface Requirements are the controlling documents for the design and implementation of any required interfaces between the components of the OOI. They also outline the responsibilities of each organization vis-à-vis collaborative developments. They are specific to the nature of the technical overlap or collaborative development.

For example, the interface requirements between the CGSN IO and the CI IO specifically address how the CI will interface to the moored and autonomous components of CGSN. The interface requirements between the CI IO and the RSN IO specifically address how the CI will interface to the cabled infrastructure and shore stations of the RSN. The interface requirements between the RSN IO and the CG IO specifically address the connection of some of the Endurance Array coastal moorings to the RSN backbone cable. The interface requirements between the CI IO and the EPE IO will outline how the EPE IO will access CI products and services and how their developed products and tools will be integrated into the CI.

DOORS will be used to manage the requirements extant in the interface requirements, and the relationships between, and orchestration of, associated activities, e.g. system acquisition, development, testing, sustainment, and operations.

3.3 Level 4 (L4) System Technical Requirements

Level 4 of the system technical requirements pertain to specific identified subsystems (Figure 3-1). They generally record the design solution work products, including the specified requirements, in the DOORS database, including the results of all tradeoff analyses, the design rationale, assumptions, and key decisions to provide traceability of requirements up and down the system structure. Level 4 requirements also define tasks that require development, or tasks that require procurement of off-the-shelf or reused solutions, which will satisfy identified requirements for associated processes (production, test, deployment/installation, training, support or maintenance, and retirement or disposal) related to the system's end products. As with L3 requirements, L4 requirements are also within the responsibility of the respective Implementing Organization.

3.3.1 L4 CI Requirements

Major CI Level 4 requirements include:

- **Sensing and Acquisition:** the subsystem responsible for providing the life cycle and operational management of sensor network environments, as well as observing activities (i.e., scheduling, collecting, processing) associated with sensor data acquisition;
- **Analysis and Synthesis:** the subsystem responsible for providing the life cycle and operational management of community models, ensembles of models and the virtual ocean simulator, as well as modeling activities (i.e., assimilation, analysis, evaluation) using observed and derived data products;
- **Planning and Prosecution:** the subsystem responsible for providing the mission and campaign planning and prosecution (execution through completion) activities to carry out simultaneous coordinated multi-objective observations across the resources of the system;
- **Data Management:** the subsystem responsible for providing life cycle management, federation, preservation and presentation of OOI data holdings and associated metadata via data streams, repositories and catalogs;
- **Common Operating Infrastructure**: provides the services and distributed infrastructure to build a secure, scalable, fault-tolerant federated system of independently operated system components;

- **Common Execution Infrastructure:** provides the services to manage the distributed, immediate mode execution of processes;
- **Implementation:** provides the specifics about the deployment of the CI, including the properties of Instrument and platform agents and Cyberpops.

3.3.2 L4 Coastal / Global (CGSN) Requirements

Major CGSN Level 4 requirements include:

- **Moorings:** Surface and subsurface moorings used in the CGSN are designed to keep the surface and water column fixed measurement stations on station between maintenance intervals, each configured specifically for a site and its functional requirements.
- **Surface Buoys:** Surface buoys provide the necessary buoyancy to support surface moorings by resisting mooring weight and drag forces. In the CGSN they are also used as platforms for meteorological sensors, RF telemetry equipment, power generation and storage systems, and data collection and control subsystems.
- **Autonomous Underwater Vehicles (AUVs):** A fleet of Autonomous Underwater Vehicles (AUVs) will be used to collect data in the general vicinity of the Pioneer Array. AUVs will operate unattended for extended durations, utilizing docking stations at the base of Pioneer Array EOM moorings to offload data and recharge batteries between missions.
- **Multi-Function Node (MFN):** A subset of the CGSN moorings will incorporate a MFN at the base 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. MFNs can be configured to incorporate an AUV docking station.
- **Platform Control:** The platform controller, or Communications and Power Monitor (CPM), provides the intelligence aboard platforms to acquire sensor data, monitor the state of health of the platform, provide the means for telemetry of data and command information to a shore facility, and to maximize the life of the platform according to predetermined operability rules.
- **Data Concentrator:** The Data Concentrator Logger (DCL) is a microcomputer based element that is the hardware interface to sensors, responsible for configuring, powering and monitoring health of sensors, acquiring, and storing data and forwarding data as requested either directly to a telemetry device or via the Communications and Power Manager (CPM).
- **Power Systems:** The power system is designed to provide continuous power to a buoy based data collection and telemetry system in all weather and seasons. Power systems may contain fuel cell, photovoltaic, and wind generators as well as primary and secondary battery banks.
- **Profiler:** Moored profilers contain a suite of sensors that are raised and lowered through the water column on a regular basis. The profiler body may travel through the water column using wire-following for deep measurements or winched technique for surface piercing measurements.
- **Glider:** Underwater gliders are autonomous vehicles that profile vertically by controlling buoyancy and move horizontally on wings. Within the CGSN, gliders will be employed for two general purposes: providing horizontal context to horizontally fixed platforms and communicating with subsurface instruments and relaying their data to shore.

- **Telemetry:** The telemetry system is comprised of a set of telemetry devices operating through satellite links, local radio links, and in some cases acoustic modems. The telemetry systems allow communications between platforms and the shore station or nearby University-National Oceanographic Laboratory System (UNOLS) ships as well as platform to platform communications.
- **Operations and Management Center:** The shore station will operate 365 days a year and support operational staff. Systems will be automated as much as possible with operator alerts available around-the-clock. Each facility will provide space for the operations staff, computers and communications equipment, and will have internet connectivity, a firewall, a GPS time server, air conditioning, and emergency backup power.
- **Instrument Package:** The Instrument Package subsystem includes all of the sensors and interfaces needed to measure the environment at rates, locations and accuracy needed to fulfill the science user requirements.

3.3.3 L4 RSN Requirements

Major RSN Level 4 requirements include:

- **Primary Infrastructure:** includes all equipment to provide power at 10 KV and bandwidth at 10 Gbps from the Shore Station on the coast of Oregon to the RSN Sites across the Juan De Fuca Plate.
- **Observatory Management System** (OMS): is a software application with interfaces to all of the Primary and Secondary Infrastructure Element Management Systems (EMS) to provide a single point of interface for command and control of the RSN infrastructure for the CyberInfrastructure and for the RSN Operations Center.
- **Low Voltage Node** (LV Node): subsystem is a power, timing and communication distribution and aggregation node in the Secondary Infrastructure that is a junction between the Sensor connected to Junction Boxes and Primary Nodes.
- **Extension Cable:** provides power and communication links between the Primary Infrastructure, Secondary Infrastructure and instruments.
- **Junction Box** (JBox): this subsystems provide connection points for instruments to the RSN infrastructure. The JBox provides power and timing to the sensors and communication between the sensor in its native format (RS232/RS485/TCP/IP) and the RSN TCP/IP communication system.
- **Vertical Mooring**: this subsystem provides the infrastructure needed to support continuous profiling of a water column from sea-floor to just below the sea-surface. The Vertical Mooring includes an EOM cable anchored to the seafloor and a fixed buoyant platform at 200 meters below the sea surface.
- **Profilers:** this subsystem includes two components of the Vertical Mooring. The Deep Profiler allows for sampling the water column from near the seafloor to the 200 meter platform along the EOM cable. The Shallow Profiler allows for sampling the water column from the 200 meter platform to just below the sea surface.
- **Shore Station:** this subsystem includes the physical building and support needed for the shore based equipment of the Primary Infrastructure. It includes providing conditioned Utility Power with backup systems and access to the cable beach terminations and backhaul access points.

- **Backhaul:** this subsystem provides a high reliability, high bandwidth link between the Shore Stations and the Cyberinfrastructure CyberPop in Portland.
- **Instrument Packages:** this subsystem includes all of the sensors and interfaces needed to measure the environment at rates, locations and accuracy needed to fulfill the science user requirements.

4 OOI Network Final Design

4.1 System of Systems

The OOI contains a continuum of observation scales in order to capture the intimate linkages between processes at work in the ocean. This continuum is simplified into three scale groupings of marine infrastructure: coastal, regional and global. The marine infrastructure is located worldwide as indicated in Figure 4.1-1. The at-sea components are integrated by the Cyberinfrastructure creating the ability to control and operate the whole system from both a centralized location and distributed local control environments. This allows remote control of the entire infrastructure thus providing the capability to adaptively change the measurement frequency when significant events occur.

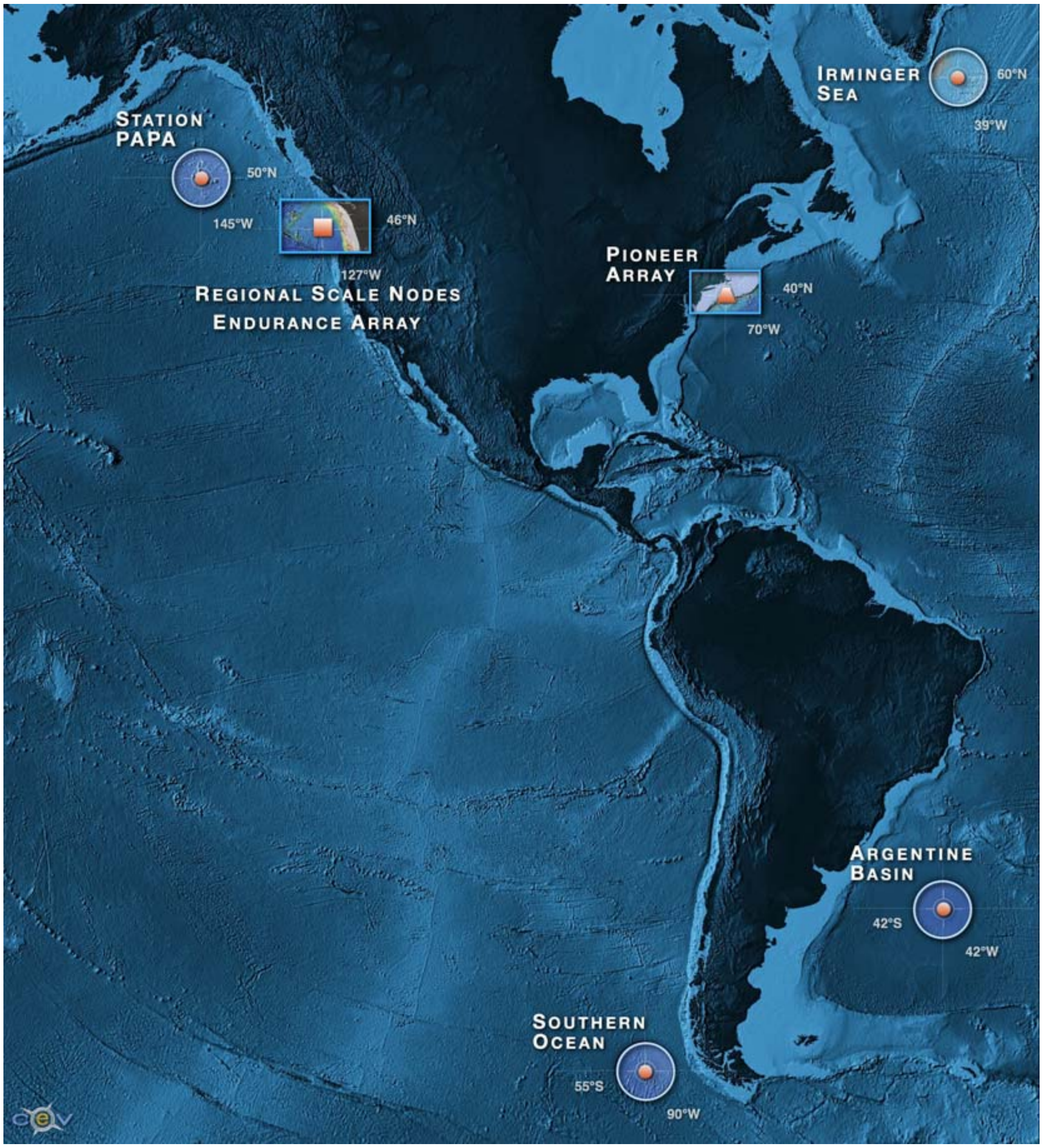

Figure 4.1-1 Location of the OOI marine infrastructure.

4.1.1 Top Level Design

The Final Network Design (FND) is based on elements of the Preliminary Design and Conceptual Design. The FND reflects the same basic technical design solution presented at PDR with more engineering detail for the components selected by the engineering team. The FND is described in its component parts in Sections 4.2 – 4.5 of this document, describing the Cyberinfrastructure, Coastal and Global Scale Nodes, Regional Scale Nodes, and Education and Public Engagement infrastructure, respectively. Engineering drawings for the OOI Final Design are contained in the Technical Drawing Package.

4.1.2 Common Elements

During PDR it was clear that a number of elements of the design could potentially be common throughout the OOI system. During the development of the Final Network Design, a concerted effort was made to develop common infrastructure where the approach yields savings in first costs or operations and maintenance costs. The following areas are representative examples of common infrastructure that were developed during the Final Design.

4.1.2.1 Moored Platforms

Moored platforms provide oceanographers the means to deploy sensors at fixed depths between the sea floor and the sea surface and to deploy packages that profile vertically at one location by moving up and down along the mooring line or by winching themselves up and down from their point of attachment to the mooring. An oceanographic mooring is anchored to the sea floor by a mooring line extending upward from the anchor to one or more buoyant floats, which can be in the water column or at the sea surface (Fig. 4.1-2). The mooring line can be plastic-jacketed steel wire rope, synthetic line, electromechanical (EM) cable with copper conductors or electro-optical mechanical (EOM) cable with copper conductors and optical fibers. These capable and proven oceanographic platforms are used throughout the OOI, by the RSN and by all the Coastal and Global Nodes of the CGSN.

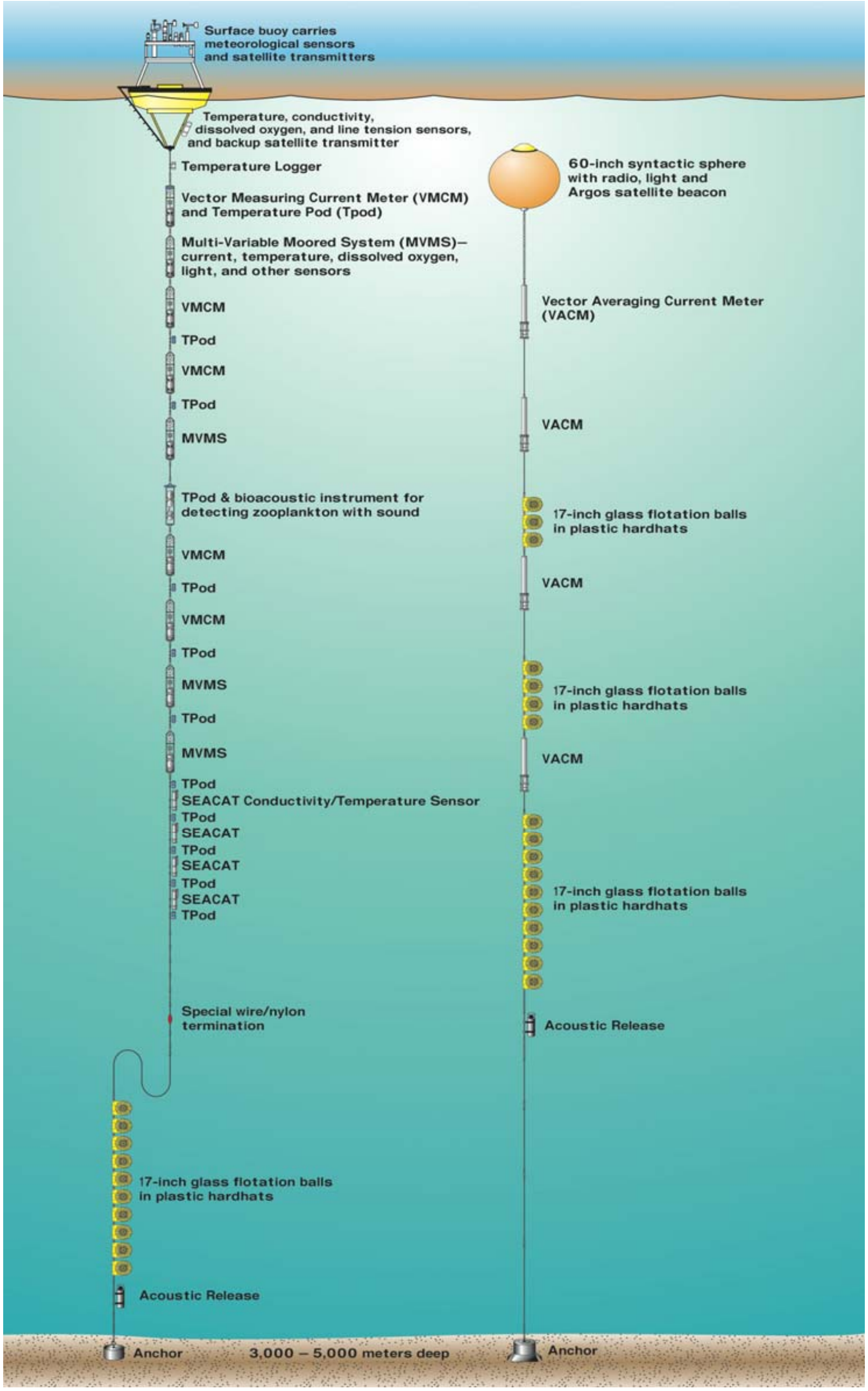

Figure 4.1-2. Schematic drawing of oceanographic mooring types. On a surface mooring (left) the buoyancy that supports the mooring line and attached instruments is a surface buoy. On a subsurface mooring (right) buoyancy is provided by a float in the water column.

Most OOI moorings are of compound construction, using more than one of these materials to optimize performance. The wire rope can be used not only for strength and resistance to fish-bite, but also for inductive telemetry of data from moored instrument packages. With inductive telemetry, a controller on a surface buoy or subsurface float can aggregate data and command instruments on the mooring line below. The wire rope also provides the pathway for wire-following profilers to ascend and descend by traction motors or buoyancy control. Synthetic mooring line is used when elasticity is needed to allow a surface mooring to stretch in response to increased ocean currents, a better option than either dragging the anchor or pulling the surface buoy underwater. Mating a synthetic line such as polypropylene (which floats) to nylon (which doesn't) allows additional scope (the ratio of mooring length to water depth) by creating an S-shaped section which can expand and contract in reaction to tension on the mooring (Fig. 4.1-2). In the OOI, use of EM and EOM cables for some moorings allows power and data to flow through the mooring line. Innovations to EM and EOM moorings for OOI include the use of molded chain and stretch-hose elements with spiral-wrapped conductors and optical fibers. These elements allow a high degree of adaptability to different water depths and oceanographic conditions.

The unique aspect of the surface mooring is its surface buoy (Fig. 4.1-3). The buoy provides a platform for mounting atmospheric sensors and ocean surface sensors, as well as a housing for equipment for power generation and storage, data aggregation and recording, two-way telemetry, and GPS location. In the OOI, the capabilities of surface buoys will be greatly expanded relative to conventional designs; power generation capability of up to 250 W (continuous) and 500 W (peak) will be implemented. The availability of power on the surface buoys supports advanced instrumentation such as stabilized communication antennae, powering of instruments on the mooring line, and transmission of power down the line for sea-floor instrument nodes and docking stations for Autonomous Underwater Vehicles (AUVs).

Figure 4.1-3. A 3-m diameter surface buoy on a surface mooring deployed in the Gulf Stream. The buoy carries meteorological sensors, including sonic anemometers for computing turbulent air-sea fluxes.

The placement of discrete instruments along a mooring line provides the capability to sample in time, possibly quite rapidly (tens of Hz), at fixed depths. The use of a profiler has the advantage that one package, with the same sensors (and sensor calibrations), sweeps through the water column covering it more cost effectively (although sampling at fixed depths less often).

A surface mooring provides the means to deploy instruments at the air-sea interface and support sampling at depths fixed with respect to the sea surface. The sea surface is a challenging environment. Mechanical loads and fatigue, as well as the problems posed by biofouling, must be addressed in the design. Static tensions on the order of 2000-3000 kg are possible at the surface buoy, with dynamically varying tensions due to wave forcing superimposed on the static load. A wire rope section is commonly used in the upper 1000 meters of the mooring where dynamic loads are highest. The wire rope also offers good resistance to damage caused by fishbite, a problem encountered within the euphotic zone, where biofouling can lead to the formation of a microhabitat that attracts fish and sharks. Below the wire rope section, synthetic line is utilized for the benefit of its light weight and elasticity. Surface mooring designs are simulated and analyzed using nonlinear 3D numerical modeling technijquies that include forcing by surface waves and swells.

In comparison, the full length of a subsurface mooring is taut, providing a good platform on which to deploy instruments at depths fixed with respect to the sea floor. The subsurface float is below the depth of strong wave orbital velocities, isolating the mooring from much of the high-frequency variability in forces that a surface mooring experiences. Thus, subsurface moorings can be used for wire-following profilers, which can operate along continuous, unobstructed sections of the mooring wire. Ocean current flows induce drag forces that pull subsurface mooring buoys down below their static design depth, but the moorings are designed to minimize this ‘blow down.’

The subsurface float can also be fitted with instruments and batteries, and serve as a base of operations for shallow or surface-piercing profilers that can provide for sampling from the subsurface float to the surface. The combination of a wire-following and surface-piercing profiler (or shallow profiler) on one subsurface mooring is called a hybrid profiler mooring. A mooring of this type provides the capability to sample the water column from near the seafloor to the sea surface. The surface-penetrating upper profiler does face the challenges, like the surface buoy, of the forces associated with the surface wave orbital velocities.

Both surface and subsurface moorings can be connected to seafloor cables, to instrumented seafloor platforms, or to garage-like docking stations (where AUVs can recharge and download data) using remotely operated vehicles (ROVs). For example, Fig. 4.1-4 depicts a hybrid profiler mooring to be deployed by RSN with a direct connection to the RSN seafloor cabled infrastructure at its base. The same design will be used at the deep-water, cabled Endurance Array site. A hybrid profiler design sharing many common elements, but adapted to an open-ocean installation without a seafloor cable, is used in the Global Arrays.

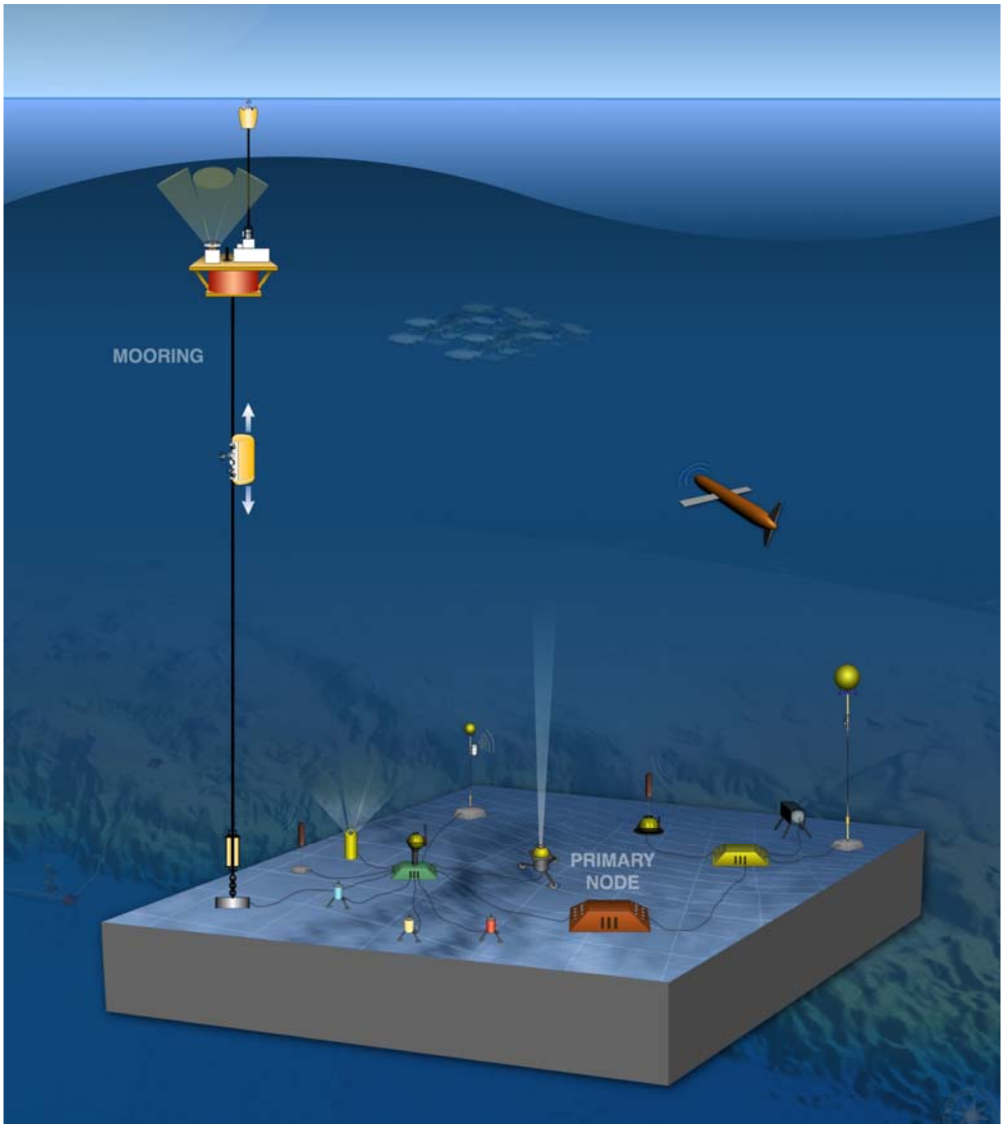

Figure 4.1-4. Subsurface hybrid profiler mooring to be deployed at two sites on RSN and at the offshore site of the Endurance Array, showing the use of an instrumented shallow profiler based at the subsurface floatation/instrument housing, instrumented wire-following profiler moving along the mooring line below, seafloor sensors, and connection to a seafloor cable.

Although not cabled to land, the moorings at the Pioneer Array show the common design approaches to sampling from the seafloor to the sea surface (Fig. 4.1-5). For the Pioneer Array surface moorings, the buoys, rather than a seafloor cable, provide both power and communications (Fig. 4.1-5, first two panels). While not all Pioneer Array moorings provide power, all include a surface expression for data telemetry and two-way command and control. The Coastal Profiler mooring consist of a conventional subsurface mooring design that is supplemented with a small surface telemetry buoy (Fig. 4.1-5, fourth panel). The Pioneer Array utilizes profilers, both surface-piercing and wire-following types, to sweep through the water column. The seafloor base stations of the Pioneer moorings include platforms known as Multi-Function Nodes (MFNs), linked by EOM cable to power generating surface buoys (Fig. 4.1-5, first two panels). Coastal surface-piercing profilers (Fig. 4.1-5, third panel) sample from seafloor to surface in locations where depth permits.

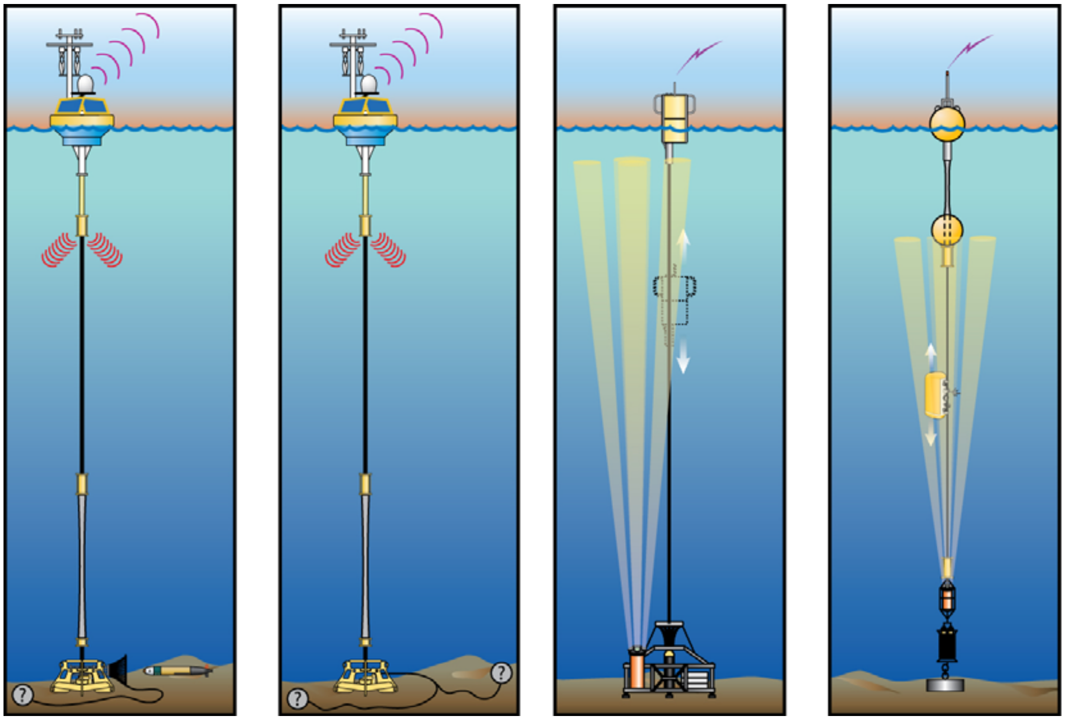

Figure 4.1-5. The Pioneer Array uses four types of moorings to provide the diverse capabilities of sampling the water column at the sea surface, sampling on and from the sea floor, and providing docking stations for AUVs. Sensor connection denoted by (?).

The Global Arrays rely on similar moored platforms (Figure 4.1-6). Each Global Array contains two taut subsurface moorings that form two of three corners of the triangular array. The discrete instruments on these moorings are battery powered and linked acoustically (via gliders being used as data and command shuttles), to the OOI network.

The Global surface mooring provides the capability, as at the Endurance and Pioneer Arrays, to observe the surface forcing of the ocean by the atmosphere and the exchange of heat, mass, and momentum between air and sea. The surface mooring also has power generation and telecommunications capabilities. The adjacent hybrid profiler mooring employs the approach used by RSN and at the Endurance Array of combing two types of profilers on one mooring to cover both the upper (sea surface to ~200 m) and lower parts of the water column.

The OOI engineering design approach has been to define common subsystems across the OOI and thus reduce development and construction costs. At the same time this simplifies maintenance and provides operational depth across the teams by allowing exchange of personnel that have familiarity with the moored systems as needed. The primary areas where significant levels of commonality have been identified are buoy and mooring design, power generation, sensors, and maintenance infrastructure (such as mooring deployment winches for use at sea and sharing of cruises between RSN and Endurance). In the design process, teams developing design approaches to technical areas (e.g., surface-piercing profilers) have had ongoing exchange through service on evaluation teams reviewing vendor responses to Requests for Information (RFIs) issued to gather information to assess the state of various technologies.

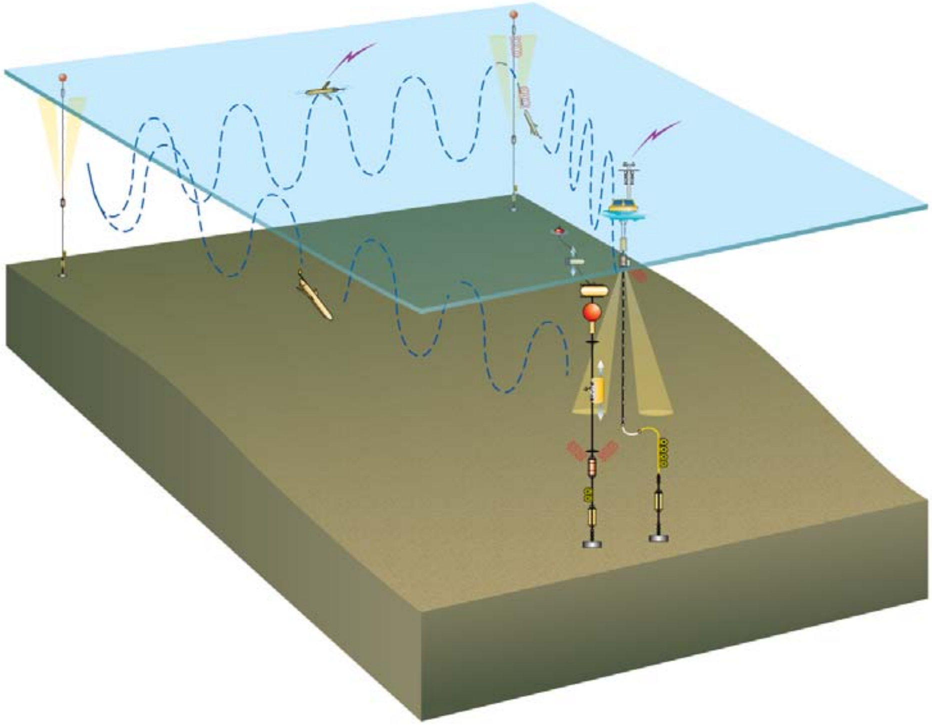

Figure 4.1-6. Schematic of a Global Array, such as the Southern Ocean Array at 55°S, 90°W. Moorings are used to define three corners of a triangular array to provide an aperture to observe the mesoscale oceanographic context. Two corners are occupied by taut subsurface moorings, and the third corner has paired surface and hybrid profiler moorings.

4.1.2.2 Mobile Platforms

Mobile platforms provide oceanographers the means to deploy sensors and move them through space, both horizontally and vertically. The OOI uses propeller-driven Autonomous Underwater Vehicles (AUVs) (Fig. 4.1-7) and buoyancy-driven gliders (Fig. 4.1-8) to meet the requirements for oceanographic sampling.

The propeller-driven, battery-powered AUVs are somewhat like an instrumented torpedo, though optimized for longer life at slower speeds while carrying a sensor payload. Optimum speeds for AUVs used in oceanographic applications are near 1.7 m s^{-1}, while maximum speeds of about 2.5 m s^{-1} may be reached. AUVs have a high payload capacity relative to gliders, and will carry a broad suite of sensors for interdisciplinary observations. They surface to obtain position fixes using GPS and while at the surface they also enter the OOI communications network using satellite telemetry. AUVs can run continuous missions of up to several days and are small enough to be deployed and recovered from a small boat; OOI will use this means of deployment and recovery. AUVs will operate at the Pioneer Array in conjunction with seafloor-mounted docking stations into which the AUV can swim to recharge its batteries and exchange data. The use of docking stations will extend the duration of AUV deployments, allowing for multiple missions between deployment and recovery. The OOI AUV Requirements specify 25 missions over a deployment period of 120 days before the AUVs will be recovered for service and support for up to 35 missions over 210 days before the docking stations will need service.

Figure 4.1-7. The Hydroid REMUS, an example of a propeller-driven Autonomous Underwater Vehicle (AUV).

The buoyancy-driven, battery powered gliders change their volume by pumping to or from an oil-filled bladder; when they dive or rise, the glider's wings achieve lift allowing the glider to fly forward through the water. They can achieve speeds of about one tenth of those of the AUVs or ~25 to 35 cm s^{-1}. Gliders shift internal mass to be able to change pitch and to roll and achieve the abilities to control their track; some also use a rudder to steer. At the surface, gliders acquire position information using GPS and transmit data and receive commands via satellite. The OOI gliders will be smaller and lighter than the OOI AUVs, and multiple gliders can be deployed and recovered from a small boat. Gliders are used throughout the CGSN Array infrastructure. While there is some diversity in the glider missions and capabilities across the OOI, efficiencies will be realized by coordination of and commonality in the glider sensor payloads, operations and maintenance, and interfaces with CI.

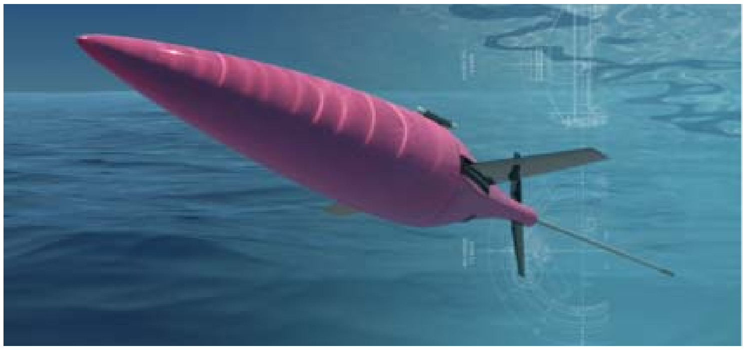

Figure 4.1-8. The University of Washington Seaglider, an example of a buoyancy-driven glider.

Use of mobile platforms enables the OOI to address science requirements for resolution of two-dimensional (vertical and horizontal) structure and variability. In particular, mobile platforms are the best way to obtain the required horizontal resolution and to provide adaptive sampling of evolving ocean features. AUVs are best suited for shorter duration sampling of rapidly changing conditions, and will be deployed at the Pioneer Array to resolve frontal processes. Two AUVs will operate from docking stations at the base of power-generating surface moorings, running synchronized, sampling missions of ~100 km along-shelf and across-shelf. The interval between missions will be 5-10 days, determined by the level of power generation by the surface buoys and the charging rate at the AUV docks. The AUV missions will be user-controllable via satellite link directly to the vehicle (while on the surface) or through the surface mooring telemetry system when docked. The third AUV will be operated via day-trips using a small 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.

Gliders are best suited for slowly evolving features with large spatial scales such as monitoring the “ocean weather,” or mesoscale. Gliders will be employed for two general purposes: providing horizontal context to horizontally-fixed platforms and communicating with subsurface instruments and relaying their data to shore. The glider subsystem will aid the transformational nature of OOI by enabling continuous monitoring of the oceanic mesoscale, allowing near real-time adaptive sampling, and making available near real-time time series data from remote locations (e.g. Global flanking moorings). Glider deployments are of three types, global, open ocean, and coastal. Global deployments require an acoustic modem and the capability to operate to 1000 m depth. Open ocean deployments require 1000 m depth capability, but not acoustic modems. Coastal deployments require relatively shallow depth capability (200 m) with the ability to maneuver and operate where the total water depth is as little as 30 m.

In order to resolve the required horizontal and vertical scales in the upper ocean, the FND calls for deployment of three gliders at each Global Array. Their primary mission will be to patrol the edges of the triangle created by three sites (the surface/subsurface mooring site and two flanking mooring sites). The Global Array gliders will also communicate acoustically with instruments on the flanking moorings. At the Pioneer Array, six gliders will simultaneously survey the outer shelf and the slope waters offshore of the moored array. Their primary mission will be to resolve mesoscale features impinging on the Pioneer moored array from the Gulf Stream. At the Endurance Array, six gliders will be deployed to provide mesoscale context and to bridge the distances between the fixed mooring sites. Their primary mission will be along four east-west lines, from approximately the 30-m isobath out to 126W. The Endurance gliders will also run north-south along approximately 126^{o} W. Gliders at all arrays will be capable of being re-directed from shore in order to provide adaptive sampling and event response.

4.1.2.3 Instruments and Sensors

The OOI core sensor suite comprises the instruments and sensors that will address the key science themes and is derived from the OOI Science Requirements. The preliminary lists of core sensors were compiled from across the RSN and CGSN infrastructure designs to determine where common instrumentation and sensor types could be used. These results are compiled into a combined OOI Sensor List with 49 sensor types, representing the 804 identified OOI core sensors. Before efforts were made to identify the common sensors across the OOI, there were 67 different sensor types. As with other OOI design documentation, the combined sensor list is under version control consistent with the CMP. The final sensor types are based on the measurement specifications (as stated in the OOI Science Requirements) and practical considerations. Installing fewer sensor types (i.e., different makes/models of the same sensor type) provides for efficiencies and economies in purchasing, interface and driver development, calibration and maintenance, and sparing. Of the 49 sensor types, 16 are common to both the CGSN and RSN, representing 425 of the 804 total sensors. For each sensor type, an exemplar (i.e., an existing make/model) has been identified for purposes of cost estimation, power and bandwidth needs, and other information required for infrastructure design. It is important to state that the exemplars are not indicative of OOI purchase decisions. Based on the choice of exemplars, a total of 31 vendors would be able to provide the 49 sensor types.

During the Pilot Period (the period from FDR to construction start), the OOI Project convened the first in a series of workshops for vendors and suppliers of ocean observing sensors and instrumentation in March 2009. The purpose of the workshop was to brief vendors and suppliers on the OOI requirements for sensors and instrumentation, including aspects such as measurement specifications, deployment, and interface requirements. The workshop format allowed participants (vendors, suppliers, and the scientific, engineering, and cyberinfrastructure communities) to engage in addressing issues of sensor/instrument readiness, biofouling prevention techniques, and interfaces. Future workshops will continue discussions of the idea of common sensors and common sensor interfaces across the OOI.

The common sensors and components will be procured from single vendors selected through a competitive process in order to achieve economies of scale. Ocean Leadership will coordinate a proposal evaluation process with the IOs and select best sources for each component. This common procurement approach, detailed in the OOI Acquisition Plan, will enable each IO to satisfy its own organizational and state procurement requirements, while at the same time providing for efficiency and economies of scale.

4.1.2.4 Cyberinfrastructure-enabled Applications and Capabilities

The science applications that are addressed by the ocean observatory span many themes, including climate change and biogeochemical cycling, ecosystem dynamics, turbulent mixing and biophysical interactions, and fluids & life in continental margin sediments. This broad, multidisciplinary range of science questions is addressed with a distributed network of deep ocean moorings, a plate-scale Regional Scale Nodes (RSN) element, a long-term coastal time series Endurance array, and a coastal adaptive sampling Pioneer array. This distributed network of observing hardware enables science that encompasses time and space scales beyond that of its individual components through advanced CI capabilities that provide any actor two-way interactivity, command & control, and data discovery through both real-time instruments and historical data archives. The user requirements driving the CI design are diverse, and flow from specific science needs that have been identified in a series of National Research Council and community science documents. Specific science goals that require CI capabilities include:

- *Data discovery and acquisition from real-time data streams and historical distributed data archives* – The ability to utilize real-time and historical data is central to enabling hindcast and data assimilation nowcast and forecast modeling efforts focused on science problems such as the temporal dynamics of ocean mixing or carbon sequestration from the sea surface to the seafloor. Key to these lines of research is the requirement for spatial time series to statistically characterize ocean processes over a range of spatial (millimeters to tens or hundreds of kilometers) and temporal (seconds to decades) scales to resolve everything from turbulence to seasonal and interannual dynamics. Archived and real-time data distributed among OOI components and national/international science agencies provide the necessary spatial data to enable these complex, multi-disciplinary studies.

- *Adaptive sampling* - One of the most powerful capabilities of the OOI is adaptive sampling of the ocean based on model forecasts and real-time data. This is a new approach for oceanographers that enables scientists to study episodic events (e.g., severe storms and shelf-slope exchange) and/or explore unexpected processes (seafloor vent phenomena) in detail. The CI network allows researchers to adaptively sample the environment using a variety of taskable mooring, glider, and AUV systems that need to be operated collectively, or providing a real-time ability to adjust the sampling by individual sensors on a mooring. The CI provides an easy to use, real-time framework for scientist actors to adjust their initial sampling strategies when unexpected events or processes are encountered.

- *Automated ocean surveillance for event detection and classification procedures* - Traditional attempts at adaptive sampling were driven by scientist actors initiating and guiding changes in the measurement protocols (i.e., a human-in-the-loop approach). Observation of episodic events and processes (e.g., events occurring at short timeframes or over larger spatial scales) are enhanced through the CI by the ability to initiate sampling in an automated, adaptive fashion based on real-time data. This is done by capturing environmental behaviors that drive network responses to events, and requires a robust command and control capability. The network behaviors are initialized by data or derived data products. For example, NASA has developed bioinformatics algorithms that combine available data streams to objectively classify water masses that can initiate increased chemical and biological sampling by OOI assets as new water masses pass into a study area. The automated activity may include single sensors or swarms of mobile assets.

The OOI is a globally-distributed multi-scale network of observing assets bound together by a cyberinfrastructure component that links the infrastructure elements, sensors, and models into a coherent system-of-systems. The two-way communication capabilities provided by the CI play a key role in transforming oceanography from a primarily ship-based expeditionary science to a distributed, observatory-based discipline in which scientists continuously interact with instruments, AUVs, actuators, facilities, and other scientists to remotely explore the earth-ocean-atmosphere system. The CI facilitates access to other (i.e., non-OOI) data streams, providing users with a coherent four-dimensional view of the ocean. Using the OOI CI, users can combine OOI water-column data with NOAA and NASA satellite ocean-surface imagery and NOAA Integrated Ocean Observing System (IOOS) subsurface data. These interactive and data aggregation capabilities complement parallel international efforts by Canada, Japan, and Europe, and will fundamentally change how ocean science is conducted.

The OOI CI provides a diversity of capabilities. Any actor – scientist, engineer, or educator – can access two-way interactivity with sensors, or data discovery through real-time data and historical data archives. An advanced CI capability facilitates data delivery, analysis, and synthesis from across the OOI on a localized semantic frame of reference. The CI mediates among different data protocols, data streams, and derived products to test scientific understanding. In accordance with the OOI program's data policy, calibrated and quality-controlled data are made publicly available with minimal delay. The delays comprise the time needed to fill a data packet (e.g., 1 s) and communicate ashore through the Internet (>250 ms for geosynchronous satellites). Generally, data latencies are on the order of seconds, although they can be larger for low-power buoys or AUVs that connect to the Internet only occasionally. These near-real-time data require sophisticated system security and policy protocols to control and prioritize access to sensors and data in accordance with agreed-upon principles.

A traditional data-centric CI, in which a central data management system ingests data and serves them to users on a query basis, is not sufficient to support the ocean science community’s OOI requirements. Therefore, throughout the observatory network, strategically placed computation and storage infrastructure is provided at Cyberinfrastructure Points of Presence (CyberPoPs). CyberPoPs include integrated, near real-time data processing and archive sites located at a few central facilities and at marine observatory shore stations or control centers. In situ computation and storage resources can be located within science instrument interface modules and selectively within the marine networks.

The CI enables virtual research observatories to be built anywhere using different combinations of physical assets. For example, investigators interested in specific problems can “subscribe” to real-time data from sensors that specifically address their research topics. This decentralized grid concept means that the CI is broadly distributed around the United States and the world, and thousands of custom views can be provided simultaneously. To complement the observational data streams, large computational models and simulations can be run on the national Grid infrastructure (e.g., the TeraGrid and the Open Science Grid). Finally, observatory participants can securely incorporate computation and storage capabilities within instrument platforms (e.g., AUVs and gliders) and research facilities. Thus, the CI blurs the conceptual boundaries of the Coastal-, Regional-, and Global Scale observing assets, instead considering the OOI network as a distributed, loosely coupled Grid of sensors, each with a unique Internet presence.

4.2 Cyberinfrastructure

4.2.1 Introduction

The OOI CyberInfrastructure (CI) constitutes the integrating element that links and binds the physical infrastructure into a coherent system-of-systems. Indeed, it is most appropriate to discuss “the OOI Integrated Observatory” as an integrated whole that allows scientists and citizens to view particular phenomena irrespective of the observing elements (e.g. coastal, global, regional, ships, satellites, IOOS) to which the observations belong.

This Final Network Design document is provided to give an overview of the OOI CI. Further details of execution management are found in the CI Project Execution Plan (DCN 2010-00001), the Transition to Operations document (DNC 2110-00002), and the Operations and Maintenance document (DCN 2010-00006). More information on the CI architecture can be found in the Integrated Observatory Applications Architecture Document, the Integrated Observatory Infrastructure Architecture Document, and in the seven Requirements Workshop reports.

Table 4.2-1. List of CI-specific Final Network Design Documents

Document Control Number	Document Description
2115-00001	Instrument Life Cycle Concept of Operations
2115-00002	Science User Concept of Operations
2115-00003	User Applications Design Workshop Report
2115-00004	Ocean Modeling Requirements Workshop-1 Report
2115-00005	Ocean Modeling Requirements Workshop-2 Report
2115-00006	Ocean Observing Programs Requirements Workshop Report
2115-00007	Data Product Generation Requirements Workshop Report
2115-00008	Integrated Observatory Management Requirements Workshop Report
2115-00009	Education and Public Engagement Requirements Workshop Report
2115-00010	User Persona Model
2130-00001	Integrated Observatory Applications Architecture Document
2130-00002	Integrated Observatory Infrastructure Architecture Document
2430-00001	COI Architecture Document
2170-00001	TV-1 Technology Catalog

The objective of the OOI CI is provision of a comprehensive federated system of observatories, laboratories, classrooms, and facilities that realize the OOI mission. The infrastructure provided to research scientists through the OOI will include the cables, buoys, deployment platforms, moorings and junction boxes required for power and two-way data communication with a wide variety of sensors at the sea surface, in the water column, and at or beneath the seafloor. Through the CI, it also includes components such as unified project management, data dissemination and archiving, and education and outreach activities essential to the long-term success of ocean observatory science.

The vision of the OOI CI is to provide the OOI user base, beginning with the science community, access to a system that enables simple and direct use of OOI resources to accomplish their scientific objectives. This vision includes direct access to instrument data, control, and operational activities described above, and the opportunity to seamlessly collaborate with other scientists, institutions, projects, and disciplines.

The core capabilities and the principal objectives of ocean observatories are collecting real-time data, analyzing data and enabling the modeling of the ocean on multiple scales and enabling adaptive experimentation within the ocean. A highly distributed set of capabilities are required that facilitate:

- End-to-end data preservation and access,
- End-to-end, human-to-machine and machine-to-machine control of how data are collected and analyzed,
- Direct, closed loop interaction of models with the data acquisition process,
- Virtual collaborations created on demand to drive data-model coupling and share ocean observatory resources (e.g., instruments, networks, computing, storage and workflows),
- End-to-end preservation of the ocean observatory process and its outcomes, and
- Automation of the planning and prosecution of observational programs.

In addition to these features, the CI must provide the background messaging, governance and service frameworks that facilitate interaction in a shared environment, similar to the role of the operating system on a computer.

The OOI system construction will occur during the confluence of several significant technology innovations in web and distributed processing: semantic webs, social networks, Grid computing, sensor networks, service-oriented architectures (SOA), event-driven architectures, policy-based security and machine virtualization. Each offers different capabilities, and each may increase the scope and reliability of the OOI system while lowering its complexity and cost. The challenge to building the CI at this time of convergence is finding an appropriate integration architecture and roadmap to deliver a functioning system as early as possible, while maintaining the ability to refine and extend operating characteristics as technology evolves.

The Integrated Observatory Applications Architecture Document (IOA-AD) specifies the final system architecture and design for the science- and education-driven applications of the OOI Integrated Observatory, developed and enabled by the OOI cyberinfrastructure. These applications include:

- Interfacing with environmental sensors, instrument platforms, and observatory infrastructure, enabling data and command flow,
- Acquisition of observational sensor data and external data into the OOI integrated observatory,
- Preservation, access, mediation, analysis, and visualization of science data and data products,
- Synthesis and preservation of derived data products such as QA/QC'ed qualified datasets and numerical ocean model output,
- Planning and control of complex, long-running ocean observations,
- Interactive control of observatory infrastructure,
- Operation and management of integrated observatory infrastructure.

The Integrated Observatory Infrastructure architecture document (IOI-AD) specifies the final system architecture and design for the infrastructure services of the OOI Integrated Observatory, as part of the OOI cyberinfrastructure. Infrastructure services include:

- Management of distributed information repositories, including science data and derived data products,
- Provision of a common operating infrastructure, comprising capabilities for communication, application integration, service registration with consistent cross-cutting identity management, governance and policy support,
- Management of observatory resources of various types,
- Provision of a location-independent execution environment for heterogeneous resources, including access to compute and storage cloud resources.

The structure and contents of these documents has been developed in accordance with the Department of Defense Architecture Framework (DoDAF) standard, which provides guidelines for developing architectures for large-scale systems and for presenting relevant views on the architecture data in a number of products. The target audience includes decision makers, subsystem implementers, and end users. This document contains final design specifications showing the full extent of the design at the higher levels of detail. Fine design and detailed specification blueprints for construction are available under configuration control in the CI specification repository [CI-SPECS].

The system's functional capabilities are structured into six services networks (SN), represented in this document as operational nodes that partake in operational activities, resulting in services that support the user applications listed above. The application supporting services networks are sensing & acquisition, data management (science), analysis & synthesis and planning & prosecution and are covered in this document. The infrastructure services networks are data management (information distribution), the common execution infrastructure and the common operating infrastructure. Data management provides both application and infrastructure services.

4.2.1.1 Fundamental Strategies

The CI integration strategy is based on two core principles: messaging and service-orientation. A high-performance message exchange provides the communication conduit with dynamic routing and interception capabilities for all interacting elements of the system of systems. The message interface is isolated from any implementation technologies, and provides scalability, reliability and fail-safety. Service-orientation is the key to managing and maintaining applications of a heterogeneous distributed system of systems. All functional capabilities and resources represent themselves as services to the observatory network, with precisely defined service access protocols based on message exchange. Services are defined independent of implementation technologies. Assembling and integrating proven technologies and tools, using the integration infrastructure, will provide the CI functional capabilities. Programming languages include (but are not limited to) Java, Python, and C/C++ for primary programming, specific purpose applications, and instrument drivers and embedded components.

The CI deployment strategy uses the concept of a capability container that provides all essential infrastructure capabilities and selected deployment-specific application support. Capability containers (discussed above in Section 4.1.2.4) can be deployed wherever CI-integrated computation is required across the observatory network and will adapt themselves to available resources and their environment. This includes platform controllers on remote, intermittently connected global moorings, compute units placed in the payload bay of AUVs and gliders and the full range of terrestrial CI deployments (CyberPoPs).

The CI multi-facility strategy supports the collaboration of multiple independent domains of authority bringing together their own resources, with no central governance and policy authority, based on agreements and contracts. This enables the sharing and use of observatory resources across the network, governed by consistent policy. CGSN, RSN and CI operate independent facilities that collaborate to form the OOI Integrated Observatory. This network can be joined by user facilities that choose to take part in the integrated observatory based on contractual agreements.

4.2.2 Architecture

4.2.2.1 Operational Overview

Figure 4.2-1 shows the links and relationships between the different operational domains that together form the OOI Integrated Observatory. The two physical infrastructures RSN and CGSN each represent one operational domain, both connected to the operational domain maintained by the CI IO, representing the Integrated Observatory to its users. Most end users interacting with the integrated observatory, such as scientist and education teams, define their own operational domains.

Each operational domain provides its own administrators, operators and policy makers. Resources can be shared with the integrated observatory from each operational domain. The core OOI instrumentation placed on the CGSN and RSN physical infrastructure are examples, as well as additional user (PI) provided sensors. Consistent governance guarantees that the policies of the observatory and the resource provider’s domain of authority are respected.

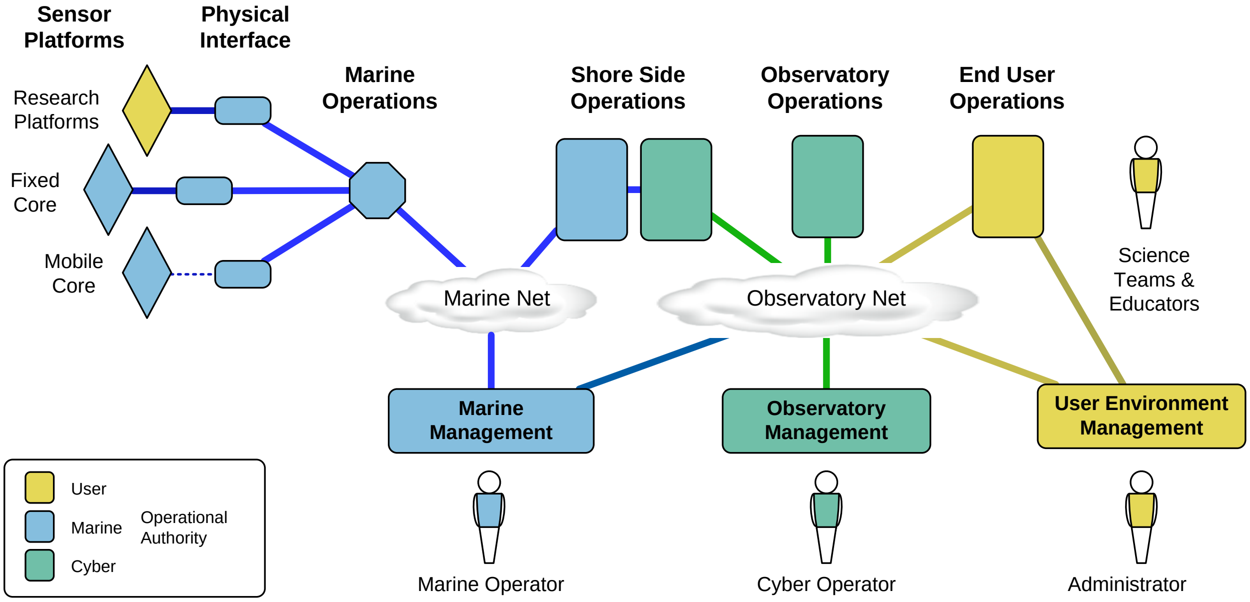

Figure 4.2-1. OOI Integrated Observatory Operational Domains (OV-4)

The lines and clouds in Figure 4.2-1 represent communication networks and the nodes represent physical sites with computation and storage resource, ranging from server clusters in data centers to embedded computing devices. The color indicates the operational authority for sensors, network infrastructure and computing resources. The blue-colored marine network components exist once for the RSN infrastructure and once for the CGSN infrastructure.

RSN and CGSN are the two observatory instances that are initially part of OOI. Besides these, provision will be needed in the future for existing or new sites to join the OOI network that are operated independently but with the ability to collaborate with the other OOI and non-OOI observatories.

Users of the OOI Integrated Observatory connect to the observatory network for accessing its resources. User collaboration applications such as OOI laboratories and classrooms allow groups of people to work together within a standard on-line framework. Many existing on-line environments now provide similar services; the OOI will apply the same concepts to a scientific and educational collaborative environment.

OOI core sensors, together with marine and cyberinfrastructure, form the core OOI Integrated Observatory. In addition, OOI users can bring their own resources into the OOI network, thereby extending the resources available to the public. The OOI provides a virtual observatory concept to all of its users. Users can select and operate their resources virtually, from any location in the network, subject to policy and existing agreements for resource utilization.

4.2.2.2 Deployment Overview

One purpose of the OOI Cyberinfrastructure (CI) is to provide all the infrastructure capabilities and services bundled as a “capability container,” such that selected applications and functional capabilities can be integrated and deployed as needed, where needed throughout the OOI. Infrastructure capabilities span multiple concerns, from communication in a distributed system to resource management, interaction coordination, and processing. The CI capability container provides a rich infrastructure environment for applications and services. It discharges most infrastructure service needs that are required for any OOI and CI application services. The CI capability container is based on the Rich Service Architecture blueprint. Not all instances of the capability container need to provide all infrastructure services, depending on the deployment needs. There are a number of deployment configurations for Cyberinfrastructure Points-of-Presence, which determine the set of capabilities required for each of these configurations. Because of their pervasive nature, the CI capability containers are ideally suited to addressing cross-cutting infrastructure concerns, including security, reliability, governance, and scalability. CI capability containers enable an easy deployment of the OOI collaboration and policy framework. They also establish the interfaces of the CI with both marine infrastructures provided by the CGSN IO and RSN IO and the EPE infrastructure.

Capability containers can be deployed wherever CI-integrated computation is required across the observatory network and will adapt themselves to available resources and their environment. This includes platform controllers on remote, intermittently connected global moorings, compute units placed in the payload bay of AUVs and gliders, and the full range of terrestrial CI deployments (CyberPoPs).

The primary compute and storage building block for the CI is the Cyberinfrastructure Point-of-Presence (CyberPoP). The CyberPoP implements the CI capability container described above. From the perspective of users, observatory operators, and the CI, CyberPoPs are virtual resources that can be provided in ways ranging from actual hardware installations to an elastic service analogous to Amazon®’s Elastic Compute Cloud®.

Figure 4.2-2 shows a schematic overview graphic of a CI capability container 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

CI 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. The primary goal is to support the activities and applications of:

- Scientific Investigation
- Educational Participation
- Community Collaboration

To that extent, there exist a variety of resources of different type and purpose that are represented in the OOI Integrated Observatory:

- Observation Plans, providing activity sequences, service agreements and resource allocations for specific observational campaigns or as templates for event-response behaviors
- Data Sets, representing observational and derived data and data products
- Processes, representing data collection and processing workflows comprised of multiple steps involving multiple actors and resources.
- Instruments, as the virtual representations of physical sensors and observatory infrastructure
- Models, for instance numerical models and their configuration,
- Knowledge, representing the entire wealth of meta-data, ancillary data, analysis results, reference and correspondence links between resources, and knowledge captured in ontologies for mediation purposes

The supported activities and managed resources are based on a collection of infrastructure services that support resource management, interaction, communication and process execution.

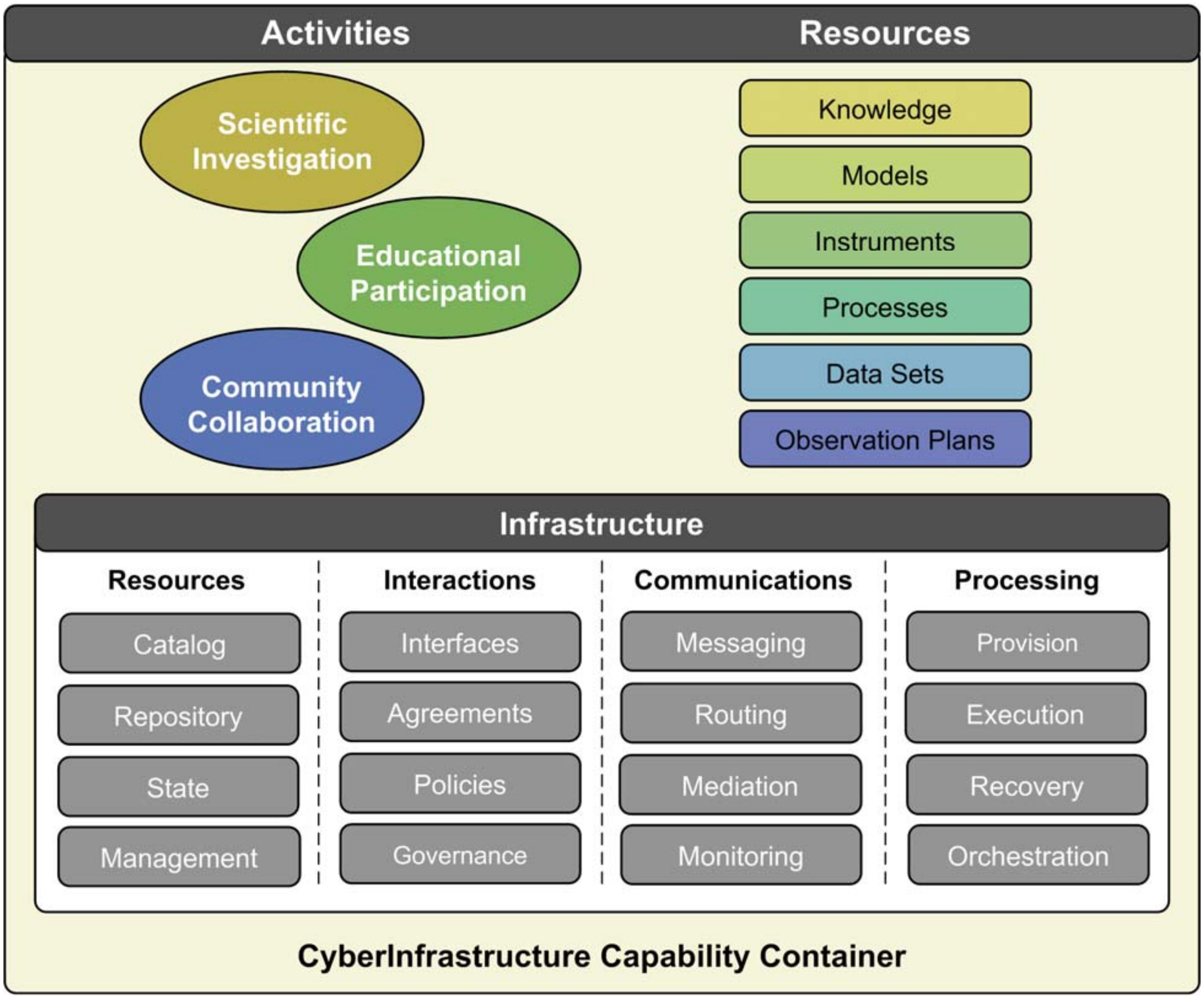

Figure 4.2-2. CI Capability Container activities, resources and infrastructure

Figure 4.2-3 shows an illustrative depiction of a capability container connected to its environment. Part of the environment are physical resources, such as instruments and further observational infrastructure, storage resources such as disks and network drives, and execution resources such as grid nodes, cloud computing instances, CPUs on mobile assets such as AUVs.

On the other hand, the capability container is connected to user interfaces, user tools and applications, user provided resources of various types and to similar capability containers in different facilities in their own domains of authority and operation. Nonetheless, the capability container provides all the infrastructure and application support required to compute within the OOI integrated observatory network. The footprint of a capability container can vary depending on the resource constraints of its hosting environment. The selection of functional capabilities present in a specific capability container depends on the respective needs and resource availability at this specific location in the network. For instance on a intermittently connected instrument platform, instrument access, data acquisition and data buffering capabilities are required, while at the primary compute nodes, data processing, numerical model integration and event response behaviors need to be present.

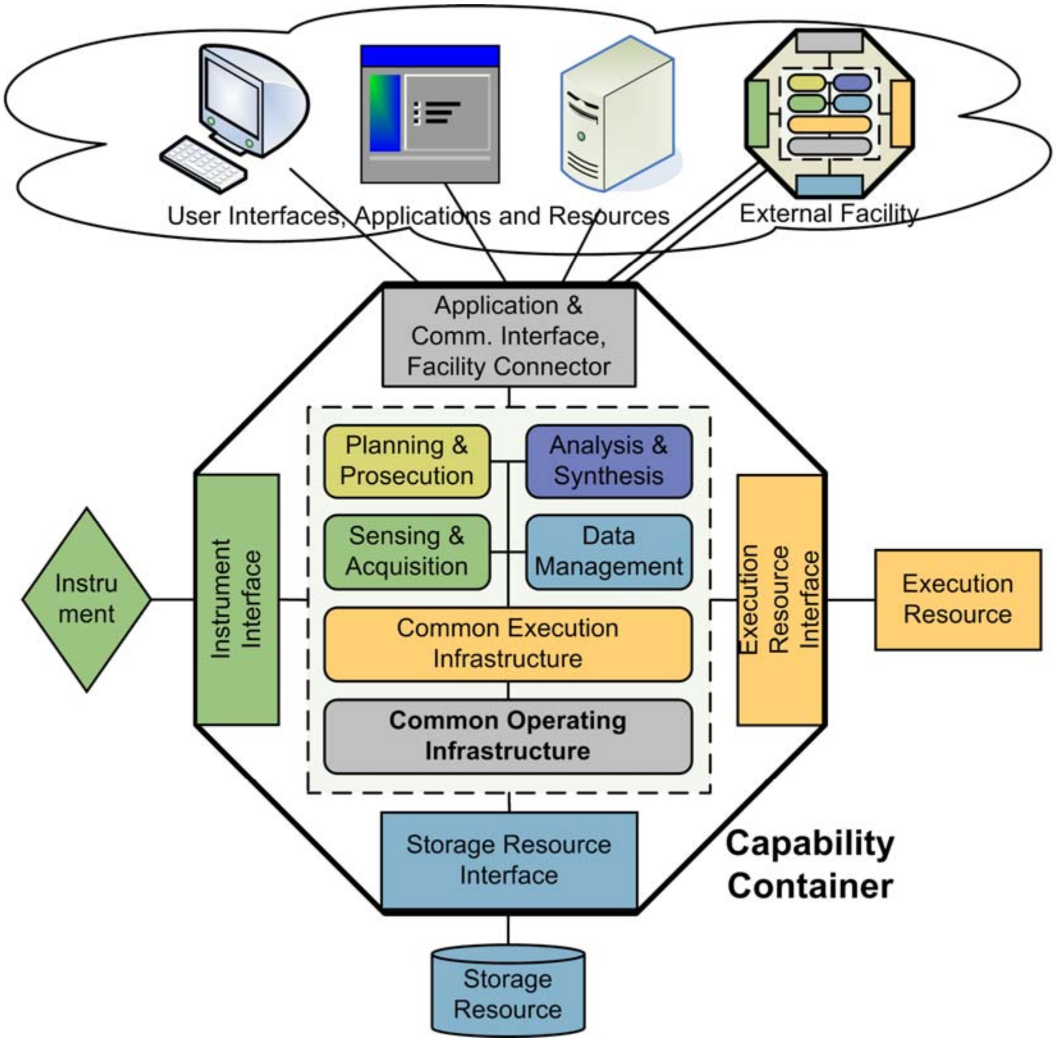

Figure 4.2-3. CI Capability Container with External Interfaces

Figure 4.2-4 provides an illustrative depiction of a partial deployment scenario based on the CI Capability Container (Figure 4.2-3). The primary elements visible are the CI facilities operated within each of the domains of authority. This includes RSN and CSGN marine operations with wet-side and shore-side components respectively, the integrated observatory facility operated by the CI IO, and further facilities that are connected on behalf of user organizations joining the integrated observatory network based on contractual agreements.

The rectangular shapes show physical deployment nodes within the integrated observatory running in partial or full CI software. The octagon shape within each of the deployment nodes indicates that there is an instance of the CI capability container deployed with selected infrastructure and application support capabilities, depending on resource availability. Full feature CyberPoPs are deployed on the shore side of each of the marine observatories and within the CI facility. In addition, the CGSN wet-side shows a deployment of a capability container hosting an instrument adapter specific to the instrument platform and their sensors. Within the user facilities are instances of capability containers hosting execution engines for Kepler workflows and for executing the ROMS/HOPS numerical models, respectively.

All of the above capability containers are connected across the network and in their entirety present themselves as the OOI Integrated Observatory. All resources are still operated within their respective domains of authority, and policy specific to these facilities applies independent of the behalf on which the resource is used.

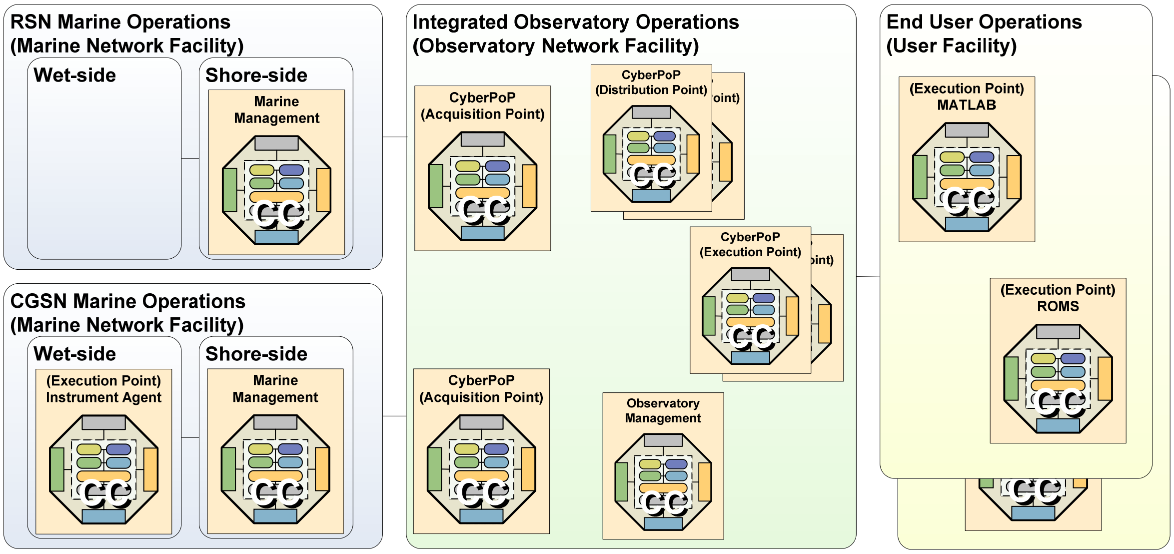

Figure 4.2-4. Partial View of OOI Deployment Strategy

Figure 4.2-5 illustrates the deployment of tailored CI capability container services for the data collection activity scenario throughout the observatory network. It makes use of the various CyberPoP configurations. This specific scenario reflects a CGSN Array with a low bandwidth, intermittent connection between the physical instrument interface of the CI with its acquisition capabilities and the remainder of the CI network. Because of the resource-constrained nature of this scenario, the Instrument Point Capability Container provides only general CI infrastructure and instrument proxy services. The Acquisition Point Capability Container illustrates the use of infrastructure services to implement the processes in the data collection activity scenario. Both Instrument Point and Acquisition Point are deployed as Marine Execution Point CyberPoPs, MEP.

On the shore side, the Ingest Point, deployed in an Observatory Acquisition Point CyberPoP OAP, is responsible for accepting data from a low bandwidth satellite based network and for providing data repository ingestion, cataloging, metadata association services.

The process execution infrastructure service provides the filtering and triggering processes in this capability container. An additional function supported by the capability container is the presentation capability implemented in the Access Portal capability container.

The infrastructure elements that support the Data Collection Activity of a Coastal-Global array are one deployment scenario. This spans the entire range of deployed systems and networks from ocean-based instruments to CyberPoPs and user applications.

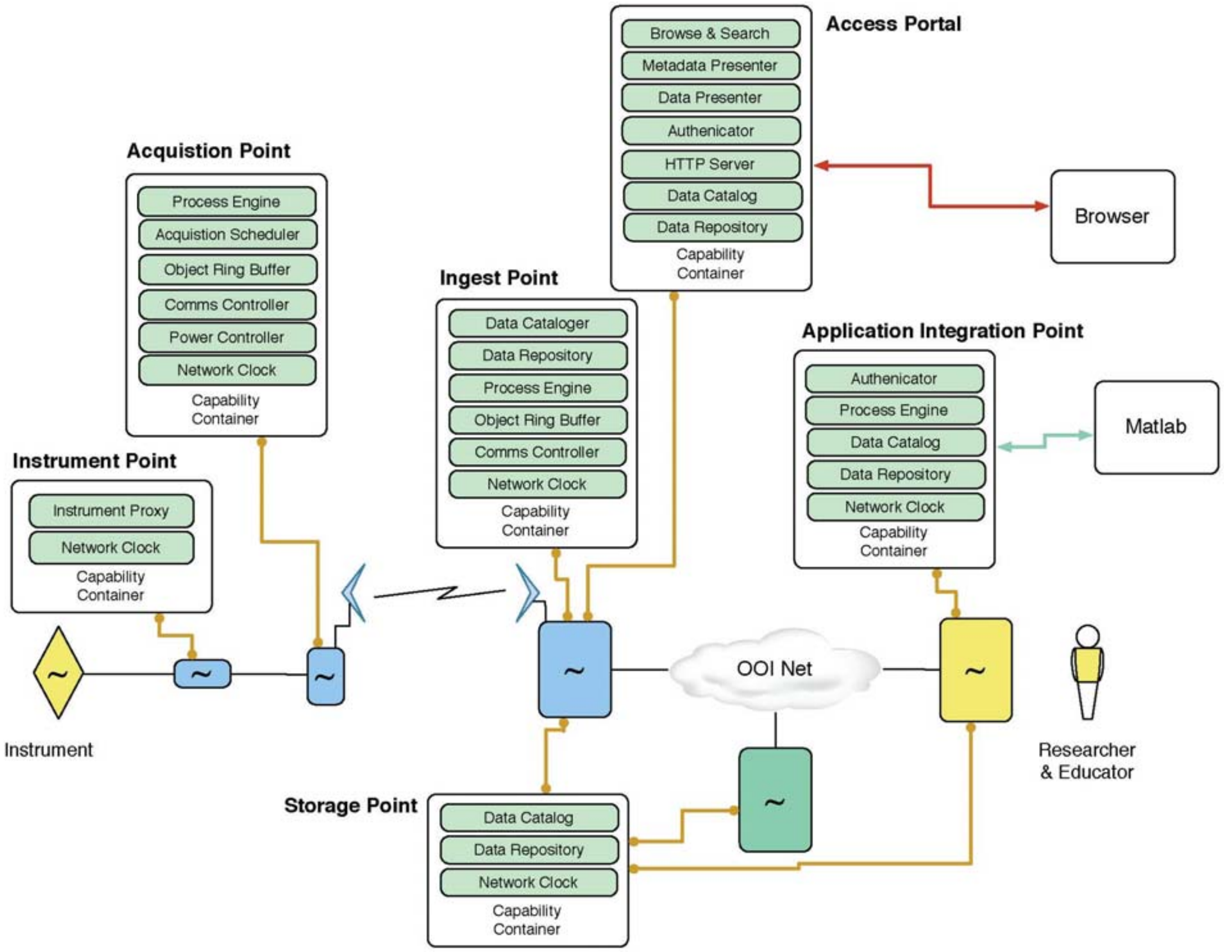

Figure 4.2-5. Capability Container Deployment Model (Coastal-Global Mooring Scenario)

The primary physical hardware and software building block and configuration item for the CI is the CyberInfrastructure Point of Presence (CyberPoP). It provides computation, storage and network resources at a designated installation site as part of the OOI network. A CyberPoP contains a CI Capability Container described in above. There are several classes of CyberPoPs:

- Observatory Acquisition Point (OAP)
- Observatory Distribution Point (ODP)
- Observatory Execution Point (OEP)
- Operations Management Point (OMP)
- Marine Execution Point (MEP)
- National Internet Infrastructure (NII)

The Observatory Acquisition Point (OAP) is a hardware environment to be deployed within a protected data center facility, comprising a CI capability container configuration that provides the primary point of access for Marine observatories to the CI and all the necessary computational, storage and network resources in a redundant layout. It provides a highly reliable, scalable and secure environment for data acquisition, initial data processing such as segmentation and QA/QC and data preservation.

The Observatory Distribution Point (ODP) is a hardware environment comprising a CI capability container configuration for OOI data distribution across the distribution network and for peering with external network providers, cloud execution and storage environments such as the Amazon Elastic Cloud and the Teragrid.

The Observatory Execution Point (OEP) is CI capability container configuration to be deployed either on OOI operated hardware or in cloud execution environments. OEPs can be provisioned on demand when required for the execution of user processes, such as numerical models and data visualizations. The CI provides Common Execution Infrastructure services for the elastic provisioning of such CyberPoPs in cloud environments, such as the Amazon EC2 and Scientific Clouds based on the TeraGrid.

The Operations Management Point (OMP) is an environment comprising hardware and a CI capability container configuration deployed at various physical locations close to marine observatory and CI control centers, providing observatory network and resource operations and state of health monitoring capabilities.

The Marine Execution Point (MEP) is a hardware environment and a CI capability container configuration to be deployed in science payload hardware environments of marine observatory infrastructure, such as aboard global buoys and AUVs. MEPs interface with proprietary instrument and platform controller software and represent their resources and capabilities to the OOI network. MEPs do not modify or replace existing software and hardware installations but instead provide a layer on top of them with direct connectivity to the OOI integrated observatory network. The hardware configuration in a MEP deployment is limited in terms of available computational, storage, power and bandwidth resources. The MEP is designed to be independent of the computational and storage hardware environments embedded in off-the-shelf marine infrastructure and instrumentation components. However, the software environment around the CI capability container supports the direct deployment on available hardware, providing sufficient power, computational and storage resources are provided.

The National Internet Infrastructure (NII) provides the communication network environment for the OOI integrated observatory. For its high bandwidth (data) distribution network, it is based on the CI IO operated exclusive Layer-2 10 Gigabit Ethernet network loop around the US using National Lambda-Rail infrastructure. Furthermore, it makes use of routed Internet-2 IP network infrastructure to provide access to the public Internet and as redundant lower bandwidth management network for the distributed OOI installation sites. The different CyberPoP configurations are clients to these networks.

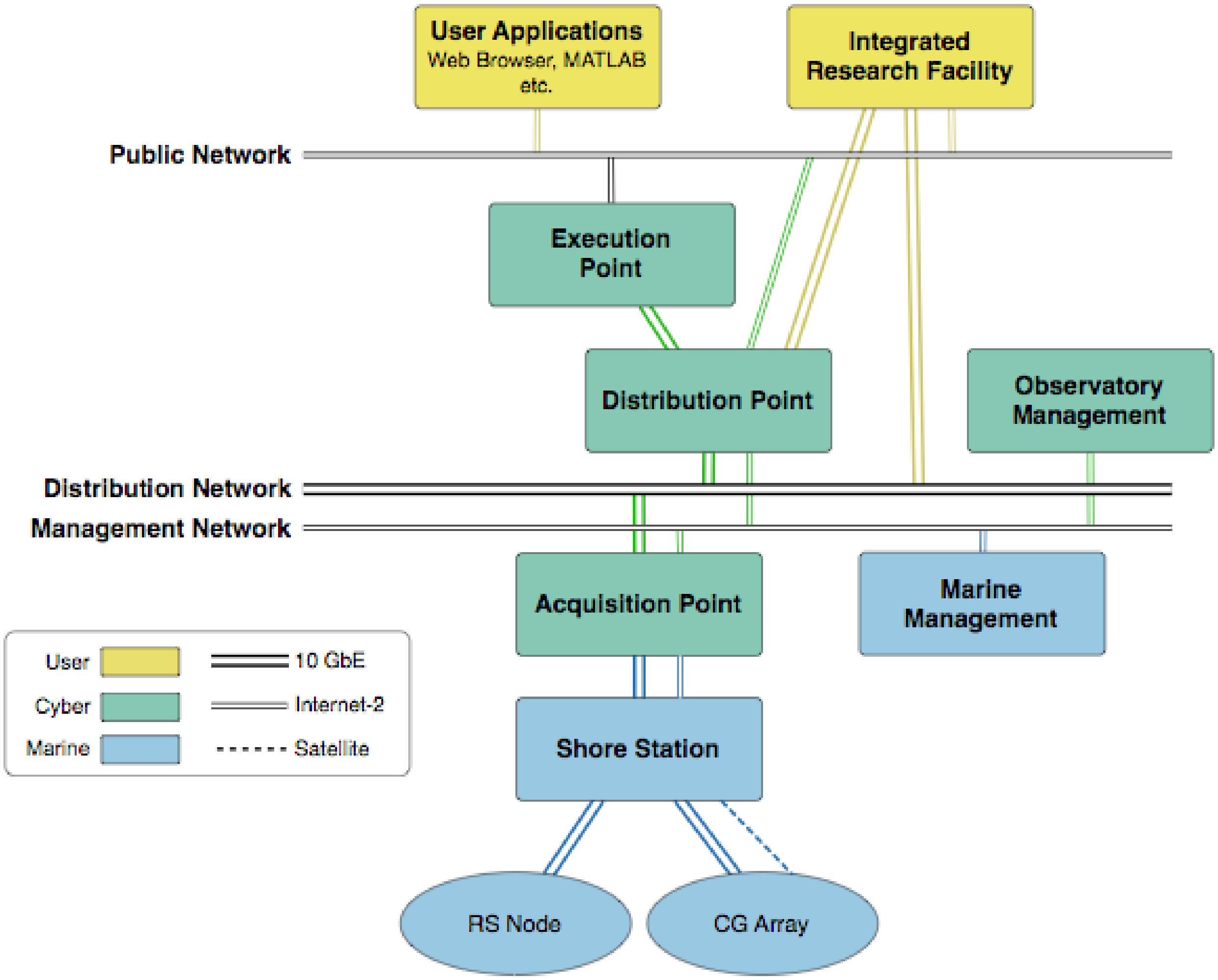

Figure 4.2-6. OOI Network Architecture

Figure 4.2-6 specifies the OOI network architecture, enabled by CI hardware and software infrastructure. The main elements of the network architecture are explained below; the CI operated elements are directly related to the CyberPoP configuration items as introduced above.

The Marine observatory networks operated by CGSN and RSN consist of the physical infrastructure, deployed instrumentation such as sensors and mobile assets, and of shore stations with infrastructure management systems. Marine observatory assets can contain a CI software deployment, the Marine Execution Point (MEP) CyberPoP, which will interface directly with asset resources and provide CI services and CI connectivity directly at the local execution point.

The primary interface to the CI is realized in the Acquisition Point. The Acquisition Point is the Observatory Acquisition Point CyberPoP (OAP), based on a CI Capability Container implementation deployed in a physical location, such as a rented data center facility, with a local deployment following the secure, reliable deployment patterns as specified in the Infrastructure Architecture. The acquisition point provides all the capabilities provided by the Sensing & Acquisition and Data Management subsystems based on the COI and CEI infrastructure services. If needed, further services can be deployed. Thereby, observational data from the Marine observatories will be accepted and stored reliable and made available to the remaining network and the public as needed. The Acquisition Point also interfaces with infrastructure management systems of the Marine observatories and enables management and control of the Marine infrastructure and in particular the deployed instrumentation.

The Distribution Network (part of the National Internet Infrastructure NII configuration item) is a 10 Gigabit Ethernet switched Layer 2 network forming a loop throughout the US. It is based on exclusively rented bandwidth agreements using the National Lambda-Rail infrastructure. The CI IO will operate it. The distribution network is accessed by the various Acquisition points and further CyberPoP installations of the OOI network, such as Distribution Points and user operated Integrated Research Facilities.

The Management Network (part of the National Internet Infrastructure NII configuration item) is a Layer 3 IP network based on Internet-2 infrastructure with much lower bandwidth guarantees redundantly available connecting the different CyberPoPs and in particular providing management and operations access to the various network sites. The CI also enables direct access to observatory infrastructure and instrumentation through management network, for instance required by instrument providers for low level access and failure recovery.

The Marine Management and Observatory Management (realizing the Marine Operations Point MOP) nodes are based on a CI Capability Container implementation and provide network and resource monitoring, management and control capabilities. They also provide means and interfaces for operations control room consoles.

The Distribution Point refers to the Observatory Distribution Point (ODP) CyberPoP that acts primarily as a peering point into the various execution sites that provide data access, manipulation, analysis and visualization. It is also based on a CI Capability Container.

The Execution Point is a deployment of a CI Capability Container, listed as the Observatory Execution Point (OEP) CyberPoP, providing user-targeted data access, manipulation and visualization capabilities. Execution points are instantiated at various execution sites that the CI supports and has contractual agreements with. The CEI provides services to provision and manage such execution points realizing elastic computing services. User integrated numerical models, graphical visualizations of observational data and other processes can be scheduled and executed. Web portals providing access to the OOI will be deployed on execution points on CI operated hardware, while user requested executions will be deployed in Cloud execution environments.

The Internet-2 IP network provides access to execution points from anywhere in the Internet, for web browsers, user software tools such as Matlab and other applications.

If users choose to join the OOI network, they can operate an own Integrated Research Facility with a software installation based on the CI Capability Container. This facility will have the capabilities to directly integrated with the OOI network and provides access to all OOI resources and services subject to policy. Users can directly tap into the OOI distribution network with 10 GigE high bandwidth communication link, by providing (renting) a communication line to an OOI peering point.

Fig 4.2-7 shows the full physical layout of the OOI network indicating the configuration of deployed CyberPoP installation, network connectivity and physical sites.

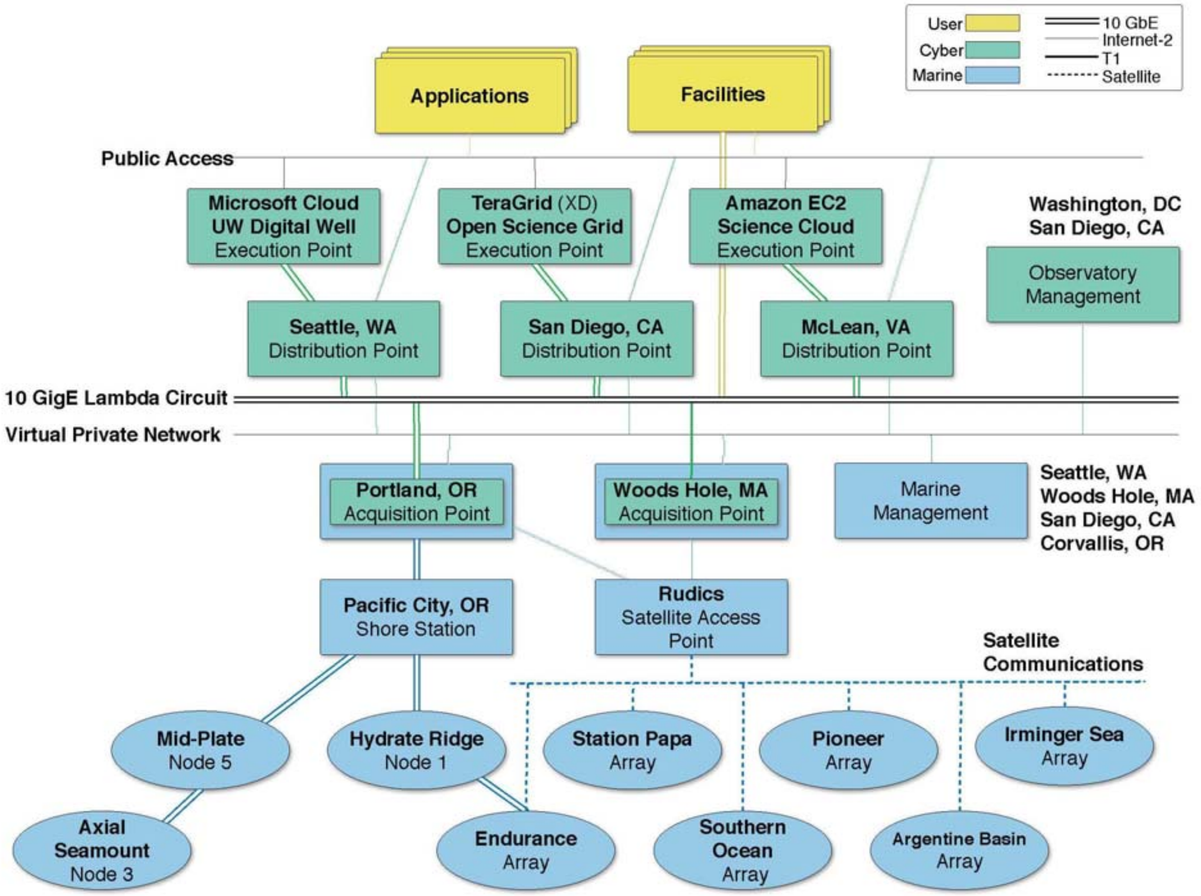

Figure 4.2-7. OOI Network Deployment

4.2.2.3 Logical Overview

Figure 4.2-8 shows all the services networks that provide and support the functional and infrastructure capabilities of the OOI integrated observatory. The infrastructure services networks provide the foundation for the application services networks that provide end user application support.

The actual distinction between infrastructure and application is based on the supported end user applications and the enabling fundamental infrastructure. For the CI architecture and design, the infrastructure covers the operating infrastructure as well as resource management, process execution and information distribution, while data transformation and access (science data management) are clearly in support of end user applications such as instrument data acquisition or scientific data analysis. The Data Management services network is split into two complementing parts for this reason.

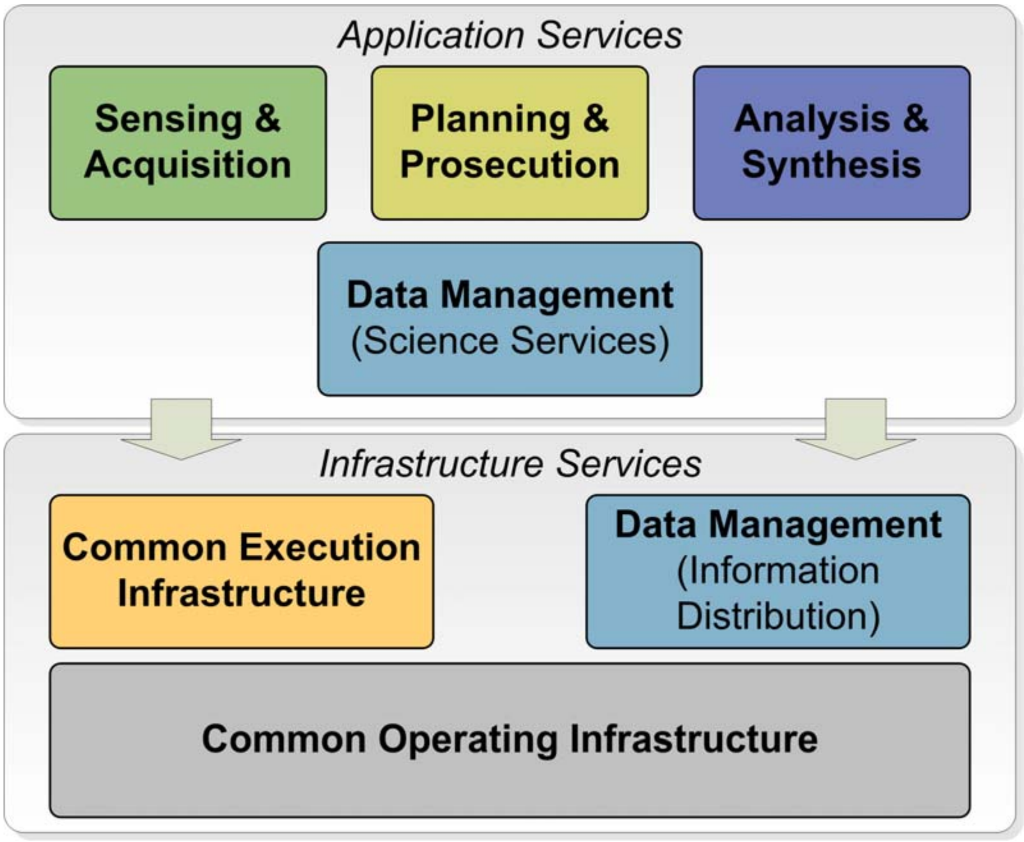

Figure 4.2-8. Services Networks

4.2.2.3.1 Common Operating Infrastructure (COI)

The COI provides the integration substrate for all functional capabilities, user and application interfaces and all types of resources forming the OOI integrated observatory to realize an integrated system of systems. It implements the integration strategy based on message exchange and service orchestration. The COI provides consistent identity management, governance and policy enforcement. The COI also provides uniform life-cycle management and access for the various kinds of resources governed by the integrated observatory. Resources include instruments, information products of any kind, source code and executables, workflows and representations of all connected physical resources from sensors to instrument platforms, management infrastructure, execution sites, storage and networking. The provided services enable to manage the resources, their supported activities and their representation of state in a uniform way. Technologies applied include Mule for the Enterprise Service Bus, RabbitMQ for the message broker infrastructure, and Shibboleth and Gridshib (making use of SAML and XACML exchange formats) from the Internet2 project for identity management and policy enforcement, respectively.

Figure 4.2-9 depicts the *COI* architecture and services. The Exchange messaging layer decouples the services of the COI and manages their interplay. The COI-provided infrastructure services include *Identity Management, Governance Framework, Resource Management, Service Registry/Framework, State Management*, and *Presentation Framework*. *Governance* defines the policy management framework that is implemented throughout the cyberinfrastructure. The *Service Registry* stores resources and associates them with their descriptions and relations with other resources. A *Policy Validator* is responsible for processing new policies upon submission by human operators prior to storing and enforcement.

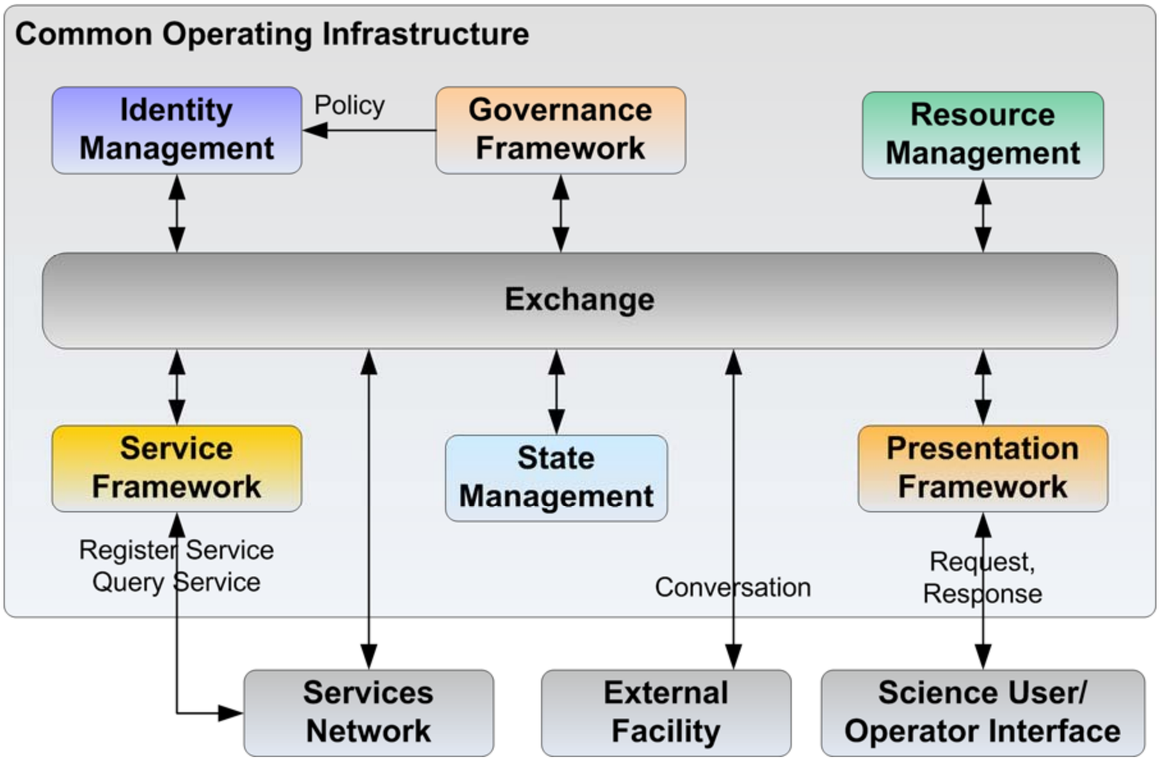

Figure 4.2-9. Common Operating Infrastructure

4.2.2.3.2 Common Execution Infrastructure (CEI)

The CEI services provide the means to schedule and execute any kind of computation in the observatory network at any location independent of the characteristics of the executing environments. The CEI provides the abstractions and adapters for specific environments and manages their provisioning and remote operation. Computational resources include user-defined processes such as workflows and user provided numerical models, but also fully capable, deployable images with CI capabilities that can be provisioned on demand in elastic computing environments such as the Teragrid and its logical successor, the Open Sciences Grid (OSG) and commercial facilities such as Amazon's Elastic Cloud. The technologies applied include XEN virtual machine images, Nimbus Virtual Workspaces for contextualization in cloud environments and CohesiveFT's elastic server for package management and the generation of deployable images.

Figure 4.2-10 shows a decomposition view of the Common Execution Infrastructure. The core element is the *Computation Scheduler*, which receives Service Agreement Proposals from other services in the OOI that require processing via the *Exchange*. These Service Agreement Proposals contain the processing request as well as the exact conditions under which the plan should be executed. The Computation Scheduler enters a negotiation and agreement process. Upon agreement, the Computation Scheduler determines a Processing Plan and initiates the processing by triggering the *Computation Controller*. This controller is the entity responsible for enacting the processing plan within the boundaries of the plan and the service agreement. It provides status about scheduled and ongoing computations to the Exchange for routing to the service requestor. A *Fault Monitor* is an independent entity monitoring any ongoing process and providing Fault Analysis information to the service requestor via the *Exchange*.

There are two distinct entities that the Process Execution Services Network controls. *Operational Units* are independent, self-executing units of processing that can be instantiated on demand by the *Provisioner* and retired when not needed anymore. *Execution Engines* are a special kind of operational unit that waits for processes it can handle to be executed. The Computation Scheduler determines how processes get executed on these execution engines.

In order to instantiate operational units, the Provisioner receives a Processing Plan, and retrieves the corresponding Deployable Type from the Deployable Type Repository. A Deployable Type is a machine and environment independent representation. The *Execution Environment Adapter* has knowledge about the characteristics of the intended target execution environment and automatically performs this adaption, resulting in a Deployable Unit. The Provisioner can then instantiate this unit into an operational unit.

In order to execute processes, the Computation Scheduler receives process definitions from the *Process Definition Repository* and delegates execution by negotiating with a suitable Execution Engine.

All repositories are based on the underlying services of the DM *Information Distribution* SN.

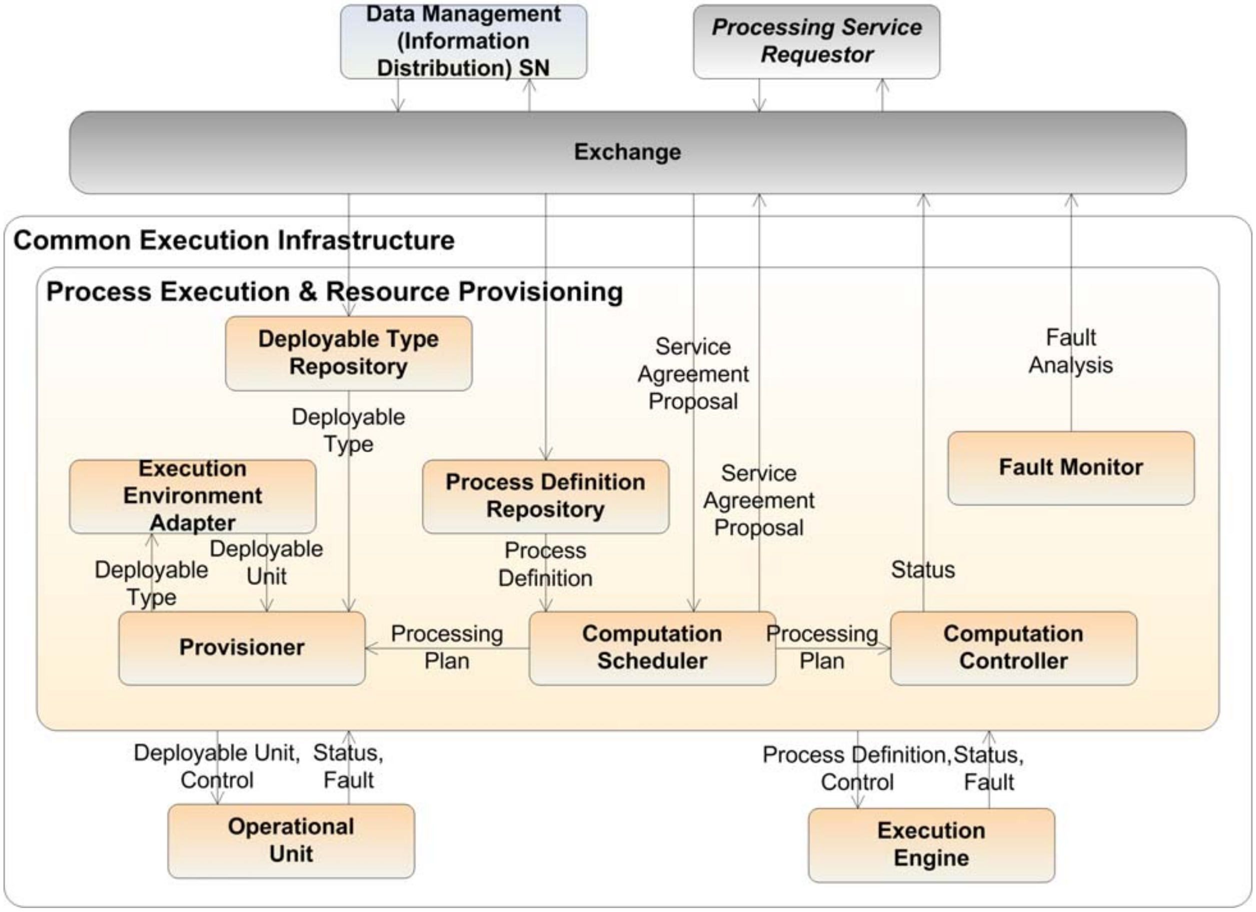

Figure 4.2-10. Common Execution Environments

4.2.2.3.3 Data Management SN

The information distribution services of the Data Management SN provide information distribution, persistence and access across space and time, making data accessible across the observatory network over extended periods of time. Information includes observational data and derived data products along with other information resources required for the operation of the integrated observatory, such as ancillary instrument information, user identities, workflow definitions, and executable virtual machine images. All information products are managed together with their metadata. Data collection and processing activities are based on the distributed exchange framework, supporting flexible access to data at all steps of the activities. The technologies applied include iRODS (Integrated Rule-Oriented Data System from San Diego Supercomputer Center) for data preservation and replication, OpenDAP to efficiently transfer science data products across the network, NetCDF as data export format, and THREDDS as a data externalization catalog.

The Data Management (Science) SN supports observational data ingestion into data repositories (managed by the infrastructure) alongside their metadata. It supports syntactical data and information format transformations as well as ontology-supported semantic mediation, providing access to various information products based on metadata and other search criteria. Standard models applied include the VSTO (Virtual Solar-Terrestrial Observatory) Ontology model together with ESG (Earth System Grid) Faceted Search for data access based on vocabularies from the Marine Metadata Interoperability (MMI) project. The Data Management (Science) SN is complemented by the Data Management (Information Distribution) SN specified in the IOI-AD, which provides preservation and data distribution services. Together, they are implemented by the Data Management subsystem.

Figure 4.2-11 shows the decomposition of the Data Management SN into logical entities: ingestion, transformation, and presentation. The exchange service is depicted as the integration conduit in relationship with the other infrastructure related services, namely preservation and inventory.

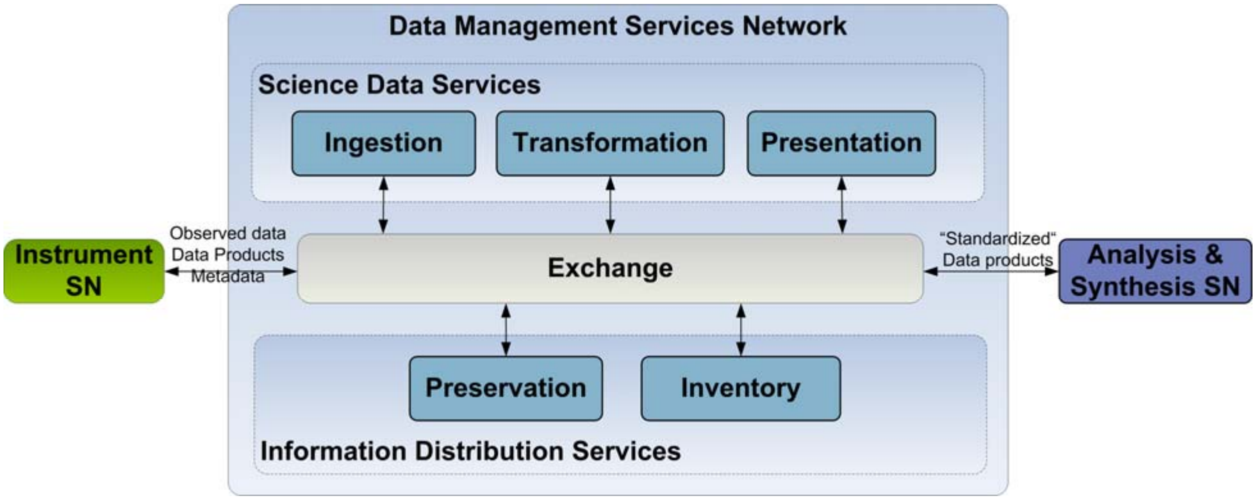

Figure 4.2-11. Data Management SN

From the point of view of science applications, the critical services are ingestion and transformation. The *Ingestion* service acts as a bridge to the Instrument Services Network and other subsystems providing data products (e.g., Analysis & Synthesis Services Network). Its main responsibilities are initial data parsing, initial metadata extraction, registration, and versioning of received data products.

The *Transformation* service handles the data content format conversion/transformation, mediation between syntax and semantics of data (based on ontologies), basic data calibration and QA/QC, additional metadata extraction, qualification, verification and validation.

The *Presentation* service enables data discovery, access, reporting, and branding of data products. For data discovery, it provides the mechanisms to both browse/navigate specific data products and search/query of them based on specific metadata or data content. To access the data, a client may specify various subsetting or aggregation constraints to tailor the received data products to its specific needs. Any transformation between the internal representation of the data and that requested by the client is handled by the *Transformation* service.

The exchange, preservation, and inventory services are infrastructure-related services. A brief description is provided below, with details following up in the accompanying OOI-CI Integrated Observatory Infrastructure Architecture Document.

The *Exchange* service is a projection of the COI capabilities, with the main purpose of establishing a publish-subscribe model of communication that ensures distributed data delivery to all end-points. Hence, its primarily responsibilities are enabling subscription-based data access, data transportation with adequate routing, notification services based on subscription, and real-time (as defined by OOI data policies) data streaming.

4.2.2.3.4 Sensing & Acquisition SN

The Sensing & Acquisition SN provides instrument and instrument platform access, as well as observatory management. In this capacity, it interfaces with individual sensors, sensor platforms, platform controllers, and observatory infrastructure such as power and communication bandwidth controllers, as well as with observatory infrastructure management systems. It is the primary interface to the CGSN and RSN systems and to PI-provided instruments deployed across the OOI infrastructure. In addition, the Sensing & Acquisition SN supports interfacing with external streaming data sources, such as from IOOS (Integrated Ocean Observing System) and NEPTUNE Canada. For all of the available resources, the Sensing & Acquisition SN provides abstract internal agent representations that interact through specific adapters with vendor-provided software and hardware. Activities supported by the Sensing & Acquisition SN include sensor data acquisition, instrument interactivity and control, and observatory operations management. Technologies applied include an Infrastructure-as-a-Service (IaaS) implementation based on an OSGi container to represent controllable resources within the OOI network and the Antelope Object Ring Buffer (ORB) to draw upon the existing pool of environmental observatory instrument drivers. Existing instrument adapters that are incorporated include MBARI’s SIAM (Software Infrastructure and Application for MOOS) data models and the MBARI PUCK instrument interface. Observatory resource management will be provided by integrating the Intermapper tool that provides network maps to monitor the status of devices and the network flow.

Figure 4.2-12 illustrates a high-level view of the Instrument Services in relation to the other services networks. The *Instrument* device model consists of one or more physical sensors or actuators, and is represented in the cyberinfrastructure by a logical device, the *Instrument Agent*. The physical device provides sensor data and status information to the *Instrument Agent*, and receives configuration information and commands from the *Instrument Agent*. The Instrument Agent communicates with the physical device via a *Device Port*, which is controlled by the cyberinfrastructure via a *Port Agent*. The *Port Agent* supervises the port communications and power. The physical devices, as well as the device ports themselves, are powered on or off in a graceful manner, according to the requirements for power management. Each *Instrument Agent* has an *Instrument Supervisor* that is responsible for monitoring the state of health of the Instrument. Each platform has a *Platform Agent* that is responsible for controlling all devices on that platform (Instruments and Ports altogether). The *Observatory Management* is responsible for coordinating all observatory resources to ensure their safe operation.

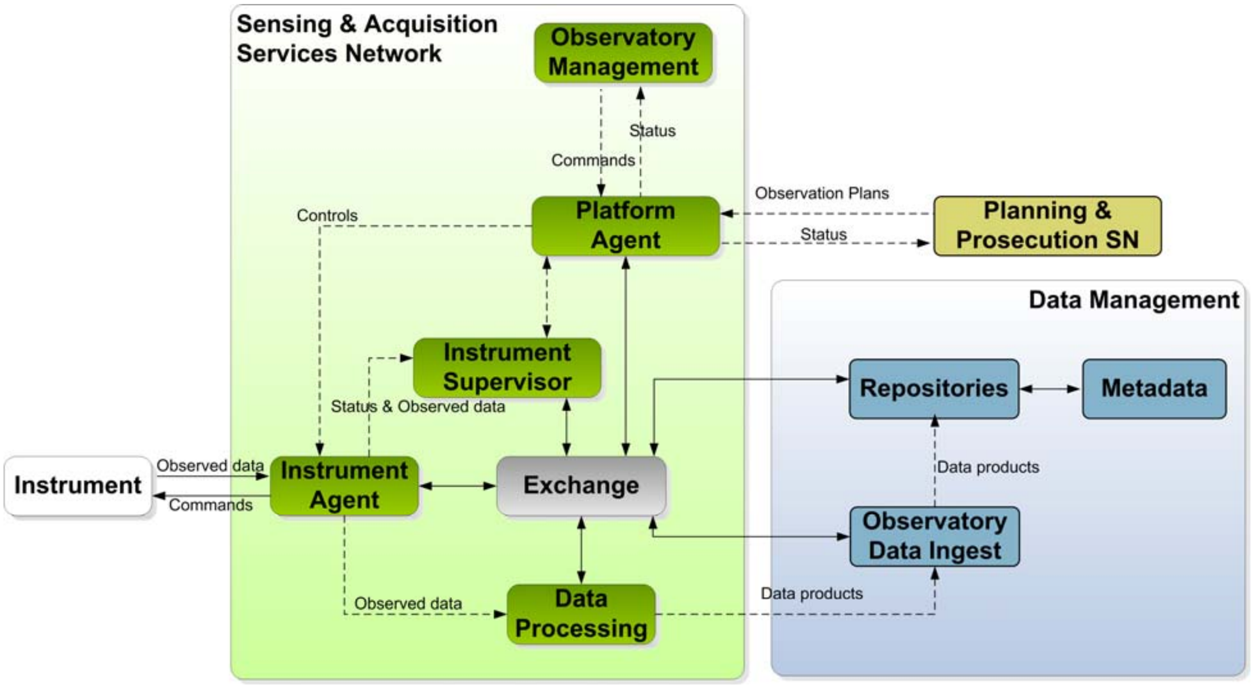

Figure 4.2-12. Sensing & Acquisition SN

4.2.2.3.5 Analysis & Synthesis SN

The Analysis & Synthesis SN supports a wide variety of data and data product analysis, manipulation, generation and presentation, especially through visualization. It also provides the virtual collaboration platform that will be applied to realize virtual observatories, classrooms and laboratories. Most of these activities require interfaces to tools and applications provided by the science and education users. Important activities supported by the Analysis & Synthesis SN include event and event pattern detection, data assimilation, and model integration and execution. In addition, a powerful workspace component provides access to a standard set of analysis and visualization tools for interactive analysis and visualization applications directly driven by the user. Technologies applied include Pegasus from the University of Southern California for distributed workflow execution. The project will provide a framework for the integration and execution of user-provided numerical ocean models such as the Regional Ocean Modeling System (ROMS) and Harvard Ocean Prediction System (HOPS). A suite of integrated applications, including a standard Web portal interface and Matlab, Kepler, and WS-BPEL workflow editors will support process and model specification, simulation, analysis, and visualization.

Figure 4.2-13 shows the core Analysis and Synthesis Services Network with its operational nodes and needlines. Because of the integration architecture surrounding the Exchange as data and message distribution network, all nodes are connected to it to receive and produce information. Operational nodes that are frameworks enable the plug-in of user-provided processes, workflows, applications, and tools to perform the designated functions.

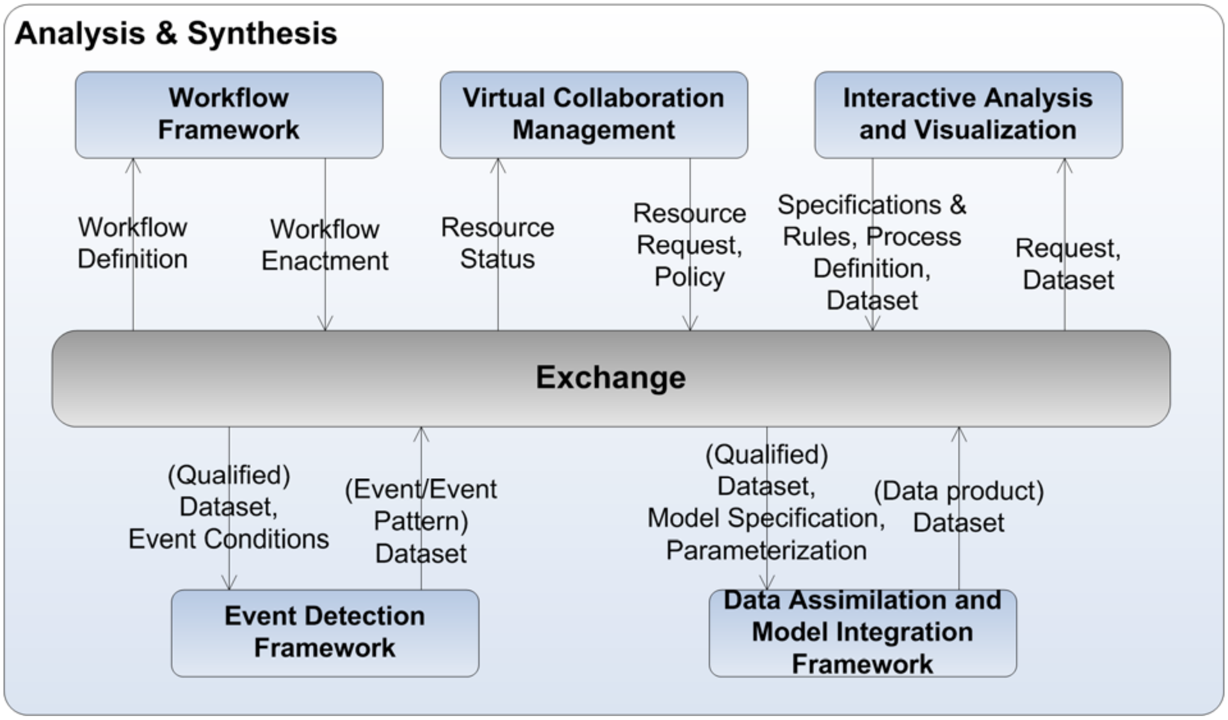

Figure 4.2-13 Analysis & Synthesis SN

4.2.2.3.6 Planning & Prosecution SN

The Planning & Prosecution SN leverages the capabilities of the consistent integrated network of sensing, modeling and control resources supporting resource nesting and resource autonomy. It provides generalized resource planning and control activities that will be applied to plan, schedule, and prosecute multi-objective observational programs. A part of it is the event-response framework. In addition, this SN provides embedded control of autonomous sensor systems, such as intermittently connected, low-bandwidth global mooring controllers and AUVs. Technologies applied include ASPEN and CASPER from NASA Jet Propulsion Laboratory for resource planning and control and MOOS (Mission Oriented Operating Suite) for interfacing with autonomous instrument platforms such as gliders and AUVs. MOOS is an open source middleware for connecting software components on an autonomous platform, enabling event capture, characterization and response. In addition, the behavior-based autonomous control software MOOS-IvP for autonomous vehicle motion control will be used and further developed. MOOS-IvP extends MOOS via interval programming (IvP), a unique, new mathematical model for representing and solving multi-objective optimization problems for reconciling vehicle behaviors during deployments.

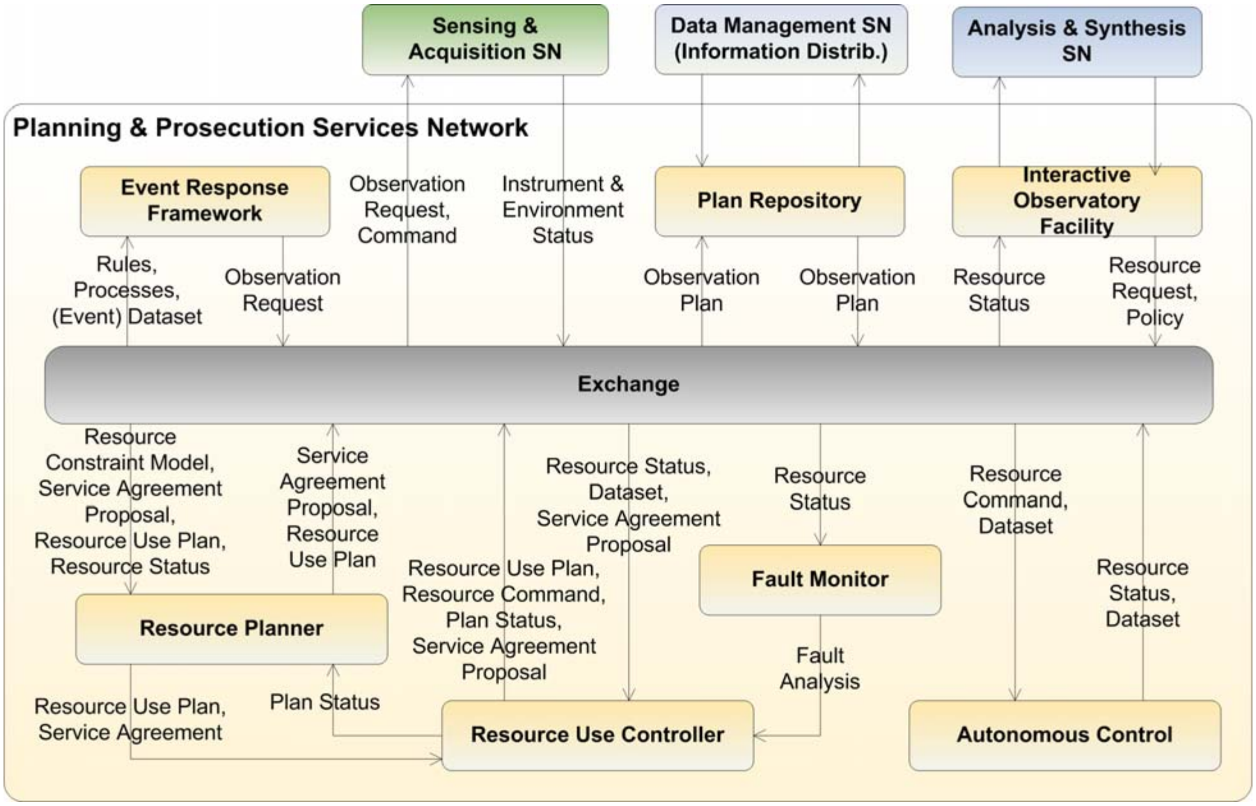

Figure 4.2-14. Planning & Prosecution SN

The *Interactive Observatory Facility* (Figure 4.2-14*)* provides the services to design, assemble, and operate configurations of resources from across the OOI into unique systems for planning, testing and prosecuting observation requests, leveraging the nested and autonomous capabilities of the fully integrated network of sensing, modeling, and control resources. It provides experimentalists with services to define, compose, and schedule multi-instrument observations that can execute across the observatory. It is based on the services provided by the Analysis & Synthesis SN for virtual collaboration management and the interactive workspace.

The *Event Response Framework* node provides automated and expert (i.e., usually involving user intervention) review of events and processes that may result in responsive tasking or retasking of instrument and mobile resources and thus provides observation requests to the Resource Planner. It subscribes to rules governing resource usage and information on processes and events from the Data Management SN.

The *Resource Planner* is a solver that requires a resource constraint model as its basis. The resource constraint model represents resources abstractly through their state condition as well as activities that can be performed on the resources. For instance, an AUV's state could consist of the battery charge condition, position, depth, and speed/energy profile. Activities for an AUV could include change position and depth or change to different behaviors, such as "return-to-base" from "loitering". The resource constraint model is entirely at the discretion of the resource provider or a resource integrator overseeing multiple resources. The resource planner acts as a constraint solver that takes a resource request as input and results in a resource use plan as output. In addition the responsibility of the resource planner is to negotiate resource use with individual resources and their respective stakeholders. The resulting service agreements and the resource use plan are the resulting envelope for the operation and control exercised by the resource use controller.

The *Plan Repository* is a repository instance based on Data Management services for storing and managing observation plans and related information, such as parameterization possibilities, resource (re)configuration, and autonomous behaviors. Observation plans in the repository can serve as templates that are modified when events response behavior is executed.

The *Resource Use Controller* operates in the framework that the resource planner has determined. The resource use controller takes as input a resource use plan and a service agreement and creates as output resource use plans on its local level of control or specific resource commands to trigger state change and activities in resources. In addition, the resource controller can defer the execution of resource use plans within a service agreement to a nested resource planner on a lower level that itself can break down the plan to the next level resources and make the respective resource agreements.

The *Fault Monitor* is a distinct separate component analyzing and overseeing resource status, providing fault analysis input to the resource use controller, which in turn might revise the plan within its local service agreement or get back to the resource planner for re-planning.

4.2.3 Releases

The capabilities of the OOI integrated observatory are specifically designed in a way that supports an incremental transition to operations. In particular, the design supports five incremental releases of the CI that increasingly support user relevant applications and processes, beginning from automated data preservation and distribution leading to advanced concepts of interactive ocean science, including instrument and observatory interactivity exploiting knowledge gained through observations and analyses. Even though multiple subsystems and infrastructure elements are being developed simultaneously, each release has a specific theme targeted at providing value to the end users and building on value previously delivered. The five releases are as follows:

- Release 1 Data Distribution Network provides a fully capable automated end-to-end data preservation and distribution infrastructure, supporting the immediate needs of instrument providers and observational data consumers.
- Release 2 Managed Instrument Network adds end-to-end control of how data are collected, supporting more advanced processes of instrument providers with managed instrument control.
- Release 3 OnDemand Measurement Processing adds end-to-end control of how data are processed, supporting more advanced processes of instrument providers and data product consumers, as well as on-demand measurements supporting event-driven opportunistic observations.
- Release 4 Integrated Modeling Network adds control of integrated ocean models driven by the data collection process, supporting data product developers and the numerical modeling community
- Release 5 Interactive Ocean Observatory adds control of data, processes, and models to drive the collection process, supporting observatory interactivity and transformative ocean observatory science for all users.

Figure 4.2-15 shows the five releases and their dependencies relative to marine implementation activities and external observatory integration.

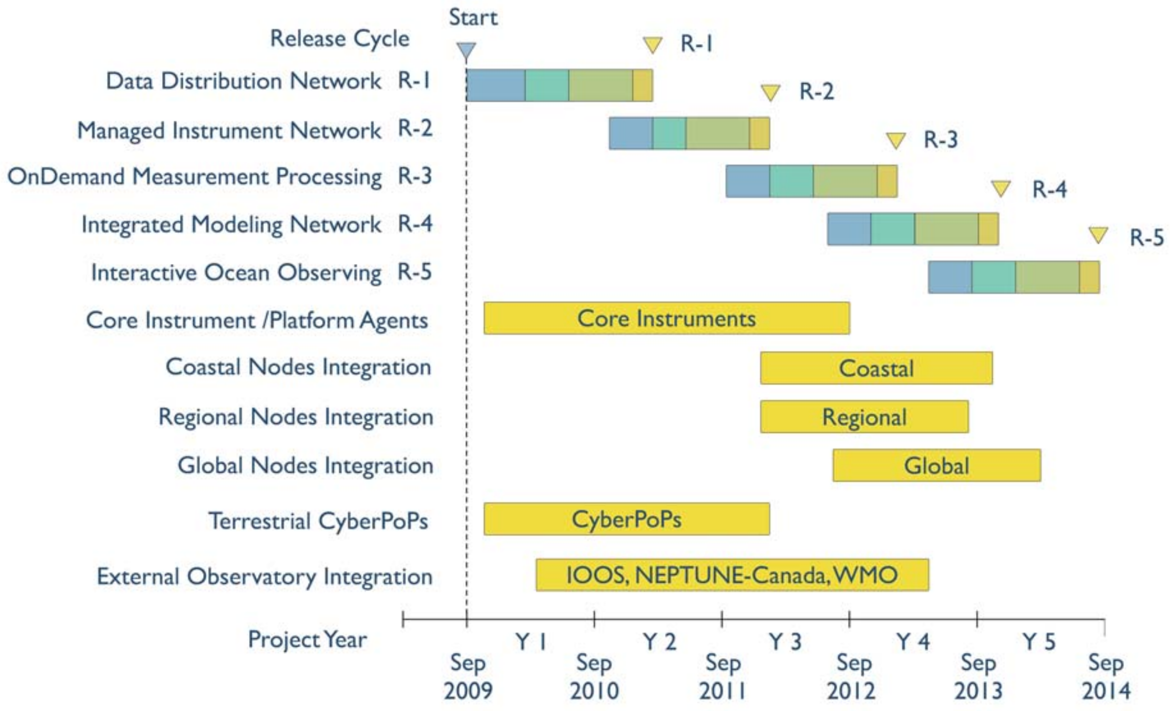

Figure 4.2-15. Construction Plan

In its final stage delivered by Release 5, the integrated observatory will support real-time modeling and data assimilation, adaptive sensing and platform control, rapid response and event capture, and closed loop, integrated sensing, modeling, and distributed network control.

The five releases are specifically designed to build from the foundation of data collection and preservation up to advanced concepts of interactive ocean science supporting:

- Real-time modeling and data assimilation.
- Adaptive sensing and platform control.
- Rapid response and event capture.
- Closed loop, integrated sensing, modeling, and distributed network control.

The six construction projects are:

- Sensing & Acquisition (S&A) Subsystem Construction Project
- Data Management (DM) Subsystem Construction Project
- Analysis & Synthesis (A&S) Subsystem Construction Project
- Planning & Prosecution (P&P) Subsystem Construction Project
- Common Execution Infrastructure (CEI) Subsystem Construction Project
- Common Operating Infrastructure (COI) Subsystem Construction Project

The integration of tools and applications is based on the framework that the CI infrastructure provides (see [IOI-AD]), in particular the service-oriented integration architecture based on governed message exchange. The deployment of system entities across the observatory network is also based on the framework that the CI infrastructure provides (see [IOI-AD]). The following sections provide further details about the subsystems and the releases to the degree relevant for the CI architecture & design specification. Further details are covered in the project plans, in particular the System Engineering Master Plan [OOI-SEMP], Transition-to-Operations Plan [CI-TROP] and the Commissioning Plan [CI-CP]. The planned construction and integration of subsystems into the five CI releases is described in the CI Project Execution Plan (DCN 2010-00001) and show in Figure 4.2.16.

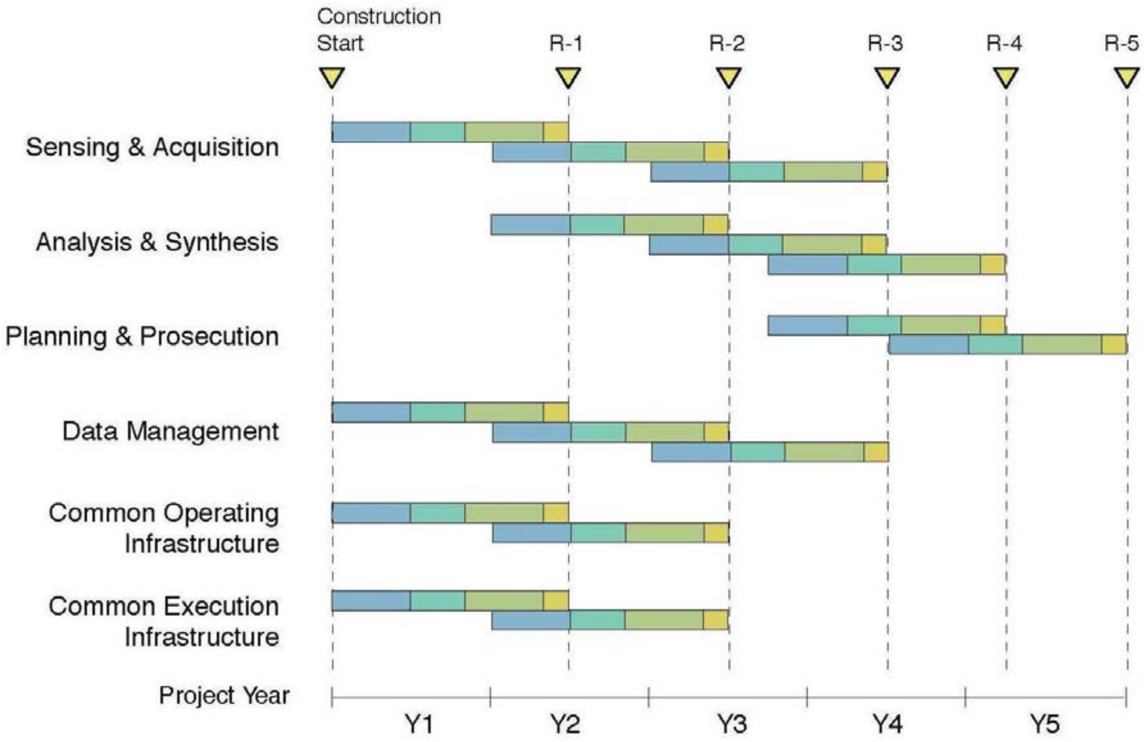

Figure 4.2.16. Subsystem Development Schedule

4.3 Coastal and Global Scale Nodes

4.3.1 Introduction

The Coastal and Global Scale Nodes (CGSN) Final Network Design (FND) is based on the elements of the Conceptual Network (CND) and Preliminary Network Designs (PND). The FND meets the OOI System Requirements (as defined in Level 2 of the DOORS database), the OOI Science User Requirements (also Level 2 of the DOORS database), and is reflected in twenty CGSN-specific network design documents (Table 4.3-1). The DOORS Level 3 Requirements define the top-level requirements for the CGSN elements. These requirements link back to the *OOI Science User Requirements* (14) and flow down to the subsystems as Level 4 Requirements. Together, Requirements Levels 2, 3 and 4 ensure that the infrastructure developed meets the scientific needs for which it will be deployed.

Table 4.3-1. List of CGSN-specific Final Network Design documents

Document Number	Document Description
3102-00001	Level_3_Requirements.doc
3301-00001	Level_4_Buoys_Surface.doc
3302-00001	Level_4_AUV.doc
3303-00001	Level_4_DCL.doc
3304-00001	Level_4_Gliders.doc
3305-00001	Level_4_Instrument_Packages.doc
3306-00001	Level_4_MFN.doc
3307-00001	Level_4_Moorings.doc
3308-00001	Level_4_Platform_Control.doc
3309-00001	Level_4_Power_System.doc
3310-00001	Level_4_Profilers.doc
3311-00001	Level_4_Shore_Station.doc
3312-00001	Level_4_Telemetry.doc
3310-00002	Profiler_White_Paper.doc
3309-00002	Power_System_White_Paper.doc
3304-00002	Glider_White_Paper.doc
3302-00002	AUVandDock_White_Paper.doc
3205-00001	Endurance_25m_Mooring_White_Paper.doc
3102-00003	Biofouling_White_Paper.doc
3305-00002	Core_Sensors_Design.doc

The CGSN FND includes two principal components (Fig. 4.3-1), the Global and Coastal Scale Nodes. The Global Scale Nodes consist of four Global Arrays located in the following critical, yet under-sampled locations: Ocean Weather Station Papa in the Gulf of Alaska (50°N, 145°W), Irminger Sea offshore of southern Greenland (60°N, 39°W), Southern Pacific Ocean west of southern Chile (55°S, 90°W), and the Argentine Basin (42°S, 42°W). The Coastal Scale Nodes consists of two Coastal Arrays, on the eastern and western continental shelves of the U.S. The Pioneer Array, in the Mid-Atlantic Bight, samples a prototypical buoyancy-driven system on a broad continental shelf. The Endurance Array, samples a prototypical upwelling regime on a narrow continental shelf. The Endurance Array consists of a moored line off Newport, Oregon (44°N, 126°W to coast) connected to the Regional Scale Nodes (RSN) cabled network, and an uncabled moored line off Gray's Harbor, Washington (47°N, 125°W to coast). The infrastructure of each array includes common elements (e.g., buoy and mooring components, power generation, telemetry, platform control) that are reflected in the CGSN subsystems and team organization. Each also has unique features – the Endurance Array has cabled elements, the Pioneer Array is designed to be relocated, and the Global Arrays are designed for extreme, high latitude conditions.

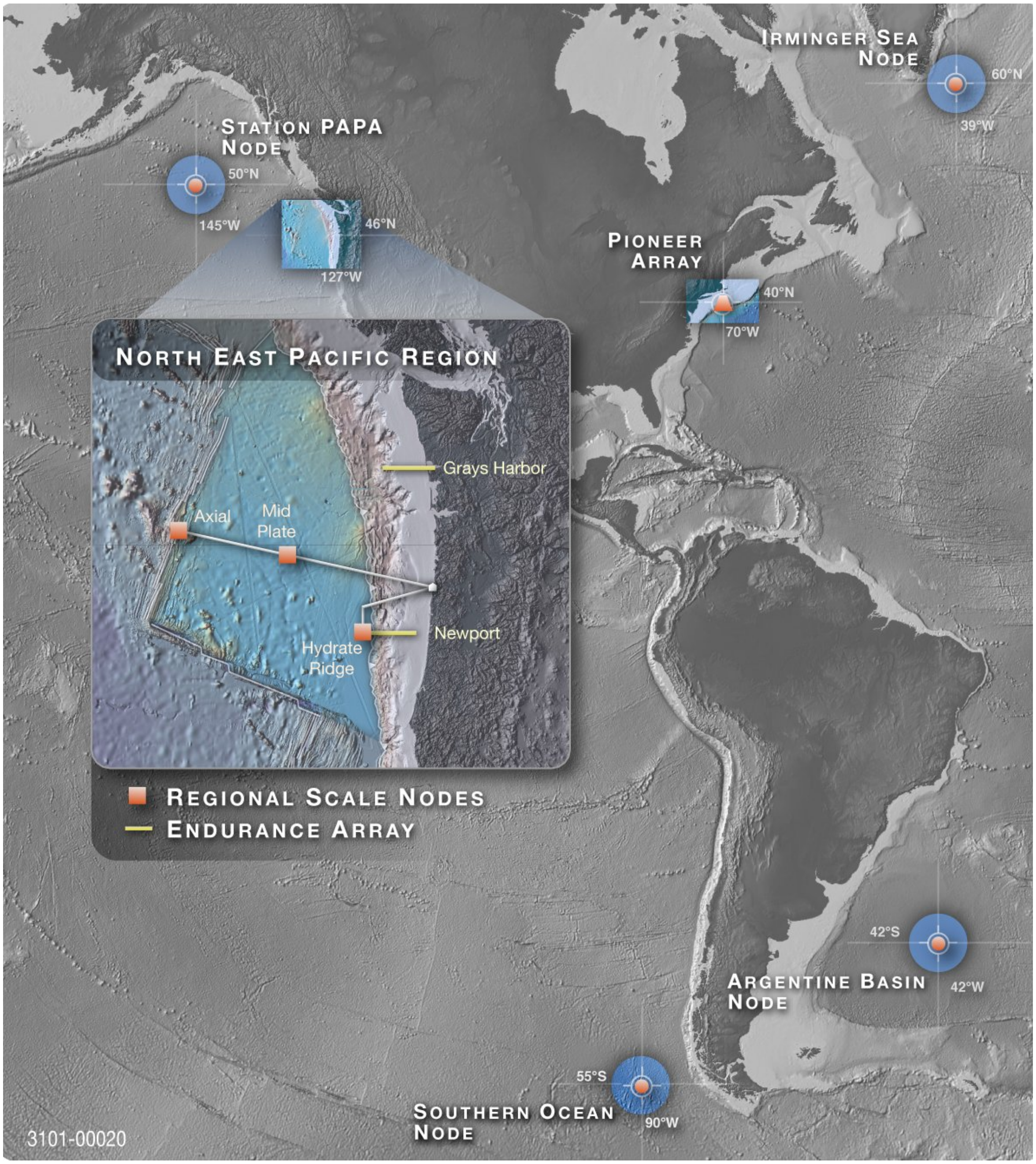

Figure 4.3-1. Map of the CGSN, showing the locations of the four Global Arrays, the Endurance Array, and Pioneer Array. Elements of the Endurance Array are connected to the RSN, which is also shown (inset).

To address the System Requirements and meet the Science User Requirements (SUR), each CGSN array uses a combination of horizontally fixed platforms (moorings) and mobile platforms (AUVs and gliders) to provide simultaneous spatial and temporal sampling capabilities (see Sec. 4.1.2.1 and 4.1.2.2). These platforms deploy a multidisciplinary set of core sensors and also provide capacity (space, power, and bandwidth) for additional science user instrumentation. Each array includes moored profilers to address the requirement to sample the full water column and mobile platforms to meet the requirement of synoptic sampling of horizontal variability. The CGSN arrays interface with the CI component and provide real time data and two-way command and control to adjust the sampling protocols.

Matching the geographic depiction of the CGSN (Figure 4.3-1) is a high-level functional block diagram (Figure 4.3-2) showing the relationships among CGSN elements as well as the relationship of CGSN elements to RSN (red) and Cyberinfrastructure (CI) (green).

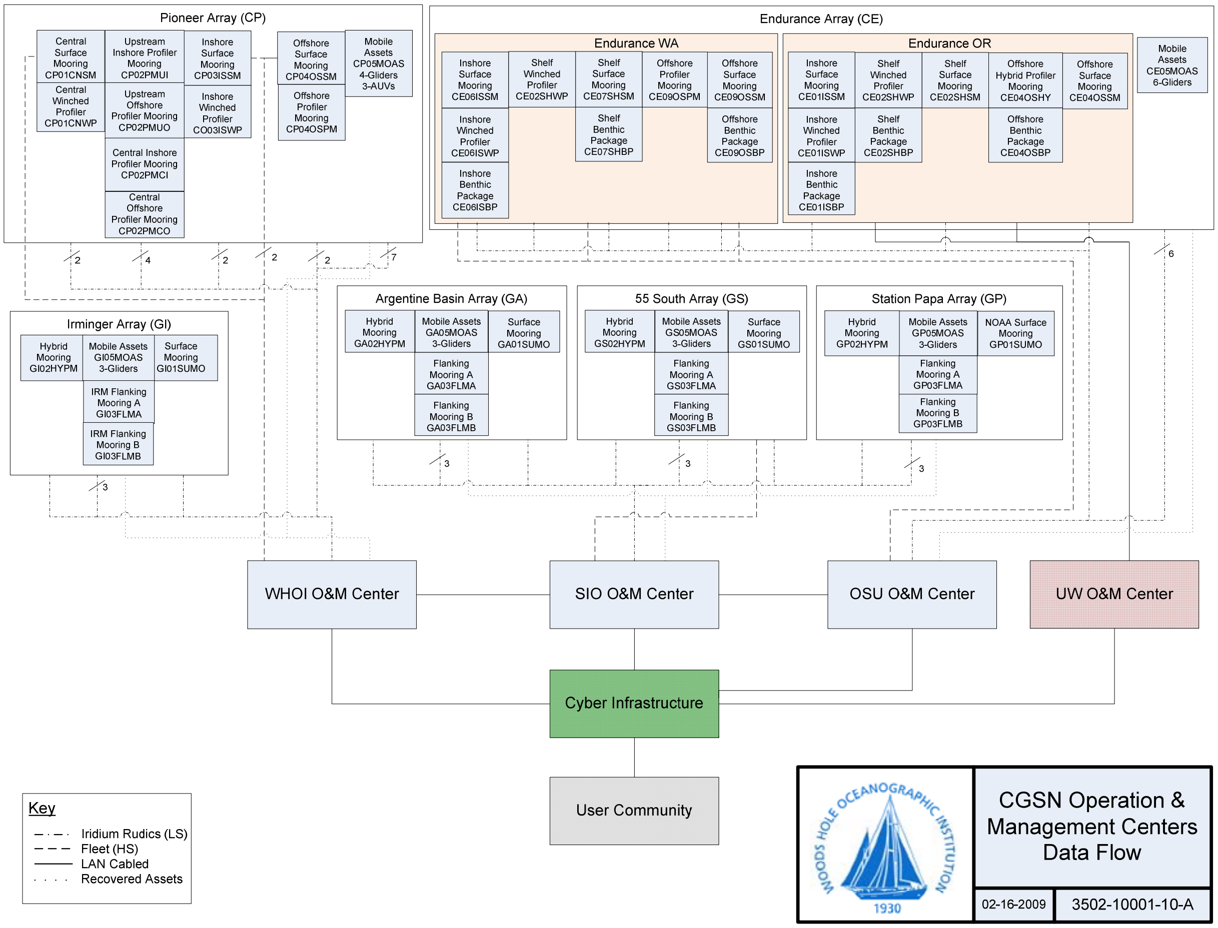

Figure 4.3-2. High-level functional block diagram of the CGSN.

4.3.1.1 Engineering Design Approach

The CGSN engineering and design team is organized around twelve subsystems that are the building blocks of the CGSN infrastructure (Table 4.3-2). Level 4 requirements were developed for each of the twelve subsystems (Table 4.3-1). Since the subsystems form the basis of the CGSN infrastructure, the twelve requirements documents effectively describe the CGSN design requirements, and thus have guided the design and specification process.

Table 4.3-2. CGSN Subsystems

CGSN Subsystem	Comment
Surface Buoys	Four variants based on modular design
Moorings	Surface and subsurface variants
Benthic Nodes	Two variants based on function
Platform Controller	Common design for all mooring platforms
Sensors	From common RSN/CGSN Core Sensor List
Data Concentrator/ Logger	Common design across CGSN installations
Buoy Power System	Three variants based on modular design
Telemetry System	Multiple capabilities based on modular design
Profilers	Three variants based on application
Gliders	Two variants based on application
AUV and AUV Dock	Unique to the Pioneer Array
Shore Stations	Three facilities integrate CGSN infrastructure

Within each subsystem the CGSN team worked aggressively to define common system components across the Global and Coastal Observatories to reduce development and construction costs and simplify maintenance while still meeting the unique requirements of each installation. Special efforts were made to assess technology readiness for four CGSN subsystems (buoy power, profilers, gliders, and AUVs and AUV docking) and two other key technology areas within the CGSN (biofouling mitigation and the Endurance Array 25 m mooring). The assessment process began with Requests for Information (RFI) from vendors. Teams of external experts in the technology area, along with CGSN staff experts, were empanelled to assess the responses, develop ranking criteria, and map the design paths. For each of these key technologies a white paper (Table 4.3-1) was generated that captures the selection process, describes the preferred path forward, identifies critical milestones and identifies alternative solutions if required. Sensor and platform lifetimes used to derive operations and maintenance schedules include limitations due to power, mechanical fatigue and biofouling. The operations plan (3101-00001 CGSN Project Execution Plan) includes cross-calibration of array sensors with shipboard sensors during deployment and recovery, and overlap of platforms with freshly calibrated sensors with platforms to be recovered.

4.3.1.2 Surface Buoys

The surface buoys to be employed will be close variants of the same basic design (Fig. 4.3-3). All buoys will share design of the main structure, consisting of an outer foam collar, an inner mechanical structure and electronics housing, and a tower assembly. The Global buoys require greater buoyancy and higher mounts for meteorological instrumentation. Thus, they have a larger foam collar and a taller tower. The Global buoy design is intended to enhance performance and survivability over that of current 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 Coastal buoys share structural elements with the Global buoys, but the foam collar is smaller and the tower is shorter. This reflects reduced buoyancy requirements in shallower water and less severe surface wave conditions. The standard-power variants of Global and Coastal buoys have a compact subsurface hull and relatively long keel section to enhance stability and provide a common mechanical interface to subsurface mooring components. The high-power variants have an extended subsurface hull to provide additional volume needed to store fuel for the power system.

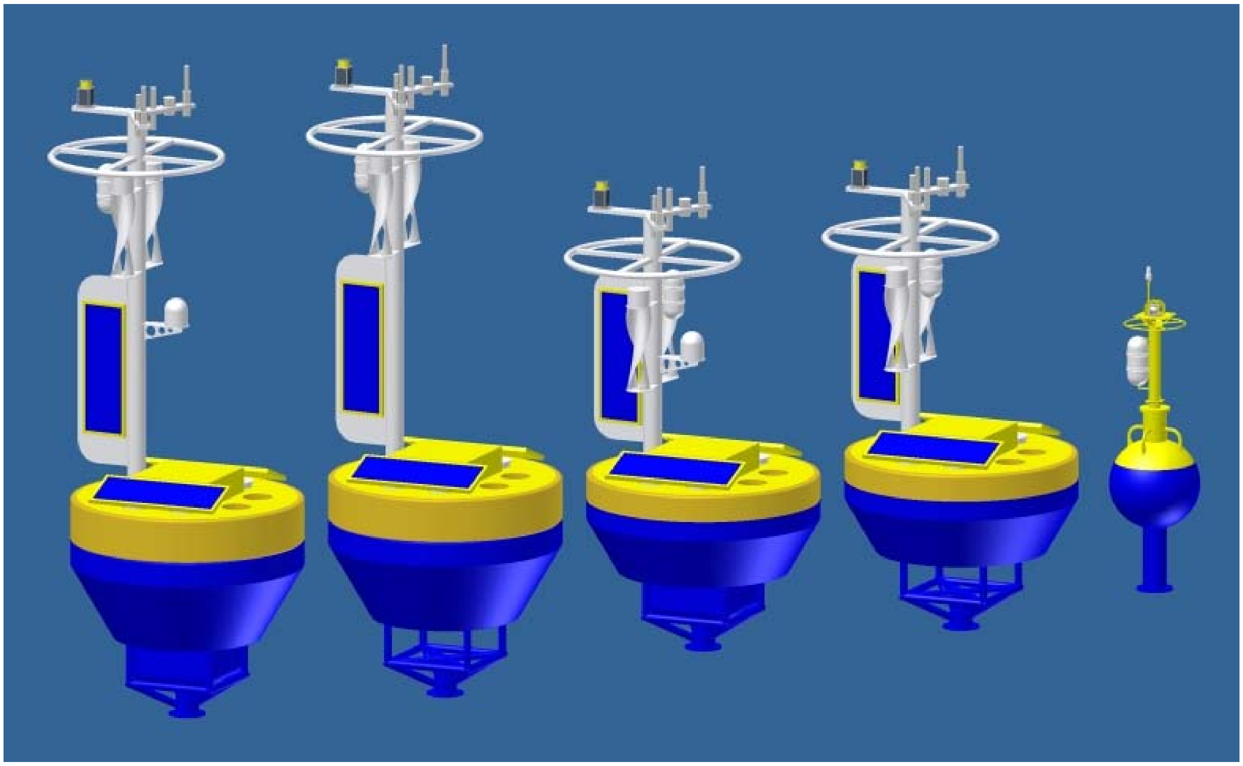

Figure 4.3-3. The CGSN buoy family. Designs for (left to right) Global high power, Global standard power, Coastal high power, Coastal standard power, and Submersible buoys share a common design, but are tailored to meet the requirements of each application.

4.3.1.3 Moorings

The CGSN moorings are innovative and more capable mechanically and electronically than previous oceanographic designs. They are robust platforms based on decades of design and installation experience within the CGSN partner Institutions. The CGSN surface mooring designs are similar for the Global and Coastal Arrays and build on experience with projects like the acoustically linked Nootka mooring (22), and other coastal and open-ocean mooring designs (Figure 4.3-4). CGSN subsurface mooring designs build on previous, simpler designs, which have been refined for OOI by including more capable platform control, communications throughout the mooring line and, in most cases, a surface expression to allow connection to the CI infrastructure.

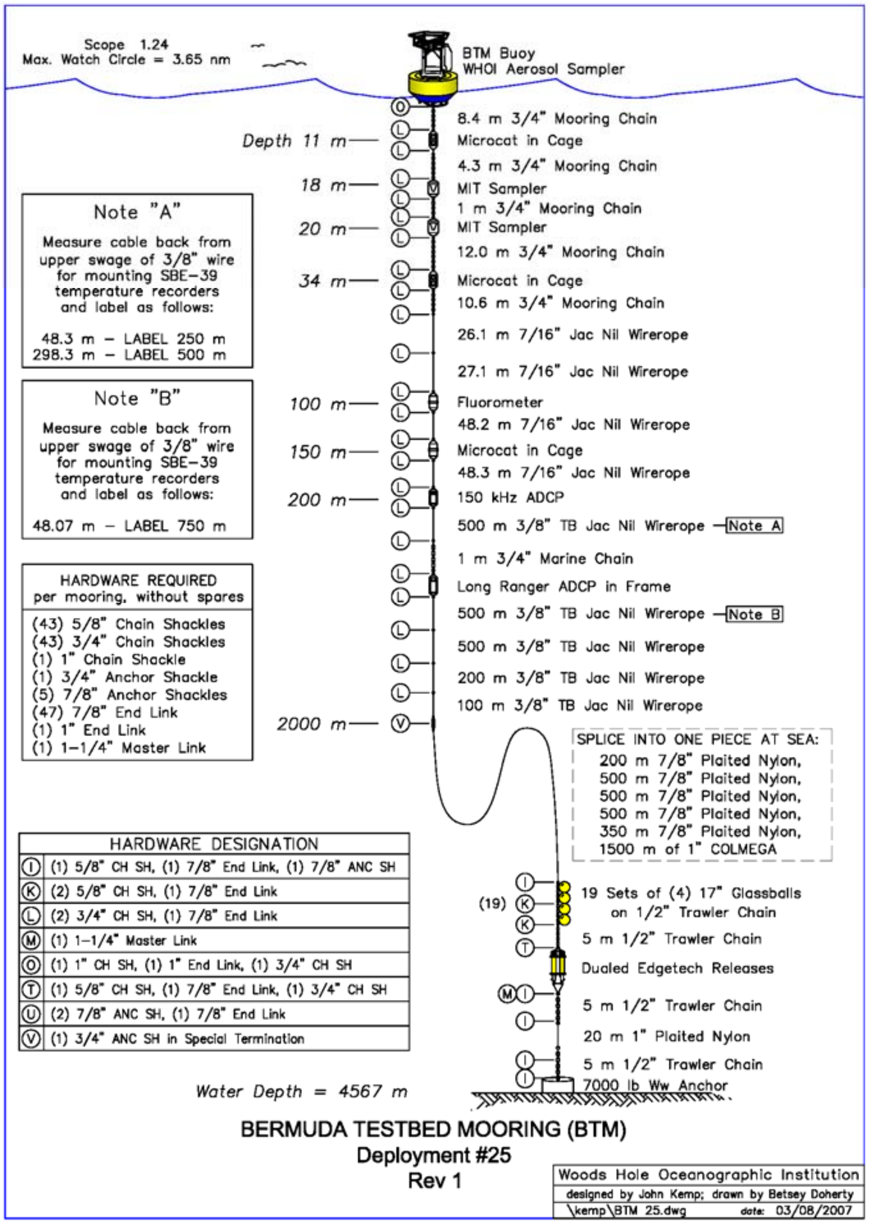

Figure 4.3-4. Example surface mooring design – the Bermuda Testbed Mooring (BTM). This design was proven over a twelve-year interval of continuous site occupation with 25 mooring turnarounds at 6 month intervals.

Coastal-Global Scale Nodes moorings use a combination of nylon-jacketed steel wire rope, various types of synthetic line, electromechanical (EM) cable with copper conductors and electro-optical mechanical (EOM) cable with copper conductors and optical fibers. Steel wire rope can be used not only for strength and resistance to fish-bite but also for inductive telemetry of data from moored instrument packages. With inductive telemetry, a controller on the mooring (usually at the buoy) can receive data and send commands to instruments on the mooring line below. The wire rope also provides the pathway for wire-following profilers to ascend and descend by traction motors or buoyancy control.

Synthetic ropes are used for light weight and elasticity. Polyethylene rope is used in the lower portions of moorings to provide buoyancy and prevent the mooring from touching the bottom in slack conditions. Nylon rope is used within moorings to provide elastic compliance.

Electromechanical (EM) and Electro-Optical-Mechanical (EOM) mooring elements are used in some CGSN moorings. These take the form of EM or EOM wire rope, molded chains, and mooring stretch hoses. These elements are combined to form a mooring strength member that includes electrical and optical pathways for the transmission of power and data along the length of the mooring.

Moorings are designed using static and dynamic modeling methods. WHOI CABLE, a general-purpose 3D nonlinear cable dynamics analysis tool developed at WHOI, is used for the static and dynamic analysis of CGSN moorings. General characteristics and commonalities among CGSN moorings are described in Sec. 4.1.2.1.

4.3.1.4 Benthic Nodes

The CGSN benthic nodes are of two principal types, the Multi-Function Node (MFN) and the Benthic Experiment Package (BEP). The MFN (Fig. 4.3-5) will be capable of supporting multiple onboard (e.g., frame-mounted) sensors, mechanically and electrically connected assemblies such as an AUV dock, and external sensor packages connected by an ROV wet-mateable connector. The MFN also serves as the seafloor anchor for an EM or EOM mooring. 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 anchor to be hauled back once the MFN is recovered. The MFN will 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. The BEP (Fig. 4.3-5) is exclusive to the Endurance Array, and provides a low profile (trawl resistant) mounting platform for sensors that require high power and bandwidth as well as near proximity to the seafloor. The BEP is based on existing, commercially available benthic platform designs, modified for connection to the RSN cabled infrastructure at the Endurance Array Offshore and Shelf sites.

The MFN acts as a power and telemetry breakout between the mooring EOM cable and the science users. The MFN includes two Data Concentrator Loggers (DCLs) that provide power and data ports and local data storage. An ROV (remotely operated vehicle) pluggable, wet-mate connector on the MFN frame will provide an Ethernet data interface and DC power.

Figure 4.3-5. The WHOI-designed Multi-Function Node (MFN, left) and the Flotation Technologies DD-100, an example of a commercial Benthic Experiment Package (BEP, right).

4.3.1.5 Power System

Three versions of power systems will be used on CGSN surface buoys. The high powered system, described in greater detail below, includes photovoltaic arrays (PVA), wind turbine generators, a methanol fuel cell, a bank of Absorbed Glass Mat (AGM) lead acid batteries for energy storage and a power controller (Figure 4.3-6). The fuel cell approach has high efficiency (thus less onboard fuel), low environmental concern, and a modular design that can be scaled to meet the requirements of particular sites. The high-power system with its average power of 250 watts and peak power of 500 watts has the ability to sustain operation of innovative, power-hungry subsea sensors at remote, non-cabled locations and represents one of the transformative aspects of the OOI program. The standard power system has no fuel cell, using PVA and wind turbines to generate average power of 50 W. Although only 1/5 the output of the high-power system, it should be recognized that this is also ten times the average power available from a conventional (battery-only) system. The third variant is a battery-only system with no power generation, consisting of a bank of primary batteries and a power controller. The power systems are designed to provide continuous power to a buoy based data collection and telemetry system over many months and in all weather and seasons. Power from the buoy will also be delivered to seafloor systems such as AUV docks with the capability to recharge AUV batteries. The power system will be capable of delivering up to 400 W peak power to an MFN (the cable voltage will be stepped up to 300 VDC to reduce power loss during transmission and transformed back to safe voltage working levels at the MFN).

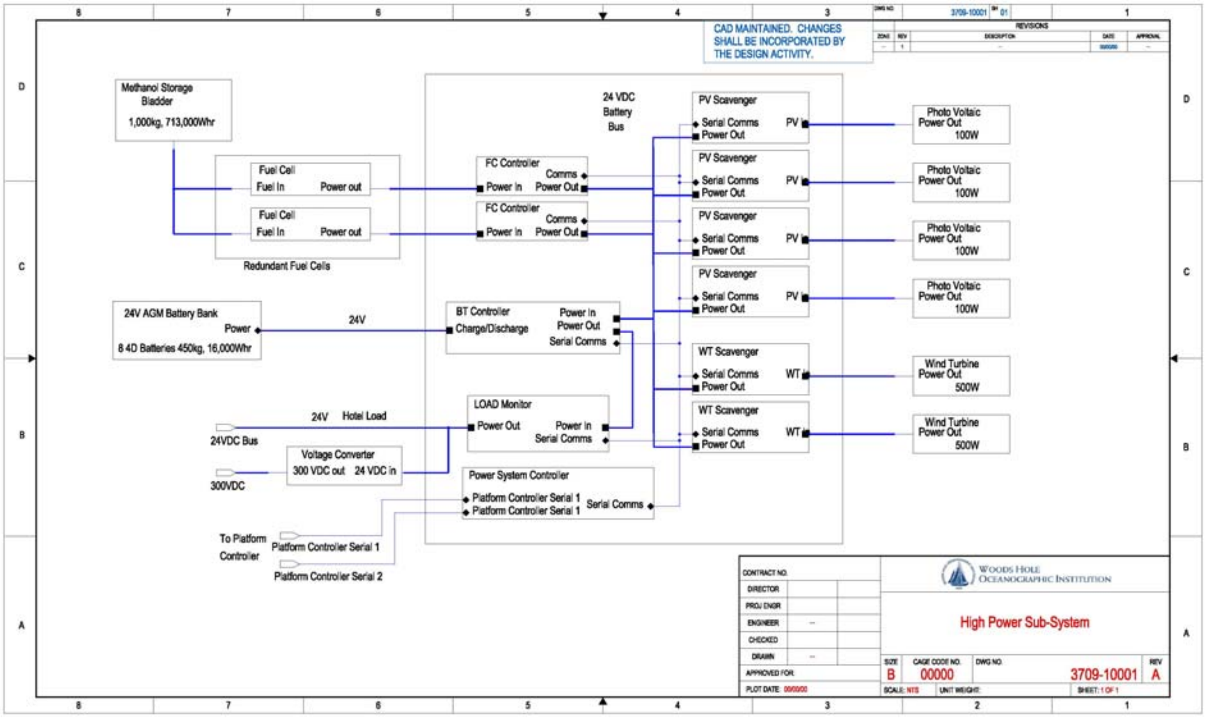

Figure 4.3-6. Power system block diagram

Four individual PVA panels are connected to separate input ports on the power system, and are adjustable to match the sun's angle of incidence for greater collection efficiency. The four-panel architecture permits the Power System Controller (PSC) to disable one or more damaged PV panels, while making full use of the remaining panels. This redundancy is repeated for the two wind turbines used by the system. The fuel cells are also connected to the power system via independent power connections, and are individually controlled by the PSC. This permits the PSC to start and stop each fuel cell 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 standard and high-power systems use a bank of AGM lead-acid batteries for energy storage with high peaking capacity. In order to maximize peak power delivery, this battery bank is made as large as possible, within the constraints imposed by total buoy weight specifications.

The PSC will monitor critical power system parameters such as voltage, current, estimated “fuel gauge” levels and ground fault leakage. The PSC is responsible for managing all power systems operations autonomously and will report status to the platform controller via a serial connection.

4.3.1.6 Platform Controller

The platform controller will provide the intelligence aboard platforms to monitor the use of power systems, control sensor data loggers, monitor the state of health of the platform, and control the means for telemetry of data and command information to a shore facility. The controller maximizes the life of the platform according to predetermined operability rules while allowing users to adapt platforms to new operating strategies. All CGSN surface buoys will utilize a fully redundant version of platform controller where the defining characteristics of CGSN surface buoy platforms are autonomy, intermittent telemetry, and highly efficient use of power (Figure 4.3-7). A simplified version of controller based on common subassemblies will be utilized on the platforms, which utilize primary battery power systems. The controllers will acquire and store all engineering data associated with the platform and in all cases on-board storage of data is required until the platform is recovered. All platform controllers are based on a commercial off the shelf (COTS) low-power, single-board computer running a variant of the Linux operating system. The controller will host the CyberPoP software, providing integration with CI and representing one of the OOI transformative elements.

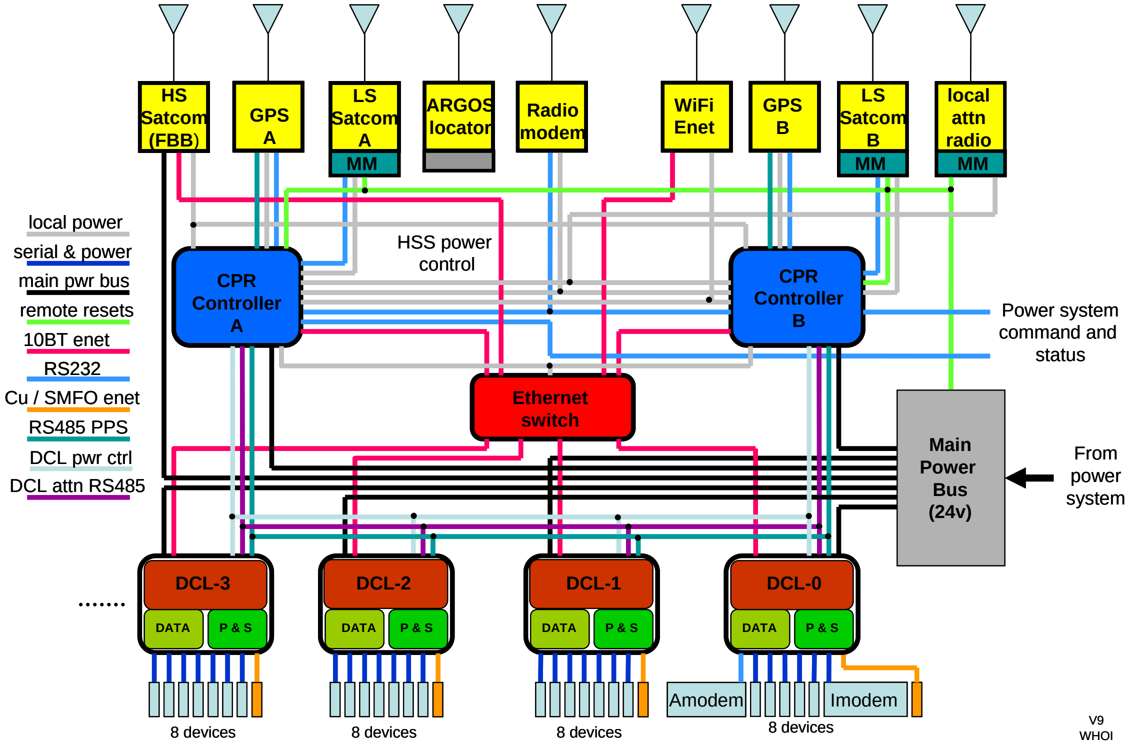

Figure 4.3-7. Platform control. Block diagram of platform control system showing fully redundant platform controllers, partially redundant telemetry subsystems, and integration with Data Concentrator Loggers (DCL) and power system.

4.3.1.7 Telemetry

The telemetry system is comprised of a set of telemetry devices operating through satellite links, local radio links, and in some cases acoustic modems, and is utilized on all CGSN platforms with the exception of the Endurance Offshore and Shelf sites, which are directly connected into the RSN cabled infrastructure.

All autonomous CGSN platforms will possess a finite bandwidth for transmitting data to shore that will depend on both power availability and budgetary constraints. As the baseline satellite telemetry link for all platforms, CGSN has selected the Iridium satellite communication system, essentially a 2400 baud phone modem, with which there is much experience in the community. A higher speed, commercial, Inmarsat-based satellite telemetry system, utilizing a shared channel, 284 kilobit per second link with a small steered antenna, will be used on some CGSN platforms to meet higher bandwidth data delivery requirements. At the highest sensor sample rates it will not be possible to telemeter all data to shore using the Iridium link. However, platforms equipped with Inmarsat telemetry will be able to transmit full-rate sensor data on demand, as conditions allow, fulfilling one of the transformative elements of the OOI.

All platforms with surface expressions will be equipped with a local “attention” radio and radio-frequency (RF) modem. The RF modem will allow a short range connection between the primary surface buoys and a nearby University-National Oceanographic Laboratory System (UNOLS) ship for two way communications over a high speed link. The attention radio will allow an operator in the immediate vicinity of the platform to get the attention of the platform or arouse it from a failure state. Likewise, the low-speed satellite communication links will be equipped for remote wakeup or recovery from failure states, as long as the platform has power.

Acoustic modems will be used to relay data and commands between subsurface equipment and adjacent telemetry-capable surface buoys. The use of directional transducers will provide high efficiency at modest power levels and support communications with sensors located on the mooring or on the seafloor up to one water column 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.

4.3.1.8 Data Concentrator Logger (DCL)

Data Concentrator Loggers (DCL) will interface with instrument packages and may be mounted either as stand-alone subsea assemblies or integrated into other subsystems such as surface buoys. The DCL is a microcomputer based element embodying the hardware interface to sensors, and responsible for configuring, powering and monitoring health of sensors, acquiring and storing data and forwarding data as requested, either directly to a telemetry device, or via a platform controller. All DCLs will run a variant of the Linux operating system and will host the CI CyberPoP instrument agent software, representing one of the OOI transformative elements.

The DCL include 8 dry-mate, electrical connectors, which provide DC power and a communication interface. Seven of the connections may be configured for RS-232 (TTL or standard levels) or RS-485 while the eighth channel has a 10/100BaseT Ethernet connection with both copper and fiber optic connectors. Two isolated DC power supplies of 12 VDC and 24 VDC are available at the connector pins. The DCL will also monitor voltage buses for over-current, out-of-range voltage, and fault to seawater.

4.3.1.9 Gliders

Gliders will be employed for three general purposes: providing horizontal context to horizontally fixed platforms, providing adaptive sampling capability and communicating with subsurface instruments and relaying their data to shore via their satellite telemetry. They are commercial off the shelf (COTS) equipment and have been so for several years. The glider subsystem will aid the transformational nature of OOI by enabling continuous monitoring of the oceanic mesoscale at CGSN nodes, allowing near real-time adaptive sampling, and making available near real-time time series data from remote locations (such as global array flanking moorings).

Glider deployments across the CGSN Arrays fall within three distinct categories; global, open ocean, and coastal. Global deployments require an acoustic modem and capability to operate to 1000 m. Open ocean deployments require 1000 m depth capability, but not acoustic modems, and coastal deployments require relatively shallow depth capability (200 m) but with the ability to maneuver and operate where the total water depth is as little as 30 m.

CGSN will utilize two glider designs, one optimized for the 1000 m depth capability required for global and open ocean deployments, and one optimized for 30 – 200 m depth operation and higher maneuverability. For global and open ocean deployments the glider will be configured for maximum mission duration with optimized sampling rates and high efficiency flight dynamics (Figure 4.3-8). Coastal gliders will carry a larger sensor suite and will be optimized for high sensor acquisition rates and shorter mission durations (Figure 4.3-9).

Figure 4.3-8. REDACTED

Figure 4.3-9. REDACTED

4.3.1.10 Autonomous Underwater Vehicles (AUVs) and AUV Docks

The CGSN Pioneer Array includes Autonomous Underwater Vehicles (AUVs) that will be deployed unattended for long periods (months) and will utilize seabed docks located in water depths from 60 to 600 m for data offload and battery charging. This represents a transformative capability to be implemented for OOI that is not presently available as a commercial product or demonstrated to be operational for long durations.

Two AUVs will be deployed for long-duration operation and will utilize the seabed docks. These AUVs will execute multiple missions – departing from the dock, completing a series of navigational objectives and returning to the dock – with a nominal interval of seven days between missions. The AUV will perform up to 25 missions before being recovered for maintenance. The AUV docking stations will draw energy from EOM moorings by connection to MFNs at their base. The MFN will supply power to the dock at a maximum rate of 100 W, and the dock will be capable of charging the AUV batteries from 0 to 100% capacity in less than 96 hours. A 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 sensors with freshly calibrated sensors (on the vehicle) as a means of mitigating sensor degradation during long-term deployment.

[redacted]

Figure 4.3-10. REDACTED

4.3.1.11 Profilers

CGSN profilers support a suite of sensors that are raised and lowered through the water column on a regular basis. Profilers will be used to collect high-resolution vertical profiles of water column properties and telemeter these data to shore in near real time. These data are critical to achieving the OOI requirements for full water column sampling. To ensure full vertical coverage, profiler data will be augmented by fixed sensors located on buoys, on moorings and on the sea floor. Commands from shore will allow alteration of the profiler sampling strategies to optimize scientific return within power and bandwidth constraints. Three types of profilers will be used within CGSN: wire-following profilers, surface-piercing profilers, and hybrid profiling systems.

Wire-following profilers propel themselves along a taut mooring line of plastic jacketed wire rope with a traction motor. These profilers will be operated beneath subsurface buoys and collect regular profiles from near the bottom to just below the subsurface buoy. Data is transferred along the mooring line to the surface buoy via an inductive modem. Wire-following profilers are well suited to profiles of long vertical extent and are depth rated to 6000 m, allowing a single basic design to be utilized for both Global and Coastal infrastructure (Figure 4.3-11).

Figure 4.3-11. REDACTED

Surface-piercing profilers raise and lower a buoyant package of sensors by varying the length of the tethering cable (Figure 4.3-12). Advantages of the surface-piercing profiler relative to a wire-following profiler are full water column profiling capability and larger payload. Surface-piercing profilers are operated from a benthic platform which serves as a docking station for the profiling body when it is not profiling and anchor for the tether when it is. The benthic platform has mounting points for sensors and it contains an anchor weight and release mechanism for platform recovery. 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 profiling body begins its ascent within a few meters of the seafloor and, with the tether fully extended, penetrates the air-sea interface. The larger payload provides the ability to house a more complete set of sensors. Limitations of the surface-piercing profiler are higher cost and a maximum expected operating depth of 200 m. In addition, approaching and penetrating the sea surface exposes the profiler and its tether to the forces associated with wave orbital velocities. Strategies to address this include sensing the wave state while surfacing and remaining below the air-sea interface in heavy seas.

At coastal sites where the water depth is less than 200 m, surface-piercing profilers will be deployed on the seafloor and profile from as near to the seafloor as practicable all the way to the surface. Most of the coastal surface-piercing profilers will be powered by internal battery stores and will utilize Iridium telemetry as a primary means for transferring data to shore and acoustic telemetry as a secondary method to transfer data to nearby platforms. One coastal profiler, at the Endurance Shelf site, will be designed to attach to the RSN cable. The coastal profilers will perform an average of six profiles per day and will profile at a minimum speed of 10 cm s^{-1}.

Figure 4.3-12. REDACTED

To achieve full water column coverage at the Global Arrays, a wire-following profiler will be combined with a surface-piercing profiler in a single, hybrid profiler mooring. The wire-following profiler will sample the deep portion of the water column, between the anchor and a 200 m subsurface float, while the winched profiler samples from the subsurface float up to the surface. Data from the wire-following profiler is transferred to the surface-piercing profiler through an inductive modem and transferred to shore along with the surface-piercing profiler data via Iridium telemetry. The surface-piercing profiler on the Global hybrid mooring is different from the coastal surface-piercing profilers in that it is optimized for open ocean deployment and for very high efficiency driven by global maintenance intervals (Figure 4.3-13). All profilers deployed in Global Arrays will be powered by an internal battery supply and will perform an average of one profile per day.

Figure 4.3-13. REDACTED

4.3.1.12 Shore Stations

The shore stations, otherwise known as Operations and Management Facilities, are responsible for system operations, fields operations, and data operations. System operations include daily operations as well as coordinating field operations, data operations, and communication with science users for planning, sensor integration, etc. Field operations include buoys, gliders, and AUV deployment and recovery operations. Data operations include real-time system and core sensor data monitoring, handling recovered platform data, quality control, and interface with CI for data dissemination, archive, and command/control.

The shore facilities will operate 24/7, 365 days a year with operator staff support available Monday-Friday, 9-5 local time. The systems will be automated to the extent practicable, with operator alerts available around-the-clock. Physically, each facility will provide space for the operations staff, computers and communications equipment, and will have internet connectivity, a firewall, a GPS time server, air conditioning, and emergency backup power (Figure 4.3-14).

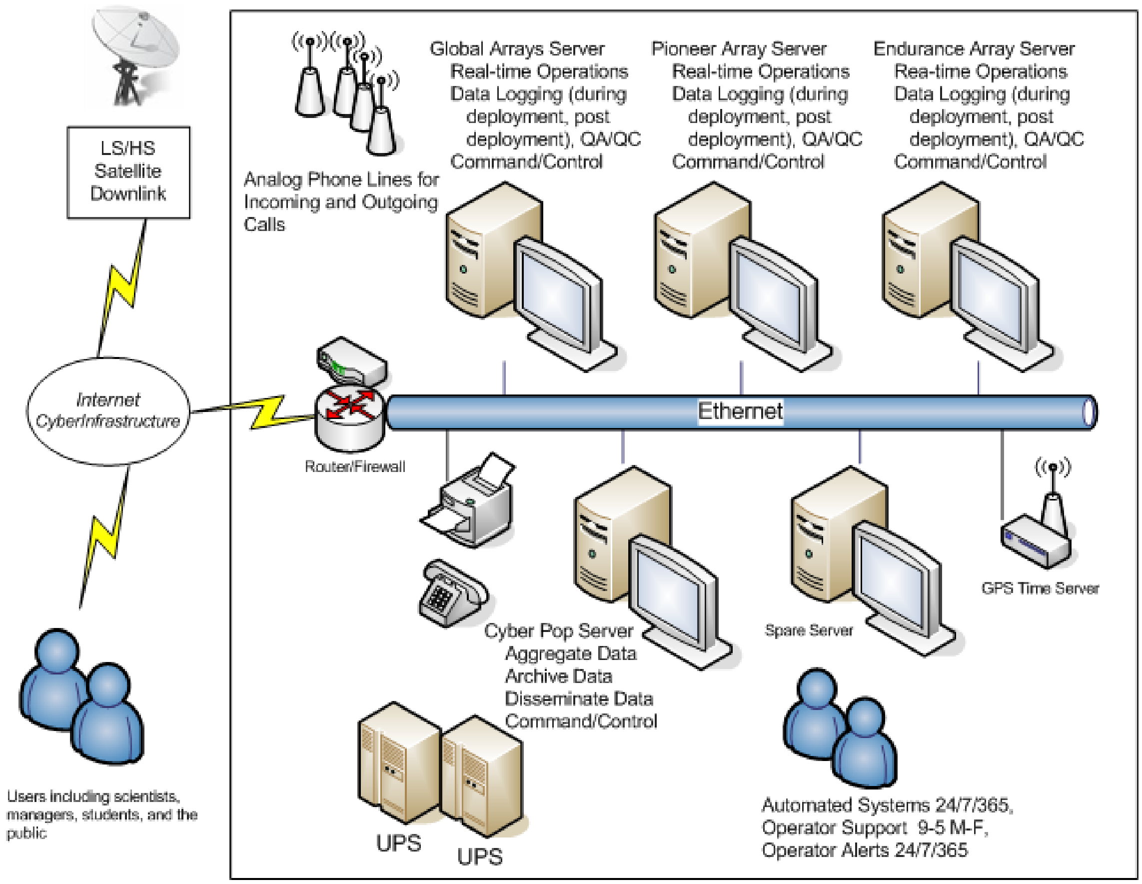

Figure 4.3-14. Shore station block diagram.

4.3.1.13 CGSN Sensors

The CGSN sensors provide the means to observe the air-sea interface, the water column, and the benthic boundary layer. Many sensor requirements are common with RSN, and this commonality has been exploited in development of the OOI Core Sensor List. The CGSN architecture includes not only the means to record and telemeter all Core Sensors, but also the capacity to increase the number and type of instruments over the lifetime of the OOI. The Core Sensors meet the requirements that flow down from the high-level science questions, traceability matrices and science user requirements. Relevant details for each sensor are described in the CGSN Core Sensor Design Document, CGSN L4 Instrument Package Requirements, and CGSN Power and Bandwidth table. The CGSN infrastructure enables 2-way communications (commands and data) to all elements. Sensors and sensor platforms (buoys, moorings, profilers and gliders) were standardized across the CGSN by specifying identical equipment to the extent possible within the unique deployment constraints of individual sites. Working together with RSN, an understanding of the multidisciplinary sensor suite judged ready for routine deployment as part of the OOI infrastructure was developed. The CGSN components from the OOI Core Sensor List are shown in Table 4.3-3.

Table 4.3-3. CGSN Core Sensors

Measurement	REDACTED	Platforms
surface fluxes (bulk)		Surface Buoys
surface fluxes (direct covariance)		Surface Buoys
CO2 flux		Surface Buoys
pCO2 water		Surface moorings, surface-piercing profilers, Benthic nodes
surface wave spectra		Surface Buoys
temperature and conductivity		Moorings, Benthic nodes Surface-piercing profilers, wire-following profilers Gliders AUVs
high-precision pressure		Surface-piercing profilers, wire-following profilers Benthic nodes Gliders AUVs
mean currents		Moorings, surface-piercing profilers Moorings, Benthic Nodes, AUVs Gliders
turbulent velocities		Buoys, surface-piercing and wire-following profilers, Benthic nodes
dissolved oxygen		Moorings, Benthic nodes, Gliders, AUVs Surface-piercing and Moored profilers
pH		Moorings, surface-piercing and wire-following profilers, Benthic nodes
optical attenuation and absorption		Moorings, surface-piercing profilers, Benthic nodes
Chl-a and CDOM fluorescence, optical backscatter		Moorings, surface-piercing and wire-following profilers, Gliders Surface-piercing and wire-following profilers, Gliders, AUVs
photosynthetically active radiation (PAR)		Surface-piercing and wire-following profilers, Gliders, AUVs
spectral irradiance		Moorings, surface-piercing profilers
nitrate		Moorings, surface-piercing profilers
nutrients (NO2,NO3,PO4,SiO4)		AUVs
zooplankton/fish sonar		Benthic nodes, Global winched profilers
digital still camera		Benthic nodes
hydrophone, passive		Benthic nodes

*Acoustic Doppler Current Profiler

The core sensors are commercial-off-the-shelf (COTS) products to the extent practicable. Exceptions are cases where the Science User Requirements and traceability matrices dictate specific observations, such as CO2 flux, direct covariance momentum flux, and or horizontal electric field-pressure-inverted echo sounder measurements, for which suitable COTS instruments may not presently exist. To ensure a robust sensor suite meeting the requirements, the core sensors were assessed relative to Technology Readiness Level (TRL). TRL is a measure used by several U.S. and international agencies to assess the maturity of evolving technologies prior to incorporating them into an operational system or application. The Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA) have adopted nearly identical nine-stage TRL descriptions that provided the starting point for assessment of OOI core sensors (23).

The OOI assessment was based on the DoD TRLs as interpreted for oceanographic sensors at the Ocean Sensors 08 workshop (http://www.io-warnemuende.de/conferences/oceans08/index.php). Working with the Alliance for Coastal Technology (ACT), the OOI Project Scientist and Sensors working group further refined the Ocean Sensors 08 definitions to produce a five-stage TRL definition applicable to the OOI. These definitions were then used to assess the OOI core sensors, showing 90% of the sensor types at a high level of readiness, 10% at intermediate levels, and none at a low level. Risks associated with sensor types with intermediate TRL have been registered as a part of the OOI Risk Management Plan and will be evaluated and, if necessary, tracked as part of the risk management process. To engage manufacturers and developers in ensuring the most robust sensor suite for OOI, the OOI team is working with ACT on a series of OOI vendor workshops to continue the process of assessment of sensor requirements and readiness levels.

Some sensors may not provide high-quality data during the full duration of unattended deployment due to calibration drift, biofouling, or other factors. Sensor maintenance issues were captured in four Sensor Maintenance Classes, and CGSN sensors were categorized within these classes. This evaluation will be used to guide and optimize the operation and maintenance strategy for CGSN. 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 directed 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. surface-piercing profilers, gliders, AUVs) will be serviceable in situ using ships of opportunity allowing re-establishment of measurement quality with minimal operations and maintenance (O&M) impact, and 5) all sensors will be post-calibrated upon recovery.

4.3.1.14 CGSN / CI Interface

The CGSN/CI interface requirements will maintain the proven reliability and survivability features of Woods Hole Oceanographic Institution’s (WHOI) current mooring control system and operations design, while incorporating the transformative elements represented by the use of mooring-resident and shore-station-resident CI CyberPoP software. The interface design is a layered architecture approach, assuming gradual implementation of CI services and increasing automation over a 5-year period. The CGSN team will be continually testing and incorporating automated CyberPoP instrument control and data delivery services as they are made available by CI. The CGSN infrastructure software provides status and control functionality of CGSN resources to the CyberPoP software. Further, this design incorporates Human-in-the-Loop (HIL) support for use during instrument driver development, during periods when software needs to be updated to reflect vendor-supplied firmware updates, and for some mission-critical platform operations.

The CGSN shore station software (CSSW) accepts OOI service requests for CGSN resources (with the exception of the cabled resources on the Endurance Array). CGSN resource destinations include CGSN Buoy Platform Controller and Telemetry 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 request directly to the destination platform/instrument for execution by buoy-resident Platform Controller/CyberPop software or hands the service request off to shore station-resident software.

The CGSN-provided operations management software (OMS), resident on the Shore Station, processes OOI service requests. CyberPoP software receives status from the CSSW OMS and informs the OOI infrastructure about actions performed on observatory resources and the state of these resources. The CGSN buoy software (CBSW), resident on the Buoy Platform Controller and Telemetry System, accepts OOI service requests over the telemetry connections to the buoy and delivers them to the buoy-resident CyberPoP software installed on the Data Concentrator/Loggers (DCL). These requests may be in the form of mission files, interactive/batch commands, or vendor supplied software. Diagnostics capabilities include the ability of the CGSN operator to initiate communications to the platforms, and with the CI software interface provide a mechanism for direct serial connections to resources and the ability to run vendor specific software packages to instruments..

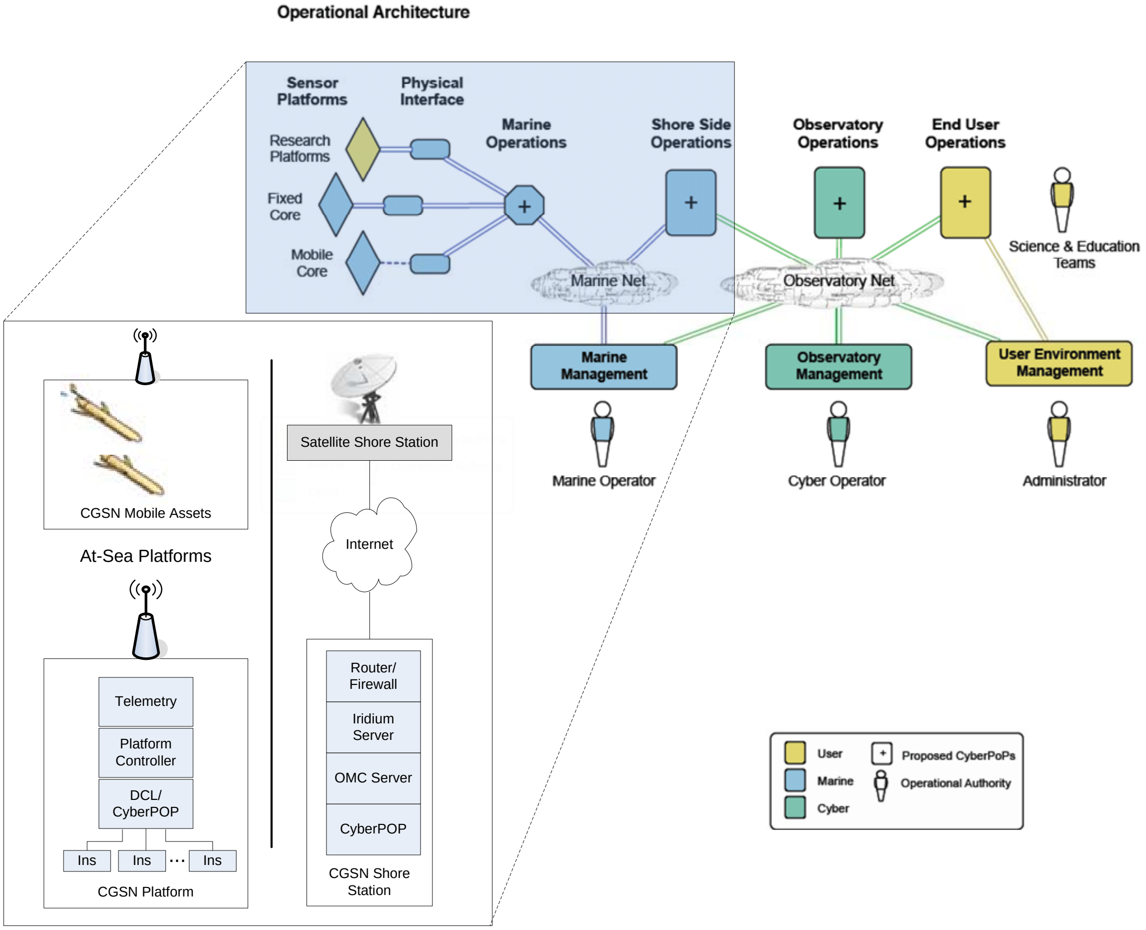

Figure 4.3-15. CGSN logical flow diagram.

The CyberPoP software that is installed on the Data Concentrator/Loggers (DCL) contains the instrument agents that configures the instrument and provides data logging, and real-time data-delivery. A platform agent is the CI interface to the platform controller.

4.3.2 Global Scale Nodes

The Global Scale Nodes consists of four Global Arrays based on a common design that combines surface moorings, subsurface moorings and gliders to achieve a unique space-time sampling capability for air-sea interaction and bio-physical processes on the ocean mesoscale (Fig. 4.3-16).

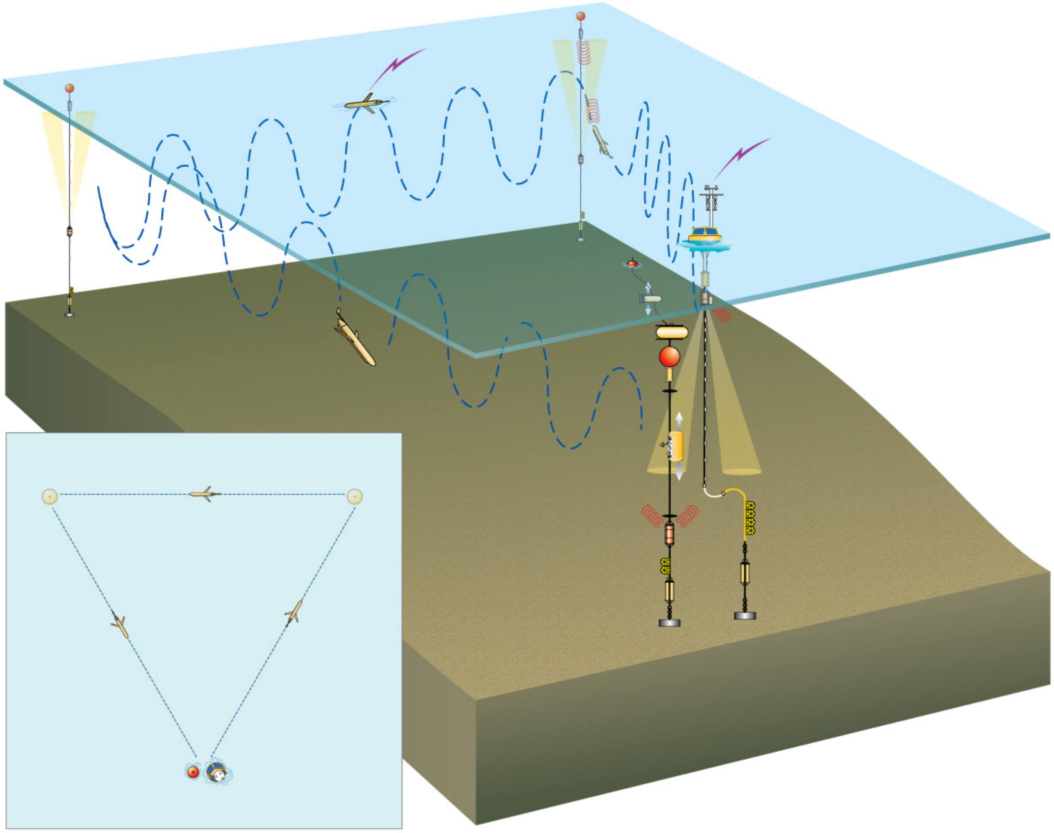

Figure 4.3-16. Schematic of Global Array design, including (foreground) a paired surface mooring and hybrid profiler mooring, (background) two taut subsurface, flanking moorings, and (dashed lines) three gliders. The moorings define a triangular region 50 km on a side (inset); gliders patrol along the axis of the triangle.

4.3.2.1 Global Array Descriptions

Three of the four Global Arrays (Southern Ocean, Irminger Sea, and Argentine Basin) will have all platforms provided by the CGSN. The forth array at Ocean Station Papa will be occupied in collaboration with the National Oceanic and Atmospheric Administration (NOAA). NOAA maintains a surface mooring there, and CGSN will deploy the hybrid profiler mooring adjacent to it, the two flanking subsurface moorings to complete a triangular array, and three gliders. The Global Arrays are described in more detail below.

Southern Ocean, SW of Chile

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

Mooring Types: Acoustically Linked Surface Mooring with Subsurface Hybrid 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-following profiler operating and one surface-piercing 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
- Three 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 Types: Acoustically Linked Surface Mooring with Subsurface Hybrid Profiler Mooring and Mesoscale Flanking Mooring Pair

Description of Infrastructure:

- One acoustically-linked Global Surface Mooring, with standard power (wind and solar) buoy and Iridium satellite telemetry
- One Global Hybrid Profiler mooring with one wire-following profiler and one surface-piercing 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 1000 m of the Surface Mooring
- Three gliders with extended endurance and acoustic communications to the Mesoscale Flanking Moorings

Argentine Basin

Location: 42°S, 42°W; Water Depth: 5200 meters

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

Description of Infrastructure:

- One acoustically-linked Global Surface Mooring, with standard power (wind and solar) buoy and Iridium satellite telemetry
- One Global Hybrid Profiler mooring with one wire-following profiler and one surface-piercing 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 1000 m of the Surface Mooring
- Three gliders with extended endurance and acoustic communications to the Mesoscale Flanking Moorings

Station Papa, North Pacific

Location: 50°N, 145°W; Water Depth: 4250 meters

Mooring Types: Subsurface Hybrid Profiler Mooring with Mesoscale Flanking Mooring Pair

Description of Infrastructure:

- One Global Hybrid Profiler mooring with one wire- following profiler and one surface-piercing profiler
- Two subsurface Mesoscale Flanking Moorings with fixed sensors and acoustic communications to gliders
- Three gliders with extended endurance and acoustic communications to the Mesoscale Flanking Moorings

4.3.2.2 Global Core Sensors

The proposed global surface and subsurface moorings will support the suite of core sensors listed in Table 4.3-4, 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 4.3-4. Global Arrays core sensor and platform summary.

Measurement	REDACTED	Platform	Comments
surface fluxes (bulk)		EM buoys: Southern Ocean, Irminger Sea, and Argentine Basin	Redundant systems will ensure complete data sets from remote locations
surface fluxes (direct covariance)		EM buoys	Direct measurement of momentum flux and sensible and latent heat fluxes
CO2 flux		EM buoys	Simultaneous measurement of air-side and water-side pCO2
pCO2 water		Surface-piercing profiler on Hybrid profiler moorings	200 m depth to surface
surface wave spectra		EM buoys	Motion sensors in buoy hull
temperature and conductivity		EM moorings	5 m below surface at EM termination
		EM moorings, Flanking Moorings	12 locations on mooring line between 30 m and 1500 m depth, inductive telemetry
		Surface-piercing profiler on Hybrid profiler moorings	200 m depth to surface
		Wire-following profiler on Hybrid profiler moorings	230 m depth to near bottom
		Gliders	Saw-tooth transects to 1000 m
high-precision pressure		Surface-piercing profiler on Hybrid profiler moorings	200 m depth to surface
		Wire-following profiler on Hybrid profiler moorings	230 m depth to near bottom

Measurement	REDACTED	Platform	Comments
		Gliders	Saw-tooth transects to 1000 m
mean currents		EM moorings	5 m below surface at EM termination
		EM moorings	Near surface to 600 m (downlooking)
		Flanking moorings	600 m to near surface (uplooking)
turbulent velocities		Surface-piercing profiler on Hybrid profiler moorings	200 m depth to surface
		Wire-following profiler on Hybrid profiler moorings	230 m depth to near bottom
dissolved oxygen		Flanking moorings	30 m depth at top of flotation sphere
		Surface-piercing profiler on Hybrid profiler moorings	200 m depth to surface
		Wire-following profiler on Hybrid profiler moorings	230 m depth to near bottom
		Gliders	Saw-tooth transects to 1000 m
pH		Flanking moorings	30 m depth at top of flotation sphere
		Surface moorings	20 m depth and 100 m depth below surface
optical attenuation and absorption		Surface-piercing profiler on Hybrid profiler moorings	200 m depth to surface
Chl-a fluorescence, optical backscatter		Flanking moorings	30 m depth at top of flotation sphere
		Surface mooring	15 m depth below surface
		Surface-piercing profiler on Hybrid profiler moorings	200 m depth to surface
		Wire-following profiler on Hybrid profiler moorings	230 m depth to near bottom
		Gliders	saw-tooth transects to 1000 m
spectral irradiance		Surface-piercing profiler on Hybrid profiler moorings	200 m depth to surface
nitrate		Surface-piercing profiler on Hybrid profiler moorings	200 m depth to surface
zooplankton/fish sonar		Surface mooring	15 m depth below surface

4.3.2.3 Technical Approach

The basic elements of the global array are the Global surface mooring, hybrid profiler mooring, Global flanking mooring, and Global glider (Figure 4.3-17). Each of these array elements is described in detail below.

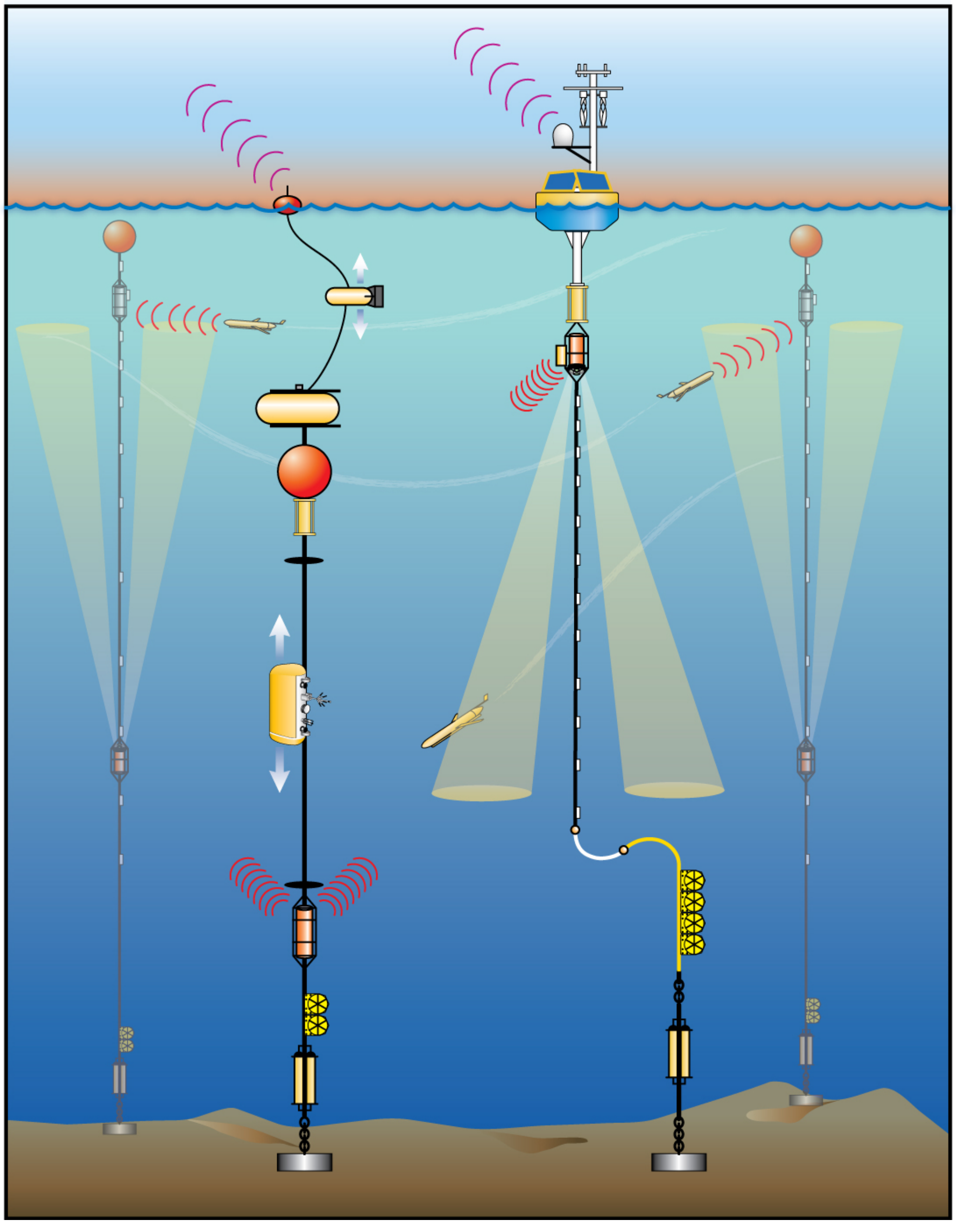

Figure 4.3-17. Schematic of a Global Array showing (foreground) the surface mooring, and hybrid profiler mooring along with (background) the two flanking moorings.

4.3.2.3.1 Global Surface Mooring

The global surface mooring (Figure 4.3-18) will support sensors at the air-sea interface, on the instrument frame at the end of the chain termination, and fixed instruments distributed along the mooring cable down to 1500 meters, as described in the global core sensor summary (Table 4.3-4).

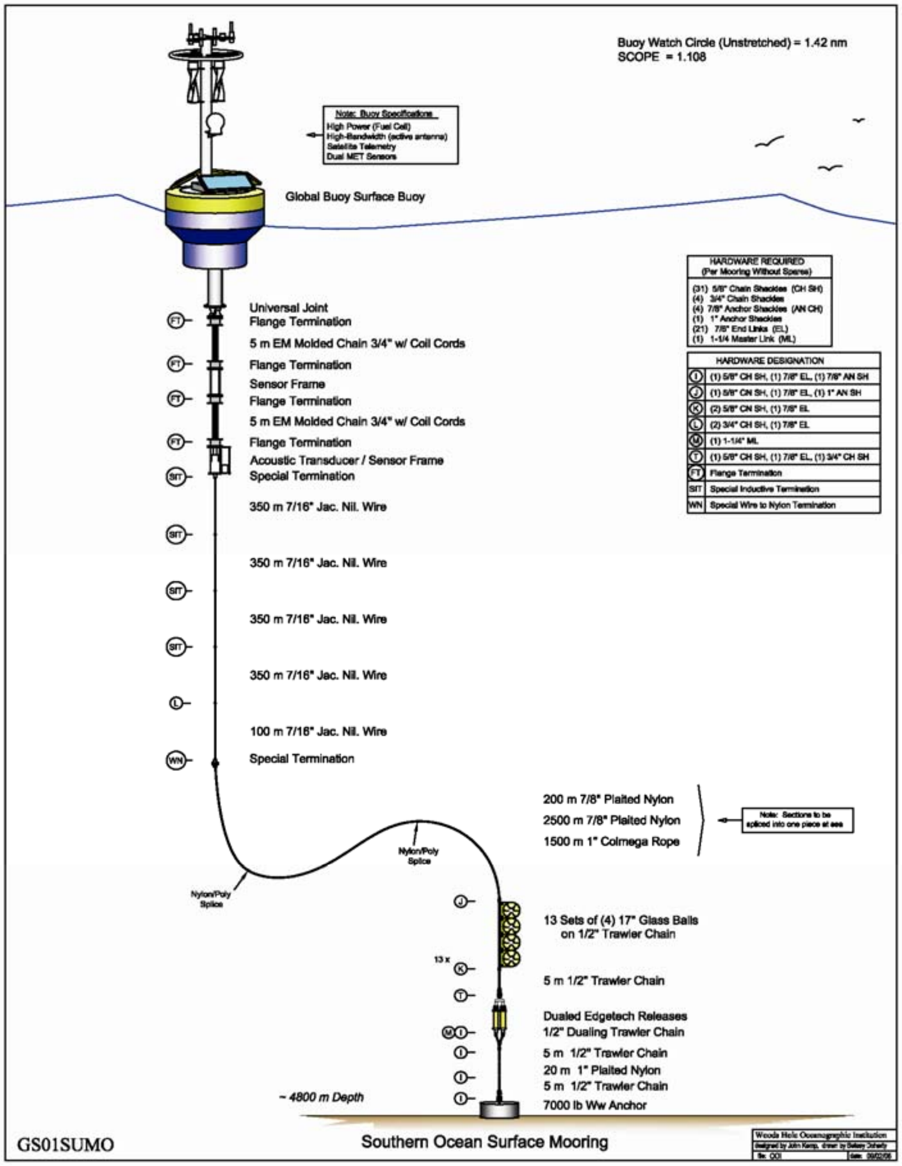

Figure 4.3-18. Global Surface Mooring.

<u>Surface Buoy</u>. The global surface buoy will use a modular buoy design with a tall, low-drag tower and deep keel (Figure 4.3-3). 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 4000 kg when loaded with batteries, and a net buoyancy of 6000 kg minimum. Unlike typical surface buoy designs that are "bi-stable," or capable of floating upside-down, this buoy will be designed to self-right. This will be achieved by the placement of heavy batteries low in the buoy's extended keel. The surface buoy will provide sufficient room for electronics and, when so equipped, the fuel cell power system, in the main well housing. In buoys equipped with fuel cell systems, the methanol fuel mixture will be stored in bladders housed in flooded compartments below the buoy hull.

Mooring. The global surface moorings will be a low-scope, inverse catenary style mooring consisting of (Figure 4.3-18, 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 1000 m of wire rope, a plaited 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 4,000 lb air weight, in order to be readily handled by UNOLS vessels.

An alternate hybrid mooring design was considered for the Southern Ocean Array, which is expected to have the most severe environmental conditions of the Global Arrays. 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 location. 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); this design has been chosen for all the global surface moorings. Climatological surface wave, surface wind, and ocean current information has been obtained for each Global Array location. Typical conditions, as well as extreme conditions derived from the climatological data were used to optimize static and dynamic performance of the mooring designs.

Power System. Two configurations of the mooring power generation and storage system will be used on the Global 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 Irminger Sea and Argentine Basin global surface moorings will have installed a standard-power system. The standard-power system will take inputs from Photo-Voltaic (PV) panels and wind turbines and in conjunction with the secondary battery system will supply a minimum of 50 W continuous power. The Southern Ocean buoy will incorporate the high-power version with two fuel cell modules; capable of generating up to 250 W each from a stored methanol-water mixture which will supply continuous power of 250 W minimum. Both systems will be capable of supplying intermittent peak power of 500 W when needed.

Platform Control, Data Logging, and Telemetry. The global surfaces moorings will include the redundant platform controller with the two independent single board computers that host the CI CyberPoP software. There will be two DCL on the mooring, one located within the surface buoy and the second located 15 meters below the surface on the instrument frame at the mooring chain termination. Global surface mooring telemetry will also be redundant with two low speed satellite links and multiple local RF links. The global surface mooring at the Southern Ocean Array will include the high speed Inmarsat satellite link. Global surface moorings will include subsurface acoustic communications and inductive communication. Acoustic modems are located 15 meters below the surface buoy and will use directional transducers with 60° beams. Inductive modems will be used to communicate with sensors located on surface moorings in the upper 30-1500 m. These modems use the mooring cable as the communication link to provide 1200 bit per second communications with sensors.

4.3.2.3.2 Global Hybrid Profiler Mooring

The Global hybrid profiler mooring (Figure 4.3-19) will support sensors in the deep wire-following profiler and in the profiling body of the shallow surface-piercing profiler, as described in the global core sensor summary (Table 4.3-4).

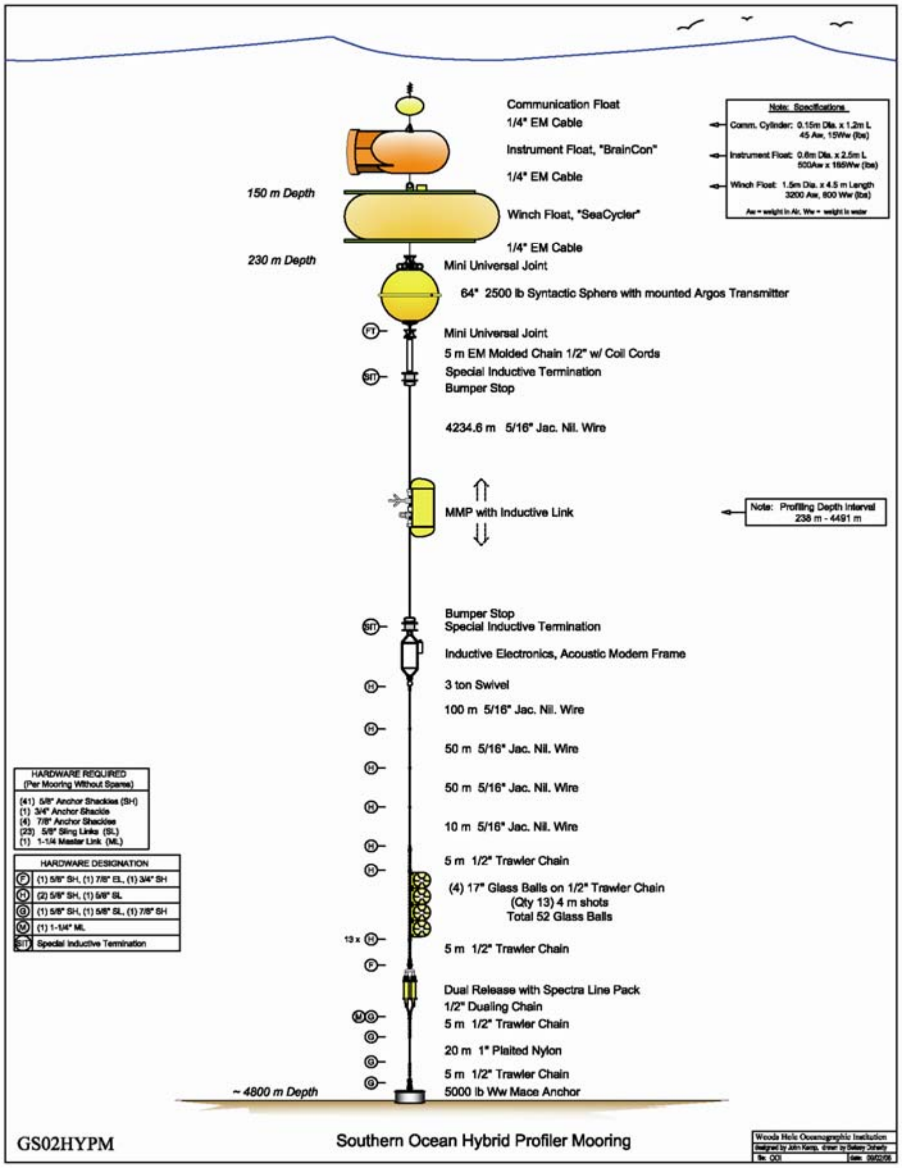

Figure 4.3-19. Global hybrid profiler mooring.

Mooring. The subsurface mooring is, at its core, a conventional design with a subsurface buoy at approximately 250 m depth (Figure 4.3-19). 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-following 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 surface-piercing 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.

Profilers. The FND calls for upper-ocean and deep-ocean profiling capability at each Global Array. This will be implemented with two distinctly different technologies. Deep-ocean wire-following 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. [redacted]

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 150 m or so. This can best be implemented with underwater winch systems.

A commercial, off the shelf upper-ocean profiler that can satisfy the scientific requirements has not been identified. The requirements 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 150 m to surface during an autonomous (battery-powered) 1-year deployment; and (4) ability to survive knockdown to 1000 m due to drag on the subsurface mooring in strong currents. The current plan is to use a profiler system, which is being developed to meet these goals based upon the SeaCycler winch. This is a consortium project, funded by NSF and the European Commission, with participants from the Bedford Institute of Oceanography and ODIM Brooke Ocean (Halifax), SIO (San Diego), MARUM (Bremen), IFM-Geomar (Kiel), National Oceanography Centre (Southampton). Once ready for production, ODIM Brooke Ocean will sell it commercially. While this is the system currently planned and budgeted, as new options become available they will be reviewed and considered.

4.3.2.3.3 Global Flanking Mooring

The flanking moorings are taut subsurface moorings with a syntactic or steel sphere at the top, an acoustic modem, and fixed instruments along the wire (Fig. 4.3-20). The instruments will have inductive modems, and glider will be used as data shuttles to provide access to the data from the flanking moorings as well as some capability to interact with these instruments.

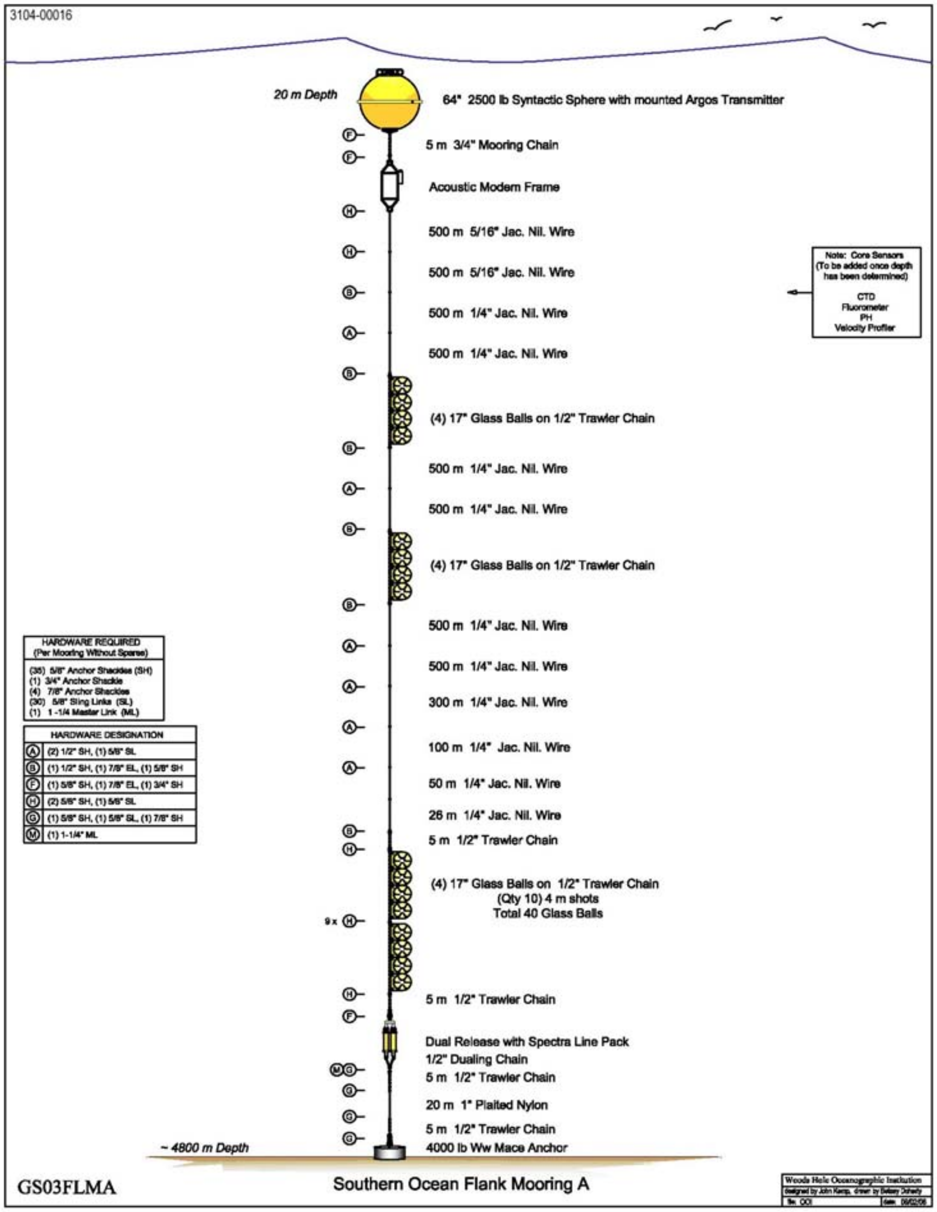

Figure 4.3-20. Global flanking mooring fixed instruments.

The flanking mooring is a taut subsurface mooring with a syntactic or steel sphere, acoustic transducer/instrument frame, approximately 4000 m of wire rope, glass spheres mounted to mooring chain for backup recovery, dual acoustic releases, and a deadweight anchor.

The flanking moorings will have no platform controller, instead each instrument mounted on the mooring will be responsible for its own data logging and telemetry and each sensor will be self-powered with primary batteries. Inductive modems will be used to communicate between the sensors located on the moorings in the upper 30-1500 m. These modems use the mooring cable as the communication link to provide 1200 bit per second communications with sensors. All of the core instruments located on the flanking mooring will be purchased with inductive modems from the manufacturer. Data compression or sub-sampling will be the responsibility of the sensor. The acoustic modems are located 10 meters below the subsurface buoy and will use directional transducers with 60° beams. The acoustic modems will be used to relay data from Global flanking moorings to Global gliders for telemetry through the glider Iridium satellite link.

4.3.2.3.4 Global Gliders

In order to provide a spatial (horizontal) footprint of the Global nodes, the global design calls for deployment of 3 gliders at each Global Array. The Global gliders will include instruments to measure salinity, temperature, depth, dissolved oxygen, fluorescence, chlorophyll-a, and optical backscatter.

The gliders will be used in conjunction with the central and the flanking mesoscale moorings at each global location. The gliders communicate acoustically with moorings when they come within 5 km of them and this would be used routinely with the gliders operating within/between the triangle of moorings.

4.3.2.4 Installation and Servicing

The Southern Ocean mooring group will be deployed at Station W off the New England coast in 2011-2012 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 Arrays, 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 Array will be coordinated with European partners and their plans for observations off southeast Greenland through the OceanSites program. In addition, the occupation of Ocean Station Papa will be based on cooperation with NOAA and with Canadian interests in ongoing sampling at and around the site.

Planning for and occupation of the Argentine Basin Array will be coordinated with international research programs such as Climate Variability and Predictability (CLIVAR), the international ocean time series scientific steering group (OceanSITES), and colleagues in Argentina, including at the University of Buenos Aires and the Hydrographic Service of the Argentine Navy. Shiptime requests will be made through UNOLS (University-National Oceanographic Laboratory System). In addition, the timing of the mooring servicing will be made know to international ship operators through POGO (Partnership for the Observation of the Global Ocean) and other ship resource sharing groups.

The CGSN IO has submitted long lead time ship time requests to alert UNOLS of the need to plan for the ship time required to visit these remote sites.

4.3.3 Coastal Scale Nodes

The Coastal Scale Nodes consists of two coastal arrays based on a common design that combines surface moorings, subsurface moorings and mobile assets to provide near real time data from the air-sea interface, through the water column and to the seafloor.

4.3.3.1 Pioneer Array Description

The heart of the Pioneer Array is a moored array that is aligned perpendicular to isobaths and spans the shelf break (Fig. 4.3-21). In order to provide synoptic, multi-scale observations of the outer shelf, shelf break frontal region, and slope sea, the moored array is supplemented by nine mobile platforms – six gliders and three AUVs.

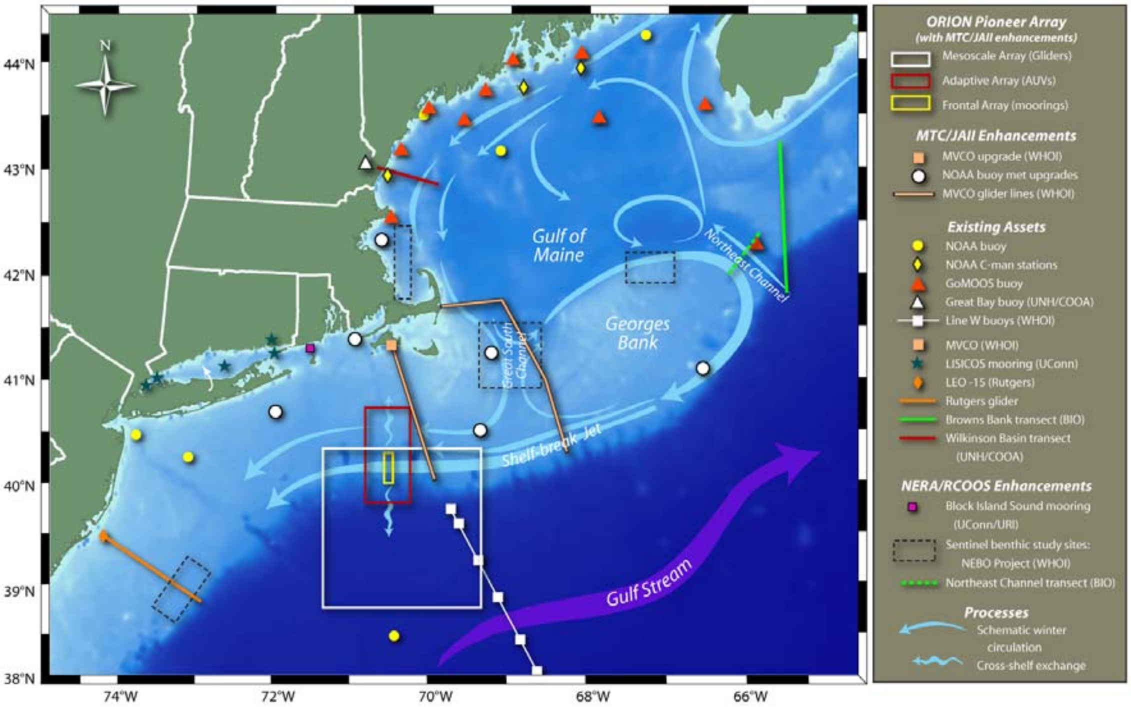

Figure 4.3-21. Pioneer Array plan view. Plan view schematic map of the multi-scale Pioneer Array in the context of other regional observing elements. A moored array will be centered at the shelf break front and jet south of Cape Cod, MA. AUVs will sample the frontal region in the vicinity of the moored array and gliders will resolve mesoscale features on the outer shelf and the slope sea between the shelf break front and the Gulf Stream.

Location, Central Mooring: 40° 03'N, 70°45'W; Water Depth: 150 meters

Cross-shelf mooring line extent: +/- 20 km from central mooring

Upstream moorings: 15 km from cross-shelf line

AUV sampling area (approximate): 80 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-following moored profilers, 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 wire-following profilers
- Two coastal surface-piercing profilers

- Two AUV docking stations
- Three AUVs
- Six gliders

The configuration Pioneer Array elements are shown schematically in Figure 4.3-22.

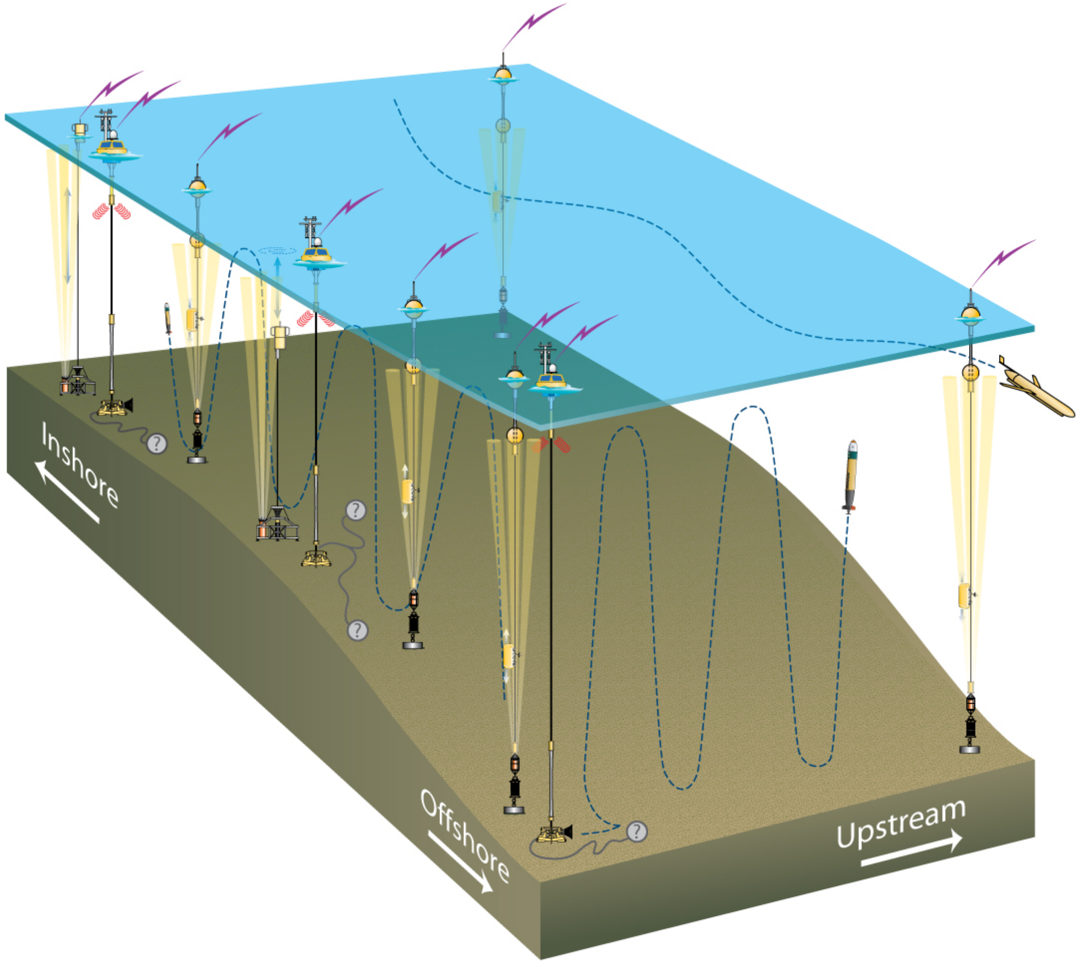

Figure 4.3-22. Schematic diagram of the Pioneer Array, showing EOM surface moorings, AUV docks (base of inshore and offshore EOM moorings), Multi-Function Node (MFN) (base of central EOM mooring), surface-piercing profilers (inshore and central sites), wire-following profilers, and (schematic) AUV and glider transects in the vicinity of the moored array. MFNs will support expansion by addition of science-user instrumentation, depicted by the symbol "(?)".

The inshore and central sites contain EOM surface moorings paired with surface-piercing profilers, while the offshore site contains an EOM surface mooring and wire-following profiler. The intermediate and upstream sites contain only wire-following profilers. All sites incorporate vertically profiling ADCPs (i.e., acoustic Doppler current profilers) to provide water column velocities to complement the scalar parameters observed by the profilers. 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 temperature-salinity (T/S) front location, and will also capture the typical meanders of the jet. The two "intermediate" wire-following profiler moorings (designated central inshore and central offshore, see Table 4.3-5) ensure that the horizontal section provided by the moored array samples the frontal system coherently. The upstream moorings provide along-shelf gradients to aid in determination of advective fluxes.

The approximate geographic locations for the Pioneer Array platforms are given in Table 4.3-5 below.

Table 4.3-5. Platforms, platform locations, and depths for the Pioneer Array.

Platform	Site	Location	Depth	Comments
EOM mooring, AUV dock, surface-piercing profiler with ADCP	inshore	40^o 14’ N 70^o 45’ W	110 m	Typical inshore extent of shelf break front and jet
Wire-following profiler with ADCP	central inshore	40^o 08’ N 70^o 45’ W	130 m	10 km horizontal separation, resolves frontal correlation scale
EOM mooring, MFN, surface-piercing profiler with ADCP	central	40^o 03’ N 70^o 45’ W	150 m	At climatological shelf break front, MFN for science user instruments
Wire-following profiler with ADCP	central offshore	39^o 57’ N 70^o 45’ W	300 m	10 km horizontal separation, resolves frontal correlation scale
EOM mooring, AUV dock, wire-following profiler with ADCP	offshore	39^o 52’ N 70^o 45’ W	500 m	Typical offshore extent of shelf break front and jet
Wire-following profiler with ADCP	upstream inshore	40^o 14’ N 70^o 38’ W	110 m	15 km horizontal separation, resolves along-stream correlation scale
Wire-following profiler with ADCP	upstream offshore	39^o 52’ N 70^o 38’ W	500 m	15 km horizontal separation, resolves along-stream correlation scale
AUVs	shelfbreak region	various	various	~80 km transects along and across shelf, centered on shelf break
gliders	outer shelf & slope sea	various	various	~150 km transects from outer shelf to slope sea

4.3.3.2 Pioneer Array Core Sensors and Platforms

The Pioneer Array core sensors and their locations are listed in Table 4.3-6. 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 National Data Buoy Center (NDBC) buoys (Figure 4.3-21), upgraded with a full meteorological sensor suite using funds external to the OOI, will provide regional scale meteorology.

Table 4.3-6. Pioneer Array core sensor and platform summary.

Measurement	REDACTED	Platform	Comments
surface fluxes (bulk)		EOM buoys	Nearby NDBC buoys will supplement Pioneer Array meteorology
surface fluxes (direct covariance)		EOM buoys	Direct measurement of momentum and buoyancy fluxes
CO2 flux		Central EOM buoy	Simultaneous measurement of air-side and water-side pCO2
pCO2 water		Surface-piercing profiler	2 m above bottom to surface
		EOM moorings	2 m above bottom on MFN
surface wave spectra		Central EOM buoy	Motion sensors in buoy hull
temperature and conductivity		EOM moorings	5 m below surface at EOM termination, 2 m above bottom on MFN
		Surface-piercing profilers	2 m above bottom to surface
		Wire-following profilers	Near bottom to 15 m below surface
		Gliders	Saw-tooth transects to 1000 m
		AUVs	Saw-tooth transects to 500 m
high-precision pressure		EOM moorings	2 m above bottom on MFN
		Surface-piercing profilers	2 m above bottom to surface
		Wire-following profilers	Near bottom to 15 m below surface
		Gliders	Saw-tooth transects to 1000 m
		AUVs	Saw-tooth transects to 500 m
mean currents		EOM moorings	5 m below surface at EOM termination, 2 m above bottom on MFN
		Surface-piercing profiler base	Near bottom to near surface
		Wire-following profiler base	Near bottom to near surface
		Gliders	Saw-tooth transects to 1000 m
		AUVs	Saw-tooth transects to 500 m
turbulent velocities		Surface-piercing profilers	2 m above bottom to surface
		Wire-following profilers	Near bottom to 15 m below surface
dissolved oxygen		EOM moorings	5 m below surface at EOM termination, 2 m above bottom on MFN
		Surface-piercing profilers	2 m above bottom to surface
		Wire-following profilers	Near bottom to 15 m below surface
		Gliders	Saw-tooth transects to 1000 m
		AUVs	Saw-tooth transects to 500 m
pH		EOM moorings	5 m below surface at EOM termination
		Inshore EOM mooring	2 m above bottom on MFN
optical attenuation and absorption		EOM moorings	5 m below surface at EOM termination, 2m above bottom on MFN
		Surface-piercing profilers	2 m above bottom to surface
Chl-a and CDOM fluorescence, optical backscatter		Surface-piercing profilers	2 m above bottom to surface

Measurement	REDACTED	Platform	Comments
		Surface moorings	7 m depth below surface
		Wire-following profilers	Near bottom to 15 m below surface
		Gliders	Saw-tooth transects to 1000 m
		AUVs	Saw-tooth transects to 500 m
photosynthetically active radiation (PAR)		Surface-piercing profilers	2 m above bottom to surface
		Wire-following profilers	Near bottom to 15 m below surface
		Gliders	Saw-tooth transects to 1000 m
		AUVs	Saw-tooth transects to 500 m
spectral irradiance		EOM moorings	5 m below surface at EOM termination
		Surface-piercing profilers	2 m above bottom to surface
nitrate		EOM moorings	5 m below surface at EOM termination
		Surface-piercing profilers	2 m above bottom to surface
nutrients (NO2,NO3,PO4,SiO4)		AUVs	Saw-tooth transects to 500 m
phytoplankton-zooplankton sonar		EOM moorings	Vertical profiler, uplooking from MFN

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-diurnal 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 the near-surface and near-bottom parts of the water column inaccessible to ADCPs and wire-following 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.

4.3.3.3 Pioneer Array Technical Approach

The backbone of the Pioneer Array will be a frontal-scale moored array with three electro-mechanical (EOM) surface moorings, two coastal surface-piercing profilers and five coastal wire-following profiler moorings (Fig. 4.3-22). Each EOM mooring will incorporate a surface buoy with power generation (wind, photovoltaic) and multiple communications systems. 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 surface-piercing profilers will provide a buoyant sensor body capable of profiling from a few meters above the bottom through the air-sea interface. The coastal moored profilers will be wire-following type profiling packages with a multi-disciplinary sensor suite, and will have surface expressions for data telemetry. The four Pioneer Array mooring types are shown schematically in Figure 4.3-23.

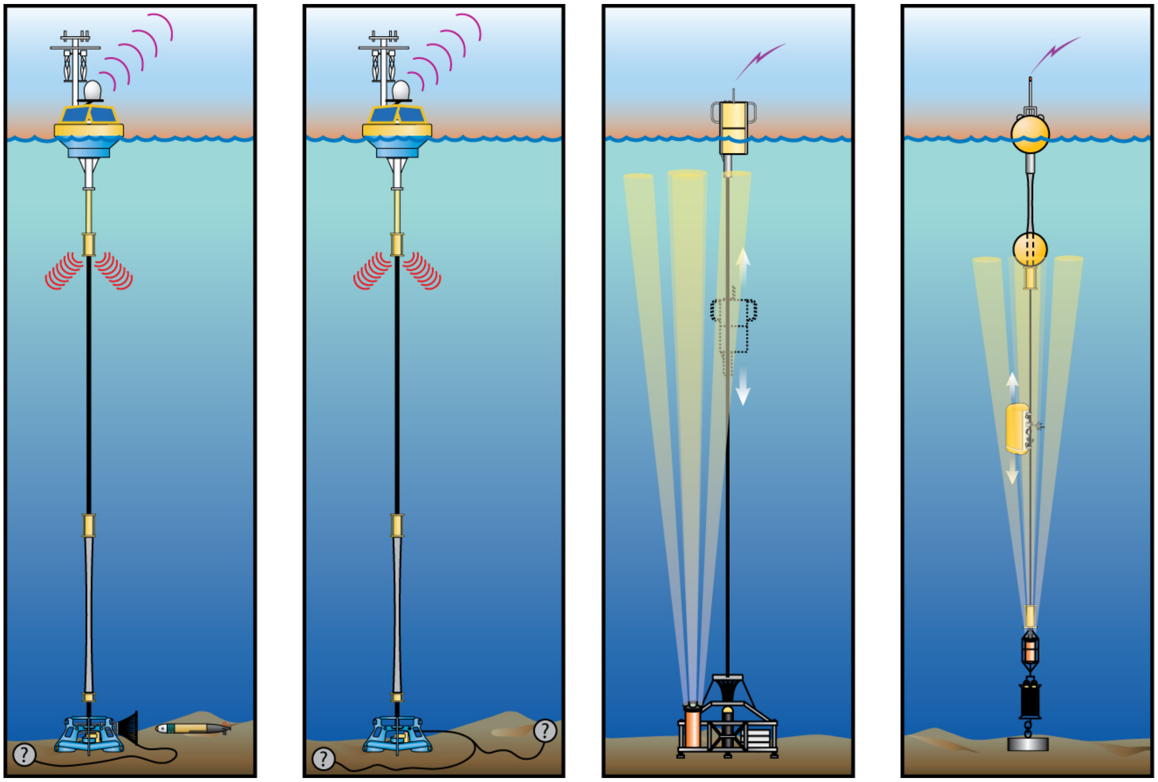

Figure 4.3-23. Schematic diagrams of Pioneer Array moorings (not to scale). EOM moorings with Multi-Function Nodes (MFNs) supporting AUV docks (first panel) will be at the inshore and offshore sites. An EOM mooring with MFN supporting science user instrumentation (second panel) will be at the central site. Surface-piercing winched profilers with ADCPs at their base (third panel) will be at the inshore and central sites. Moored wire-following profilers with ADCPs (right) will be at the intermediate sites along the inshore/offshore line, and at the upstream corners. Pioneer Core Sensors (Table 4.3-6) 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.

4.3.3.3.1 Pioneer EOM Surface Mooring

The Pioneer EOM mooring (Figure 4.3-24) will support sensors at the air-sea interface, on the instrument frame at the upper EOM termination at 5 m depth, and on the MFN on the ocean bottom, as described in the Pioneer core sensor summary (Table 4.3-6).

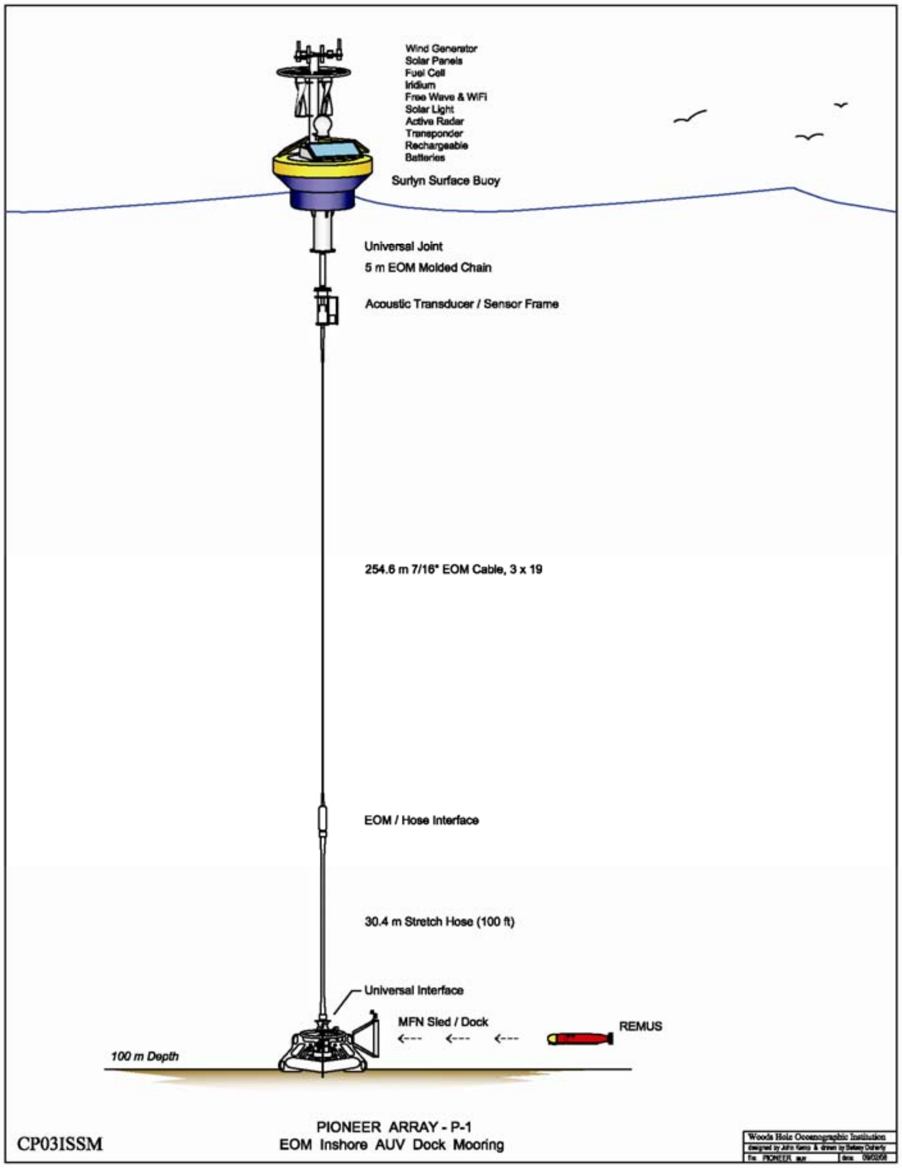

Figure 4.3-24. Pioneer Surface Mooring with multi-function node (MFN).

Pioneer Surface Buoy. The coastal surface buoy will use a modular buoy design with a tall, low-drag tower and deep keel (Figure 4.3-3). The surface buoy will be similar in construction Global buoy but with a smaller buoyancy module and lower, 3 m tower, allowing it to be deployed by regional-class UNOLS vessels. Mooring elements just below the buoy accommodate an acoustic modem transducer, sensor frame at 5 m depth, and electro-mechanical connections. The buoy will be approximately 6-7 m in overall height with a foam flotation section about 2.8 m in diameter. It will have an air weight not to exceed 3000 kg when loaded with batteries, and a net buoyancy of 5000 kg minimum.

EOM Mooring. The enabling technology for the Pioneer moorings (Figure 4.3-24), which distinguishes the design from the Global moorings, is the incorporation of a 30 m 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 hockle 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 and hose and EOM cable length. Coastal moorings are terminated at the seafloor by a Multi-Function Node (MFN) that provide data and power ports for benthic instrumentation. An ROV will not be required, reducing installation and O&M costs. As stated above, the Pioneer moorings will be designed for deployment and recovery by regional-class UNOLS vessels.

Power System. 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. It will include a methanol fuel cell supplementing wind and solar power generators as well as energy storage in Absorbed Glass Mat (AGM) lead acid batteries. The relative levels of energy storage for methanol fuel and batteries differ from the global power system due to the shorter maintenance cycle for the Pioneer Array. The power controller on the Coastal buoy will manage the distribution of power to the MFN reservoir after stepping up the voltage to reduce losses in the mooring conductors.

Platform Controller, Data Logging, and Telemetry. System control, subsurface acoustic communications, surface telemetry and data logging for the Pioneer Coastal moorings will be accomplished with the same dual-controller system used on the Global buoys. All Pioneer surface moorings will include high speed satellite telemetry. There will be 4 DCL on each mooring, one mounted within the surface mooring, one located at the instrument frame located at the upper EOM termination, and two located in the MFN. The principal differences are that a higher data throughput (4 Mbyte/day) has been budgeted for each Coastal mooring and that line-of-sight 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. Pioneer surface moorings will not include inductive communication but will have acoustic modems located 5 meters below the surface buoy.

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 an ROV wet-mate connector. 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 Pioneer MFN has equivalent functionality as the surface mooring including the fully redundant platform controller and two DCL. The MFN platform controller will supervise power usage requests based on the total power available from the surface. If the power drawn by users exceeds power available the platform controller will scale back users based on a predetermined schedule to avoid system damage or an ungraceful shutdown.

4.3.3.3.2 Pioneer Surface-piercing Profilers

The Pioneer surface-piercing profiler mooring (Fig. 4.3-23, third panel) will support sensors in the profiling body and will have a frame mounted upward looking ADCP, as described in the Pioneer core sensor summary (Table 4.3-6). For the Pioneer Array application, the frame will include a primary battery bank and power controller to re-charge the profiling package. The ADCP will be self powered and will include an inductive link. 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.

4.3.3.3.3 Pioneer Wire-following Profiler Mooring

The Pioneer Wire-following Profiler Mooring (Fig. 4.3-25) will support sensors in the profiling body and will have a frame mounted, upward looking ADCP, as described in the Pioneer core sensor summary (Table 4.3-6). The Pioneer Wire-following Profiler Mooring 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 wire-following profiler will translate all but the upper 15 m of the water column and will be equipped with an ADCP situated near the bottom. Both will transmit data using 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.

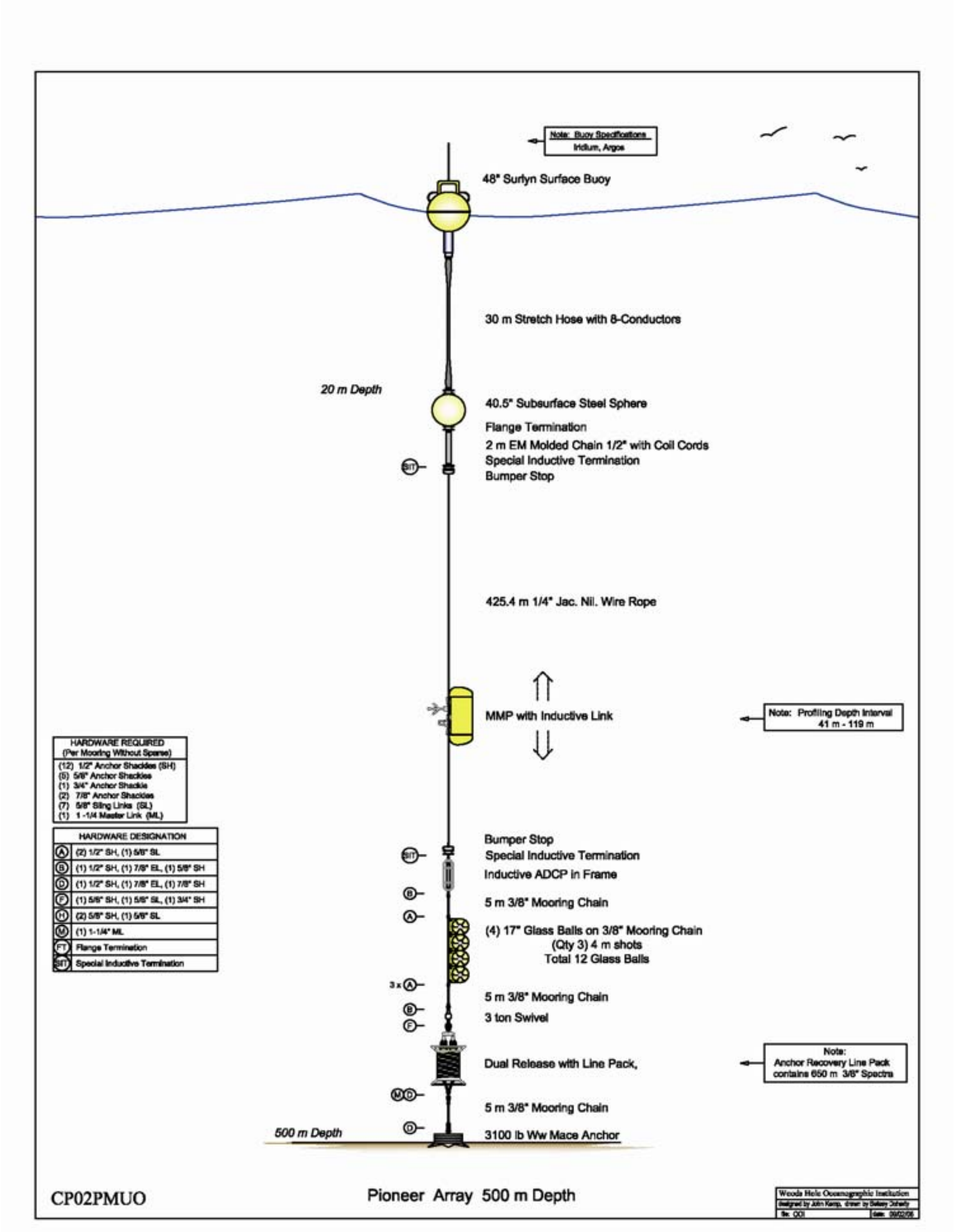

Figure 4.3-25. Pioneer Profiling Mooring.

The wire-following profiler mooring surface buoy will be a small (~1 m diameter) steel sphere containing a simple platform 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 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 candidate profiler is available from the factory with an integrated inductive modem and controller, while the ADCP will be purchased with an inductive modem, controller, and internal battery packs. The profiler is capable of approximately one million meters of travel, allowing six profiles per day for a year in 500 m water and the ADCP will be capable of at least one profile per hour for a year.

4.3.3.3.4 Pioneer AUV and AUV Dock

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 80 by 80 km centered on the moored array (see schematic example in Fig. 4.3-22 and plan view of the AUV “box” in Fig. 4.3-21). The nominal interval between missions will be seven 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 4.3-24). The AUV missions will be user-controllable via satellite link directly to the vehicle (while on the surface) or through the EOM mooring (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 AUVs will carry a multi-disciplinary sensor payload (Table 4.3-6), including bio-optical sensors with copper shutters for mitigation of biofouling.

4.3.3.3.5 Pioneer 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 will be simultaneously occupied within a 150 x 150 km “box” (Figure 4.3-21). The lines will be repeated at intervals of approximately 2 weeks and individual gliders will remain in the field for two months before being recovered for refurbishment. [redacted]

For use in the Pioneer Array, the gliders will carry a multi-disciplinary sensor payload (Table 4.3-6), including bio-optical sensors with copper shutters for mitigation of biofouling. The gliders will routinely dive to within several meters of the sea floor or 1000 m depth, whichever is greater.

4.3.3.4 Pioneer Array 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 4-day cruises on the Research Vessel (R/V) Oceanus for mooring deployment, testing and recovery and two 2-day trips on R/V Tioga for AUV and glider deployment, testing and recovery of. One 5-day R/V Oceanus cruise and one 2-day R/V Tioga cruise in year four 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 year four. 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, wire-following profiling moorings second, surface-piercing profilers, and then EOM surface moorings/MFNs and AUVs.

Once the full Pioneer Array is in place, servicing will include two mooring cruises per year on an intermediate-class vessel (the R/V Oceanus is assumed) and four 3-day cruises on a coastal vessel (RV Connecticut is assumed) per year. The Oceanus cruises would be for mooring service, glider recovery and redeployment, and AUV recovery, while the Connecticut cruises would be for AUV redeployment and, if needed, glider recovery and redeployment. Due to the desire to operate in hospitable weather, as well as the need to mitigate degradation of sensors due to biofouling, the mooring 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 Connecticut, 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 airscrew (propeller) driven style, is less well known and it is expected 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.

4.3.3.5 Endurance Array Description

The Endurance Array is a multi-scale array utilizing fixed and mobile assets to observe cross-shelf and along-shelf variability in the coastal upwelling region of the Oregon and Washington coasts, while at the same time providing an extended spatial footprint that encompasses a prototypical eastern boundary current regime and overlaps the RSN cabled infrastructure (Fig. 4.3-26). This integrated infrastructure bridges processes from the coastal zone (CGSN), through their transition into the ocean basin interior (RSN), and outward to the pelagic North Pacific (Station Papa). In order to provide synoptic, multi-scale observations of the eastern boundary current regime, two cross-shelf moored array lines, each with three instrumented sites, are supplemented by six gliders patrolling the coastal region. The Endurance Array is composed of two lines of moorings, the Oregon Line (also called the Newport Line) and the Washington Line (also known as the Grays Harbor Line). Figure 4.3-26 is a map of the Endurance Array infrastructure and Table 4.3-7 lists the locations and depths of the sites.

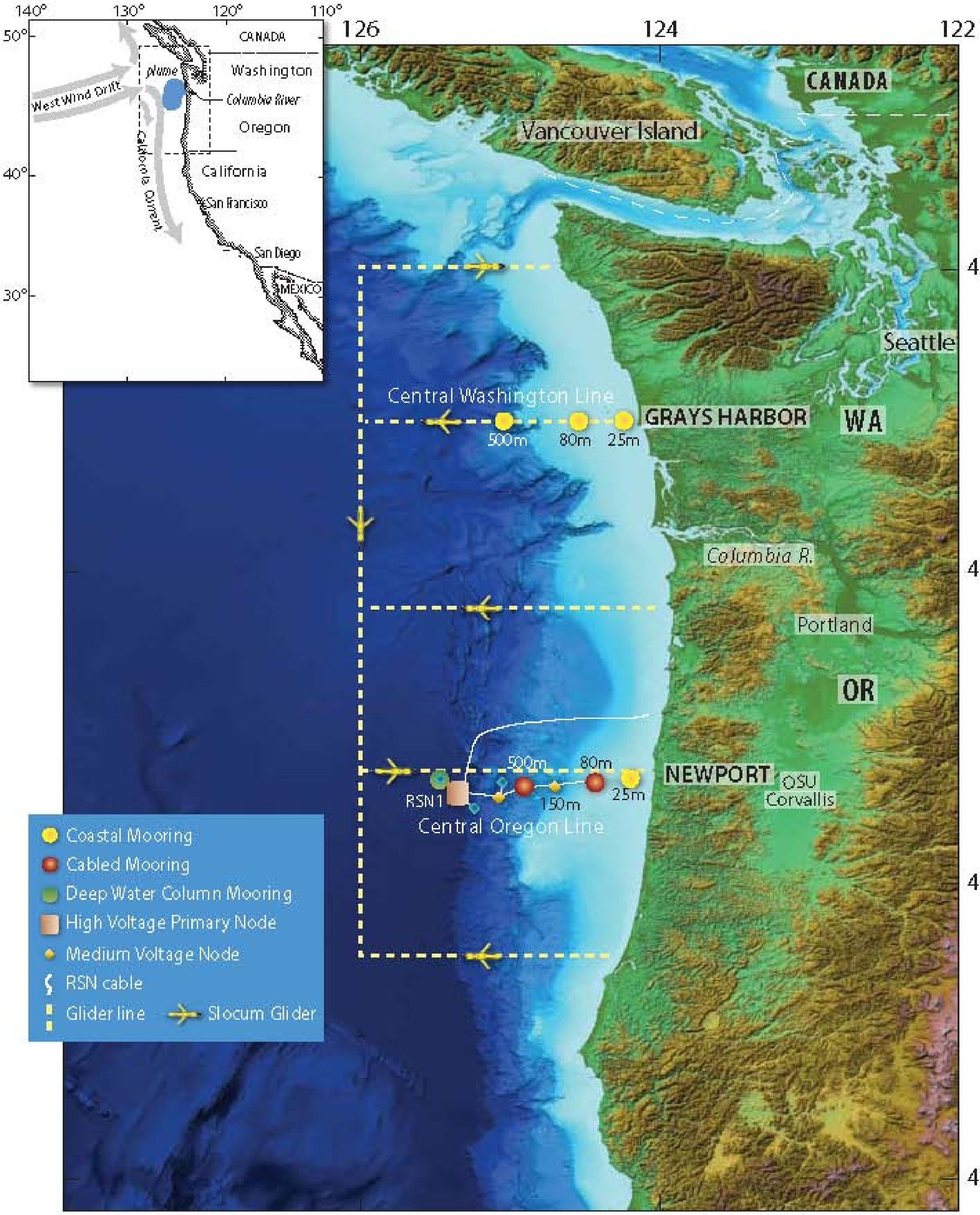

Figure 4.3-26. Plan view map of the Endurance Array, including the Oregon and Washington Lines. Also shown are the connection to the RSN cabled infrastructure (at the 80 m and 500 m sites) and regional coverage provided by multiple gliders.

Table 4.3-7. Platform locations and depths for the Endurance Array Oregon and Washington Lines.

Location description	Latitude °N	Longitude °W	Depth m	Comments
Oregon Offshore	44.65	124.90	500	Offshore site, cabled, shared infrastructure with RSN
Oregon Shelf	44.64	124.30	80	Mid-shelf site cabled, shared infrastructure with RSN
Oregon Inshore	44.65	124.10	25	Inshore site, uncabled
Washington Offshore	46.91	124.95	500	Offshore site, un-cabled
Washington Shelf	47.00	124.27	80	Mid-shelf site un-cabled
Washington Inshore	47.00	124.162	25	Inshore site, un-cabled

4.3.3.5.1 Endurance Array Oregon Line

Location: Moored array line: 44° 39’N, 126°W to coast; Water Depth: 500-25 meters.

Glider sampling area: 44° 30’ to 48° 00’N, 126°W to coast.

Platform Types: Three fixed platform sites at 25, 80, and 500 m water depth (two cabled and one un-cabled) supporting surface moorings, water column profilers and benthic boundary layer sensors, supplemented by six gliders.

Description of Infrastructure:

- Two EM surface moorings with wind and photovoltaic power generation, iridium communications, and meteorological sensors (80, 500 m)
- One EM surface mooring with battery power and iridium communications (25 m)
- Two bottom-mounted surface-piercing profiler moorings; one stand-alone (25m) and one cabled to RSN (80 m)
- One hybrid profiler mooring with deep profiler and shallow profiler cabled to RSN (500 m)
- One uncabled benthic multifunction node (MFN) with sensors, electrical communications to the surface, and supplementary battery power provided by the surface buoy (25 m)
- Two cabled benthic experiment packages (BEP) with fiber optic communications and power provided through primary nodes attached to the RSN (80 m, 500 m)
- Six gliders

4.3.3.5.2 Endurance Oregon Line Core Sensors and Platforms

The core science sensors for the Endurance Oregon Line are listed in Table 4.3-8. As with Global and Pioneer sensors, these come from the RSN/CGSN common Core Sensor List developed to satisfy the OOI Science User Requirements. 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). Upper ocean 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 hybrid and surface-piercing 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 and 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 phytoplankton blooms and hypoxic events. Glider sampling will overlap directly with the higher frequency fixed node observations along 46.65° N.

Table 4.3-8. Endurance Array Oregon Line core sensor and platform summary.

Measurement	REDACTED	Platform	Comments
surface fluxes (bulk)		EM buoys	Redundant systems will ensure complete data sets from remote locations
surface fluxes (direct covariance)		EM buoys	Direct measurement of momentum flux and sensible and latent heat fluxes
CO2 flux		EM buoys	Simultaneous measurement of air-side and water-side pCO2
pCO2 water		Surface-piercing profiler	2 m above bottom to surface
		Surface moorings	5 m depth below surface
		Benthic Nodes	2 m above bottom on BEP
surface wave spectra		EM buoys	Motion sensors in buoy hull
temperature and conductivity		EM moorings	5 m below surface at EM termination
		Surface-piercing profilers	2 m above bottom to surface
		Shallow profiler on hybrid profiler mooring	200 m depth to surface
		Deep profiler on Hybrid profiler mooring	230 m depth to near bottom
		Benthic Nodes	2 m above bottom on BEP
		Gliders	Saw-tooth transects to 1000 m
high-precision pressure		Surface-piercing profilers	2 m above bottom to surface
		Shallow profiler on hybrid profiler mooring	200 m depth to surface
		Deep profiler on Hybrid profiler mooring	230 m depth to near bottom
		Benthic Nodes	2 m above bottom on BEP
		Gliders	Saw-tooth transects to 1000 m
mean currents		EM moorings	5 m below surface at EM termination
		Surface-piercing profilers	2 m above bottom to surface
		Shallow profiler on hybrid profiler mooring	200 m depth to surface
		EM moorings	Near surface to 300 m (downlooking)

Measurement	REDACTED	Platform	Comments
		Benthic Nodes	300 m range, uplooking from BEP
		Gliders	Saw-tooth transects to 1000 m
turbulent velocities		EM buoys	Below buoy hull
		Deep profiler on Hybrid profiler moorings	230 m depth to near bottom
		Benthic Nodes	2 m above bottom on BEP
dissolved oxygen		EM moorings	5 m below surface at EM termination
		Surface-piercing profilers	2 m above bottom to surface
		Shallow profiler on hybrid profiler mooring	200 m depth to surface
		Deep profiler on Hybrid profiler mooring	230 m depth to near bottom
		Benthic Nodes	2 m above bottom on BEP
		Gliders	Saw-tooth transects to 1000 m
pH		EM moorings	5 m below surface at EM termination
		Subsurface platform on hybrid profiler mooring	200 m depth below surface
		Benthic Nodes	2 m above bottom on BEP, all sites
optical attenuation and absorption		EM moorings	5 m below surface at EM termination
		Surface-piercing profilers	2 m above bottom to surface
		Shallow profiler on hybrid profiler mooring	200 m depth to surface
		Benthic Nodes	2 m above bottom on BEP
Chl-a and CDOM fluorescence, optical backscatter		EM moorings	5 m below surface at EM termination
		Surface-piercing profilers	2 m above bottom to surface
		Shallow profiler on hybrid profiler mooring	200 m depth to surface
		Deep profiler on Hybrid profiler mooring	230 m depth to near bottom
		Gliders	Saw-tooth transects to 1000 m
photosynthetically active radiation (PAR)		Surface-piercing profilers	2 m above bottom to surface
		Shallow profiler on hybrid profiler mooring	200 m depth to surface
		Gliders	Saw-tooth transects to 1000 m
spectral irradiance		EM moorings	5 m below surface at EM termination
		Surface-piercing profilers	2 m above bottom to surface
		Shallow profiler on hybrid profiler mooring	200 m depth to surface
nitrate		EM moorings	5 m below surface at EM termination
		Surface-piercing profilers	2 m above bottom to surface
		Shallow profiler on hybrid profiler mooring	200 m depth to surface

Measurement	REDACTED	Platform	Comments
phytoplankton-zooplankton sonar		Benthic Nodes	Vertical profile, uplooking from BEP
digital still camera		Benthic Nodes	2 m above bottom on BEP
hydrophone, passive		Benthic Nodes, Offshore and Shelf sites	2 m above bottom on BEP

4.3.3.5.3 Endurance Array Oregon Line Technical Approach

The backbone of the Endurance Oregon will be three fixed sites aligned perpendicular to isobaths and spanning from offshore (500 m), mid-shelf (80 m) and inshore (25 m) regimes offshore of Oregon (Fig. 4.3-27). The offshore and shelf sites combine fully-instrumented surface platforms with cabled profilers and benthic boundary layer sensors. The inshore site combines a wave-hardened surface platform electromechanically linked to benthic boundary layer sensors and a stand-alone surface-piercing 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 most transformative design element of the offshore and shelf sites will be the cabled infrastructure which integrates the Endurance Array with the Regional Scale Nodes through an extension from RSN-1 (Fig. 4.3-26) through Nodes 1C and 1D to the Endurance Array infrastructure (Fig. 4.3-27). This CGSN-RSN partnership extends the reach and capability of the RSN infrastructure into the coastal environment, while simultaneously providing the transformative high-power, high-bandwidth capabilities to the Coastal infrastructure.

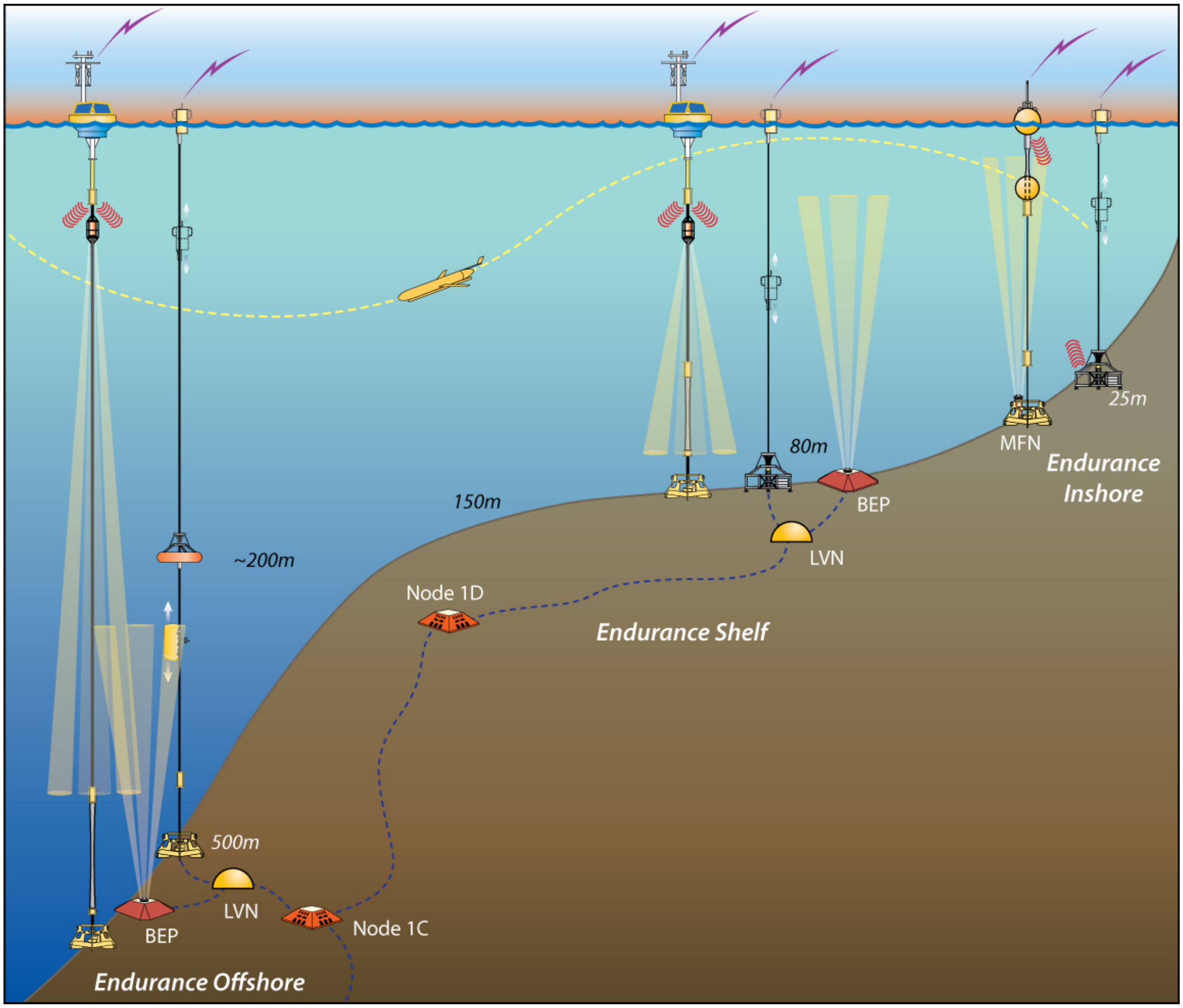

Figure 4.3-27. Schematic diagram of the Endurance Array Oregon Line, showing surface-mooring/profiler pairs at offshore, shelf and inshore sites, benthic experiment packages (BEP), and RSN cabled infrastructure including low-voltage nodes (LVN) that provide the interface between Endurance Array and RSN assets. Gliders will patrol the coastal upwelling region, with one offshore line coincident with the moored array.

Cabled infrastructure of the Endurance Oregon Line is provided through interface requirements 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 surface-piercing profilers and at benthic boundary layer nodes. Equally important, the cabled infrastructure will also provide outstanding 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 near-surface oceanographic measurements.

At the interface between the shelf and the near shore zone, the Endurance Array 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, meteorological sensors, and buried bottom cabling impractical. Instead we will install a surface buoy hardened to overtopping by waves. The buoy will support near-surface oceanographic measurements and two-way communications with the seafloor, and will also provide power to benthic boundary layer sensors via a battery pack. A stand-alone surface-piercing profiler will also be deployed at this site, communicating through acoustic modem and 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 surface-piercing profilers. 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 multiple sites with bottom cabled infrastructure provides experimental capabilities that are unique within the OOI.

4.3.3.5.3.1 Endurance Oregon Line Surface Moorings

The Endurance Oregon Line offshore and shelf surface moorings (Figure 4.3-28) will provide meteorological observations, power to surface and subsurface instruments, and real time data transmission. These moorings will be similar in design to those used in the Pioneer Array. Since they do not have to support extensive water column and benthic sensors that are here connected through the cabled infrastructure, they do not carry optical fiber or power transmission below the near surface sensor attachment point at 5 m. Like the Pioneer Array buoys, power will be generated using a combination of wind turbines and photovoltaic panels. Due to the lower power requirements of the Endurance coastal moorings, they will not include methanol fuel cells. 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 the same as the Pioneer surface moorings, including acoustic communication with subsurface sensors. The Endurance Array surface moorings will not have a high speed satellite link. One DCL will be located internal to the surface buoys and one DCL will be located on the instrument frame at 5 m beneath the buoy. The surface mooring will support sensors at the air-sea interface, and on the instrument frame at the 5 m termination, as described in the Endurance Oregon Line core sensor summary (Table 4.3-8).

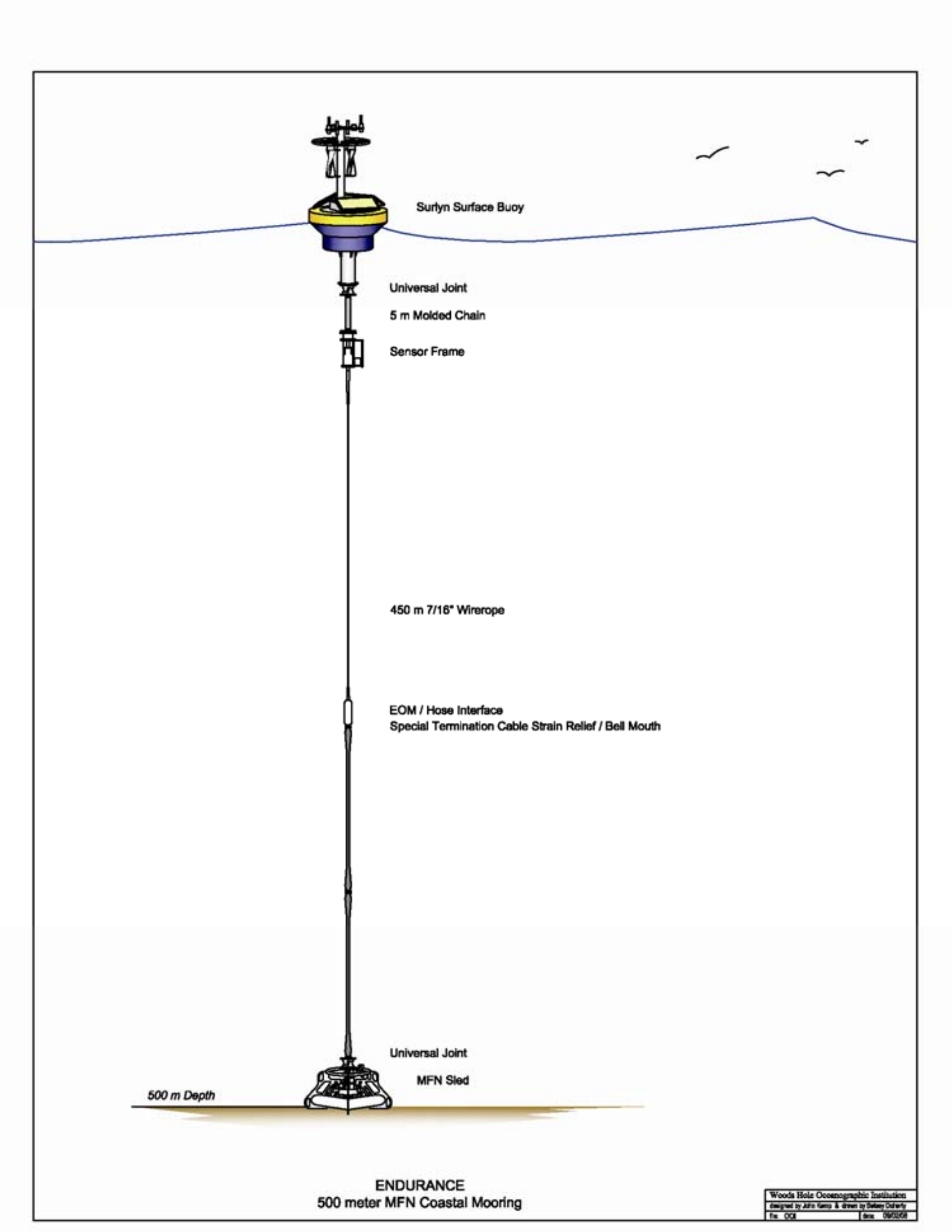

Figure 4.3-28. Endurance Oregon Line 500 m and 80 m Surface Mooring.

The inshore 25 m surface mooring (Fig. 4.3-29) will comprise a surface buoy, an EM mooring strength member running to the bottom, and a MFN with power, sensors, and data distribution capabilities. The MFN also provides the weight necessary to anchor the system. The surface buoy has a welded aluminum core structure and 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 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 batteries housed in a chamber within the buoy hull structure. Telemetry to and from the mooring is via satellite and/or radio links including Iridium, line-of-sight, and WiFi.

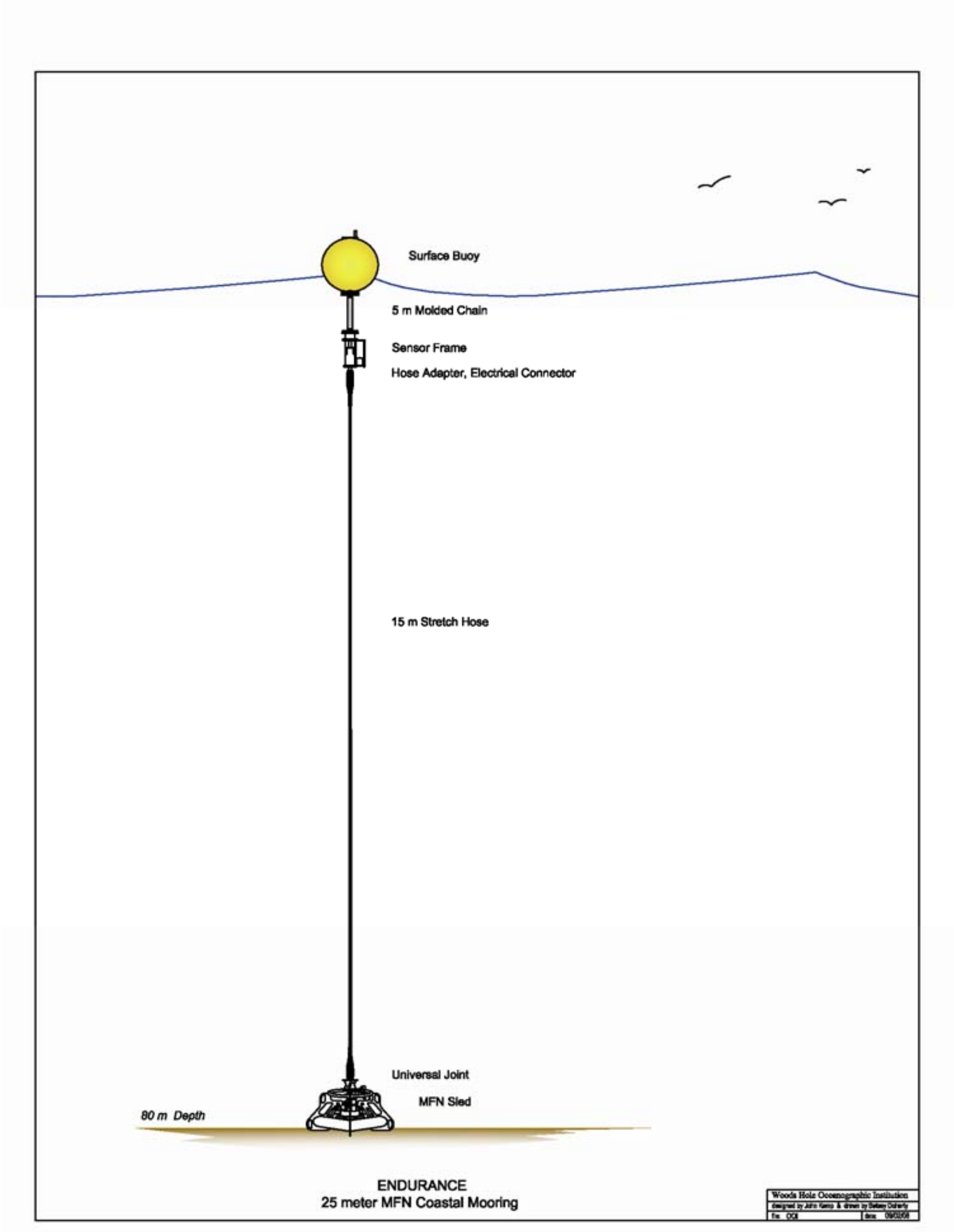

Figure 4.3-29. Endurance Oregon Line 25m Surface Mooring.

The 25 m surface mooring will support sensors at the air-sea interface, and on the instrument frame at the EM termination, as described in the Endurance core sensor summary (Table 4.3-8). 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 EM cable approximately 15 mm in diameter, EM urethane molded chains approximately 75 mm in diameter and 5 m in length, and, depending on water depth, one or two EM 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 EM cable allows for high-speed communication and power transmission between the surface buoy controller and the MFN instrumentation.

4.3.3.5.3.2 Endurance Oregon Line Surface-piercing Profilers

Each Endurance Oregon Line mooring site will have profilers paired with the surface moorings (Fig. 4.3-27). The profilers will be of two types: stand-alone (inshore) or connected to the RSN (shelf and offshore). The stand-alone winched profiler is internally powered and will communicate via Iridium telemetry while at the sea surface. The profiler can also communicate acoustically with the surface mooring located less than 2 km away. The profiler moorings connected to the RSN will receive power and communicate via the secondary cabled infrastructure. The shelf and offshore profilers will retain the capability to communicate acoustically with nearby surface moorings. Winched surface-piercing profilers 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 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 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 stand-alone 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 surface-piercing profiler. It will have the capability to communicate data to a nearby 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 for servicing. 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).

4.3.3.5.3.3 Endurance Oregon Line Offshore Hybrid Profiler

The offshore profiler mooring infrastructure will use the same design as the RSN water column moorings. This hybrid profiling mooring, constructed by RSN, consists of an electrical optical mechanical (EOM) cable that is connected to a low-voltage node (LVN) and anchored to the seafloor. The cable rises 300 m to a buoyant platform 200 m below the sea surface. The platform keeps the EOM cable taut. From the mid-water platform, a winched shallow profiler samples to just below the sea surface. At the platform, an inductive data and power coupler allows the profiler to transmit data to the 200-meter cabled junction box (J-Box) and to recharge the profiler batteries. Real-time communication with the profiler is accomplished using an inductive modem for command and control and data transfer. The profiler can be installed and removed using an ROV to facilitate service. The shallow profiler will be designed such that sensors can be serviced from a small boat when the profiler is at the sea surface. An instrumented, deep profiler will operate from just below the mid-water platform to near bottom.

4.3.3.5.3.4 Endurance Oregon Line Benthic Nodes

The Shelf and Offshore sites will have a low-voltage node (LVN) attached to the primary nodes that links to the RSN. The LVN will provide power and communications with the subsurface profilers at these locations as well as science instrumentation deployed on benthic experiment packages (BEP).

The inshore site will have a multi-function node (MFN) below the EM surface buoy. This MFN will carry sensors, and provide power and control similar to that of the offshore LVN, but without a cabled connection. Instead, the MFN 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 with core sensors and future user experiments at the inshore site. Surface meteorological sensors and wind/solar power generation are not feasible on the 25 m mooring since they are unlikely to survive 10 m waves in winter storms when the buoy may be submerged.

4.3.3.5.4 Endurance Array Washington Line

Location: Moored array line: 47° N, 125°W to coast; Water Depth: 500-25 meters.

Platform Types: Three fixed un-cabled platform sites at 25, 80, and 500 m water depth supporting surface moorings, water column profilers and benthic boundary layer sensors.

Description of Infrastructure added by Endurance Array Washington Line:

- Two EOM surface moorings with wind, photovoltaic and fuel cell power generation, high speed and low speed satellite communications, and meteorological sensors (80, 500 m)
- One EM surface mooring with battery power and Iridium satellite communications (25 m)
- Two bottom-mounted, stand-alone surface-piercing profiler moorings at 25m and 80 m water depth with acoustic communications to the surface buoy
- One wire-following profiler mooring at 500 m
- One un-cabled benthic multifunction node (MFN) with sensors, electrical communications to the surface, and supplementary battery power provided by the surface buoy (25 m)
- Two un-cabled benthic multifunction nodes (MFN's) with fiber optic communications to the surface and power provided through surface moorings (80 m, 500 m)

4.3.3.5.5 Endurance Washington Line Core Sensors and Platforms

The core science sensors for the Endurance Washington Line are listed in Table 4.3-9. As with Global, Pioneer, and other Endurance Oregon Line sensors, these sensors are in the OOI Core Sensor List developed to satisfy the OOI science requirements. Platforms, including profilers and gliders, will be similar to the Oregon Line but with modifications for the stand-alone nature of Washington Line assets.

Table 4.3-9. Endurance Array Washington Line core sensor and platform summary.

Measurement	REDACTED	Platform	Comments
surface fluxes (bulk)		EOM buoys	Redundant systems will ensure complete data sets from remote locations
surface fluxes (direct covariance)		EOM buoys	Direct measurement of momentum flux and sensible and latent heat fluxes
CO2 flux		EOM/EM buoys	Simultaneous measurement of air-side and water-side pCO2 and kinetic gas transfer velocity
pCO2 water		Surface-piercing profiler	2 m above bottom to surface
		Benthic Nodes	2 m above bottom on BEP
		Surface moorings	5 m depth below surface
surface wave spectra		EOM/EM buoys	Motion sensors in buoy hull
temperature and conductivity		EOM/EM moorings	5 m below surface at EOM/EM termination
		Surface-piercing profilers	2 m above bottom to surface
		Wire-following profiler on offshore profiler mooring	near bottom to 15 m below surface

Measurement	REDACTED	Platform	Comments
		Multifunction Nodes	2 m above bottom on MFN
high-precision pressure		Surface-piercing profilers	2 m above bottom to surface
		Wire-following profiler on offshore profiler mooring	near bottom to 15 m below surface
		Multifunction Nodes	2 m above bottom on MFN
mean currents		EOM/EM moorings	5 m below surface at EOM/EM termination
		Surface-piercing profilers	2 m above bottom to surface
		EM moorings	Near surface to 300 m (downlooking)
		Multifunction Nodes	300 m range, uplooking from MFN
turbulent velocities		EOM/EM buoys	Below buoy hull
		Wire-following profiler on offshore profiler mooring	near bottom to 15 m below surface
		Multifunction Nodes	2 m above bottom on MFN
dissolved oxygen		EOM/EM moorings	5 m below surface at EOM/EM termination
		Surface-piercing profilers	2 m above bottom to surface
		Wire-following profiler on offshore profiler mooring	near bottom to 15 m below surface
		Multifunction Nodes	2 m above bottom on MFN
pH		EOM/EM moorings	5 m below surface at EOM/EM termination
		Wire-following profiler mooring	15 m below surface on sub-surface float
		Multifunction Nodes	2 m above bottom on MFN (25m and 80m)
optical attenuation and absorption		EM moorings	5 m below surface at EM termination
		Surface-piercing profilers	2 m above bottom to surface
		Multifunction Nodes	2 m above bottom on MFN
Chl-a and CDOM fluorescence, optical backscatter		EOM/EM moorings	5 m below surface at EOM/EM termination
		Surface-piercing profilers	2 m above bottom to surface
		Wire-following profiler on offshore profiler mooring	near bottom to 15 m below surface
photosynthetically active radiation (PAR)		Surface-piercing profilers	2 m above bottom to surface
photosynthetically active radiation (PAR)		Wire-following profiler on offshore profiler mooring	near bottom to 15 m below surface
spectral irradiance		EOM/EM moorings	5 m below surface at EOM/EM termination
		Surface-piercing profilers	2 m above bottom to surface
nitrate		EOM/EM moorings	7 m below surface at EOM/EM termination
		Surface-piercing profilers	2 m above bottom to surface
phytoplankton-zooplankton sonar		Multifunction Nodes	Vertical profile, uplooking from MFN
digital still camera		Multifunction Nodes	2 m above bottom on MFN

4.3.3.5.6 Endurance Array Washington Line Technical Approach

Analogous to the Oregon Line, the backbone of the Washington Line will be three fixed sites aligned nearly perpendicular to isobaths and spanning from offshore (500 m), mid-shelf (80 m) and inshore (25 m) regimes offshore of Washington (Figure 4.3-30). The offshore and mid-shelf sites combine fully-instrumented surface platforms electrically, optically and mechanically linked to benthic boundary layer sensors and a stand-alone profiler. These moorings will provide continuous meteorological and near-surface oceanographic measurements. The inshore site combines a wave-hardened surface platform electromechanically linked to benthic boundary layer sensors and a stand-alone, surface-piercing profiler, identical to the inshore site of the Oregon Line. The Washington and Oregon Line will be serviced by the common 6-glider fleet.

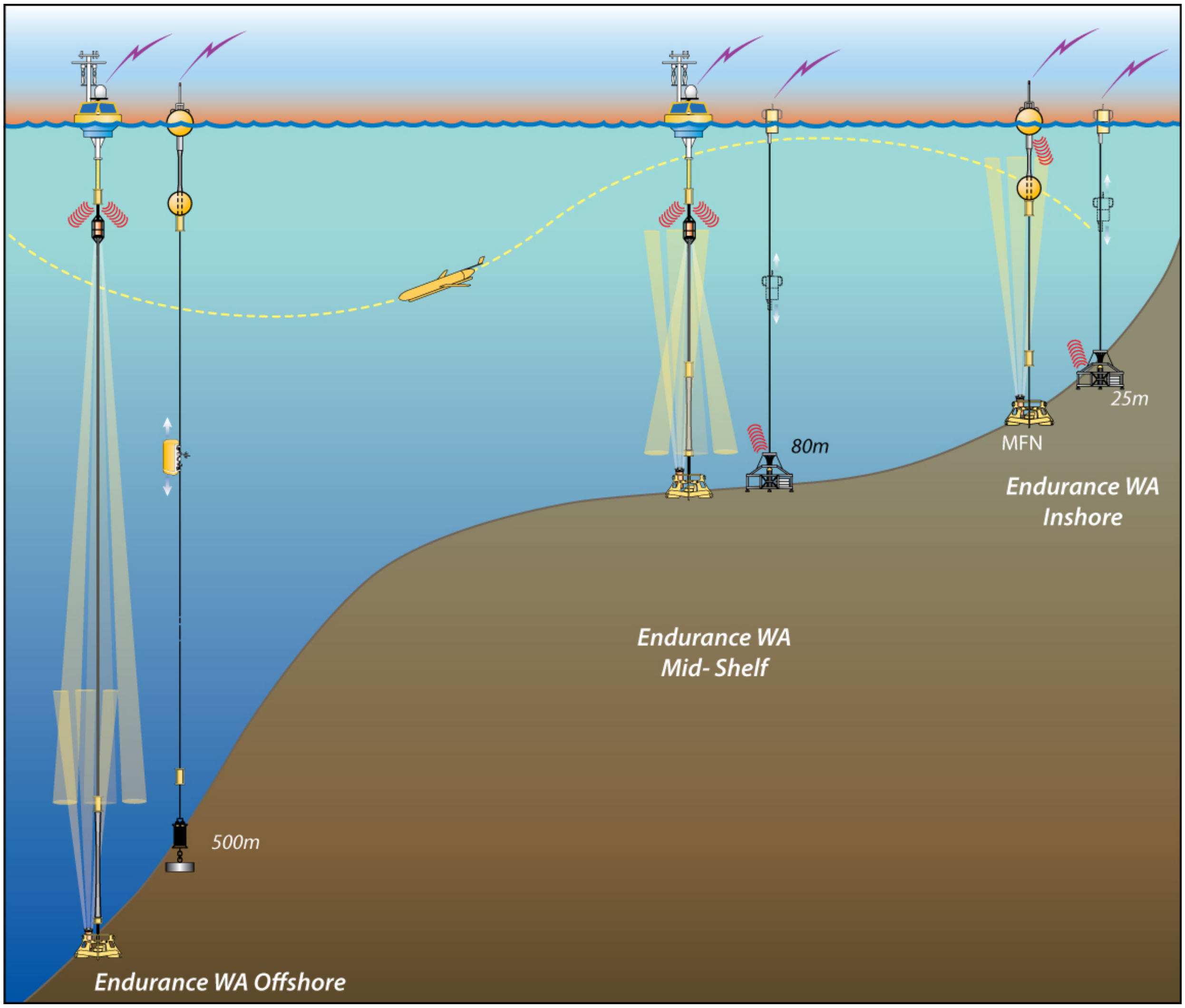

Figure 4.3-30. Schematic diagram of the Endurance Array Washington Line. Shown are surface-mooring/profiler pairs at offshore, shelf and inshore sites, benthic multifunction nodes (MFN), Gliders will patrol the region, with one offshore line coincident with the moored array.

4.3.3.5.6.1 Endurance Washington Line Surface Moorings

The Endurance Washington Line moorings use the same designs as Pioneer moorings (section 4.3.3.3.1 and Figure 4.3-28) at the 500 m and 80 m sites and the inshore Endurance mooring (section 4.3.3.5.3.1 and Figure 4.3-29) at the 25 m site.

4.3.3.5.6.2 Endurance Washington Line Surface-piercing Profilers

The Endurance Array Washington Line 80 m and 25 m moorings use the same designs as the inshore Endurance Oregon mooring (section 4.3.3.5.3.2 and Figure 4.3-27) at the 25 m site.

4.3.3.5.6.3 Endurance Washington Line Offshore Profiler

The 500 m offshore profiler mooring infrastructure will use the same design as the Pioneer profiler mooring described in section 4.3.3.3.3 and shown in Figure 4.3-25.

4.3.3.5.6.4 Endurance Washington Line Multifunction Nodes

The inshore, shelf and offshore sites will have a multifunction node (MFN) attached to the base of the surface mooring. This MFN will carry sensors, and provide power and control similar to that of the low voltage node (LVN) described for the Endurance Oregon Line mooring array (sections 4.3.3.5.3.4), but without a cabled connection. Instead, the MFN will be powered internally and also receive power from the surface buoy. It will communicate with the surface buoy via an EOM communication link at the 500 m and 80 m sites and an EM link at the 25 m site. The MFN will provide power and real time communication with core sensors and future user experiments.

The MFN design is identical to that used for the Pioneer Array (section 4.3.3.3.1). The Endurance Washington Line MFN will be identical to the Pioneer array central site (P1) in that it will not include an AUV dock, but instead be dedicated to instruments including science-user added instruments. The MFN is a benthic platform to supply communications and power for “clients” that include unspecified science-user instrumentation. For the Endurance Washington Line, the MFN power system will initially 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 an ROV wet-mate connector. Power available for science-user instrumentation will be limited at the inshore site due to battery limitations in the inshore buoy, but the MFN at the shelf and offshore sites will have power from the surface mooring, allowing sensors and instrument packages to be placed at the mid-shelf and continental slope.

Analogous to the Pioneer Array, the Washington Line MFN acts as a power and telemetry breakout between the mooring EOM (EM) cable and the science users. The MFN has equivalent functionality as the surface mooring including the fully redundant platform controller and two DCL. The MFN platform controller will supervise power usage requests based on the total power available from the surface. If the power drawn by users exceeds power available the platform controller will scale back users based on a predetermined schedule to avoid system damage or an ungraceful shutdown

4.3.3.6 Endurance Gliders

An array of six gliders will survey the shelf and slope waters of the eastern boundary current regime offshore of Washington and Oregon, and provide high resolution transects along the Endurance mooring line (Fig. 4.3-26). The gliders will carry a multi-disciplinary sensor payload

(Table 4.3-8), including bio-optical sensors with copper shutters for mitigation of biofouling. The gliders will operate along four cross-shelf lines at 43.5, 44.6, 47.0 and 48.0° N latitude, from approximately the 20 m isobath out to 126° W. The gliders will also run north-south along 126° W. The northernmost glider track will not enter the Canadian Exclusive Economic Zone (EEZ) but will allow some continuity with the VENUS (Victoria Experimental Network Under the Sea) and NEPTUNE Canada (NorthEast Pacific Time-Series Undersea Networked Experiments) arrays as well as RSN, GSN, and NOAA assets. Repeat missions of several hundred kilometers 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.

4.3.3.7 Endurance Array Installation and Servicing Requirements

Since many of the non-cabled Endurance array components are the same as Pioneer Array components, testing will occur when the Pioneer components are tested. Surface-piercing profilers will be developed and tested with deployments of increasing duration off the Oregon coast in years two and three. The nearshore buoy will also best tested in years two and three. The initial operational deployment of the nearshore 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.

The secondary cabled array components of Endurance will be developed and tested by the RSN with the collaboration of CGSN. The buried fiber optic cable will be laid as part of the RSN's secondary infrastructure installation after site surveys are completed. Deployments of all cabled infrastructure will be coordinated with RSN using the same ship and ROV they employ.

Note that the installations of cabled and non-cabled components are independent of one another. That is, installations of non-cabled components (surface moorings, uncabled profiler moorings, and the 25 m sites) do not depend on cabled infrastructure and vice versa. Similarly, glider deployment does not depend on the deployment of fixed assets.

Our collective experience indicates that most instruments will require servicing twice per year in the coastal environment 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 would be cleaned and checked as would mooring hardware. Most sensors will need recalibration once per year and the budget for this is in the initial operations and maintenance years. Based on experience, we anticipate that many mooring components (e.g., molded chain and stretch hose) will last at least two years and have budgeted accordingly.

Endurance Array components that are connected to the RSN will be serviced annually. Servicing would be done using a ship with ROV support capabilities, and will be coordinated with RSN servicing of other Node N1 and N2 infrastructure. For replacement of cabled infrastructure, we use similar attrition rates as for other moored components. The surface-piercing profilers are designed to be sent to the surface where slack wire can be run out. The profilers can then be recovered on deck and serviced. This servicing will occur twice per year when non-cabled 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 similar glider operations carried out at OSU and elsewhere. These costs include small boat time, Iridium-based communications, sensor recalibration, and other maintenance.

4.3.4 Shore-Side Facilities

There will be three shore facilities to support the CGSN operations and maintenance plan. The facilities reside at Woods Hole, MA, San Diego, CA, and Corvallis, OR and are responsible for system operations, fields operations, and data operations. The Woods Hole shore station (Figure 4.3-31), operated by Woods Hole Oceanographic Institution, will manage the Pioneer Array and Irminger Sea Global Array assets including gliders and AUVs. The San Diego shore station operated by Scripps Institution of Oceanography, will manage the Station Papa, Argentine Basin, and Southern Ocean Global Arrays including gliders. The Corvallis shore station, operated by Oregon State University, will manage the Endurance Array including the Oregon and Washington Lines and gliders.

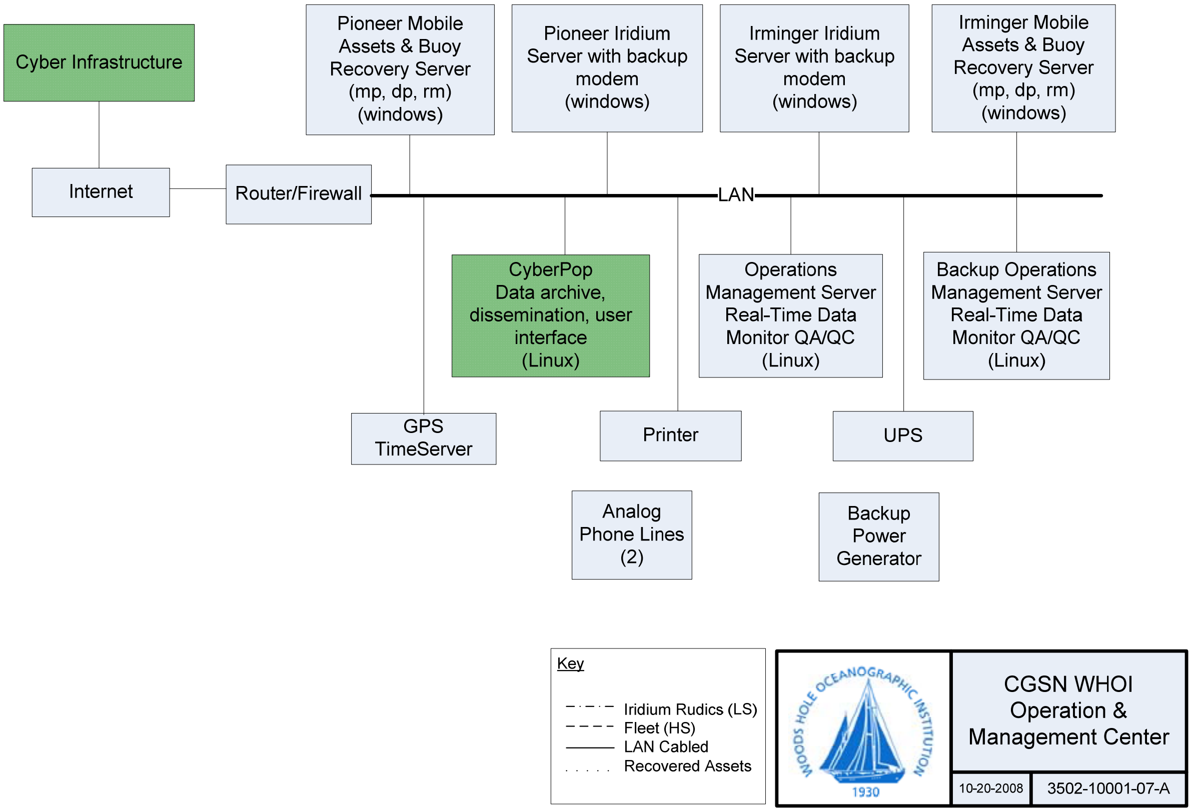

Figure 4.3-31. WHOI shore facility in Woods Hole, MA.

4.4 Regional Scale Nodes

4.4.1 Introduction

The Final Network Design (FND) for the Regional Scale Nodes (Figure 4.4-1) is based on elements of the Preliminary Network Design, on criteria outlined in the *OOI Science Requirements*, eleven RSN-specific requirements documents (Table 4.4-1) and on five technical specifications documents. This design also incorporates the findings of two trade-off studies completed by the RSN IO to investigate optimal configuration of the cabled backbone infrastructure or Primary Infrastructure (the *Regional Scale Nodes Wet Plant Primary Infrastructure White Paper*; 24) and shore station location(s) *(Regional Scale Nodes Shore Station Options White Paper*; 25*)*, and an additional White Paper describing the Secondary Infrastructure (*RSN Secondary Infrastructure White Paper*; 26). In concert, this system provides unprecedented power (10 kV) and bandwidth (10 Gb/s, upgradeable to 40 Gb/s) to sensor arrays on the seafloor and throughout the water column using instrumented moorings. Figure 4.4-2 illustrates the high-level block diagram for the RSN.

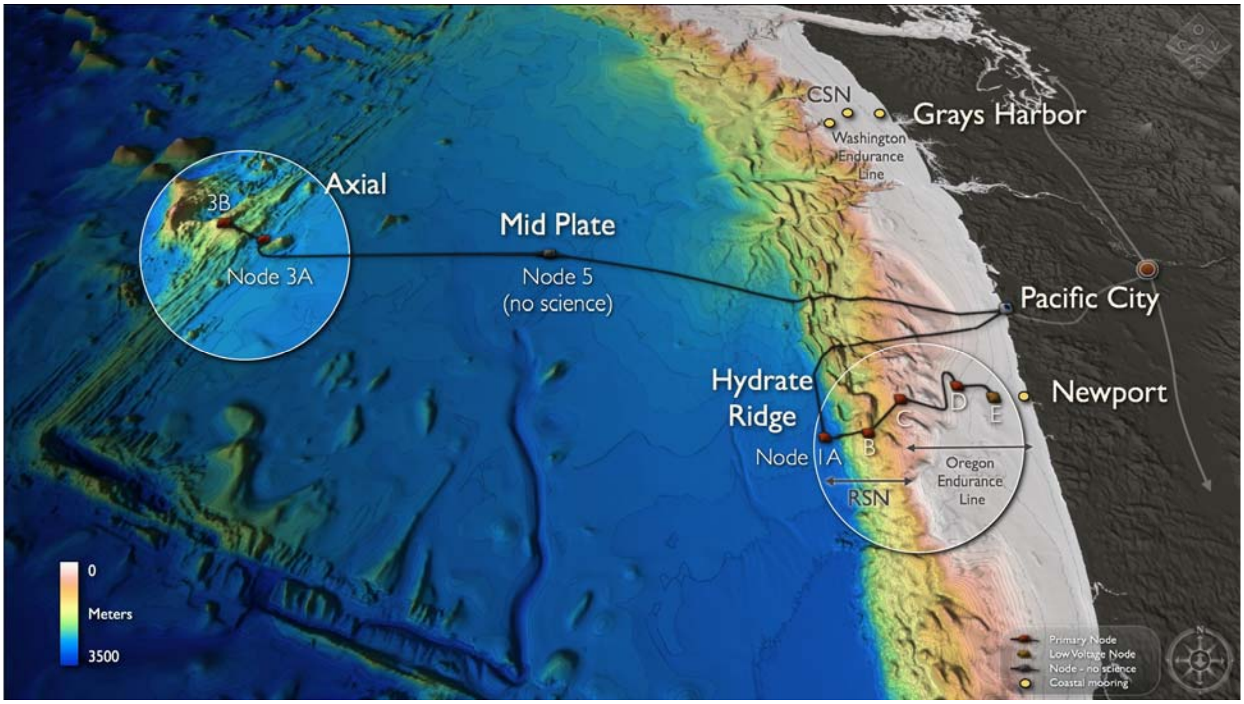

Figure 4.4-1. This illustration shows the configuration for the Regional Scale Nodes that includes the backhaul cable routes between the Pacific City Shore Station and the backhaul connection to the Cyber POP at Portland, Oregon. Also shown are the sub-sea cable segments and the Primary Nodes.

The RSN utilizes a Star configuration with one shore station and seven Primary Nodes (Figures 4.4-1 and 4.4-2) with the following designations: Node 1A (Hydrate Ridge) and Node 1B (Southern Hydrate Ridge); Node 3A (Axial Seamount) and Node 3B (Eastern Caldera); and Node 5A (Mid-Plate). The Hydrate Ridge infrastructure also includes two additional Primary Nodes, Node 1C and Node 1D, which comprise part of the CSN Endurance Oregon Line extension: Node 1C is shared by RSN and CGSN. The shore station located in Pacific City, Oregon includes two cable landings serving Hydrate Ridge, Axial Seamount, and the Mid-Plate site. The Primary Nodes convert the high cable line power voltage (10 kV) to a lower (375 V) level and distribute it to Science Ports along with communications and timing signals. A 5 km cable will extend from the mid-plate site for future expansion.

Table 4.4-1. RSN Final Network Design Documentation

Reference #	Document
4306-00002	RSN Wet Plant Primary Infrastructure White Paper
4307-00002	RSN Shore Station Options White Paper
4311-00001	RSN Secondary Infrastructure White Paper
4308-00002	RSN Core Sensor Design
4308-00005	RSN Sensor Maintenance, Risk, and Replacement Document
4101-00001	RSN L3 System Requirements
4301-00001	RSN L4 Backhaul Requirements
4302-00001	RSN L4 Extension Cable Requirements
4308-00001	RSN L4 Instrument Package Requirements
4303-00001	RSN L4 J-Box Requirements
4304-00001	RSN L4 LV Node Requirements
4305-00001	RSN L4 OMS Requirements
4306-00001	RSN L4 Primary Infrastructure Requirements
4307-00001	RSN L4 Shore Station Requirements
4309-00001	RSN L4 Vertical Mooring Requirements
4310-00001	RSN L4 Vertical Profiler Requirements

In the following sections, the RSN system is described from the Backhaul to the sensors. Representative Block Diagrams of individual components are included in follow-on sections for illustration of the RSN subsystems (e.g. Figure 4.4-2). Detailed Functional Block Diagrams have been developed for all of the Secondary Infrastructure by site that include specific OOI-Reference Designators, Node Locations, Cable Lengths and Connector Types, as well as specific component numbers. Drawing Trees reference all schematics and provide ease in accessing the detailed Node, Sensor, and Connector schematics. An example for the Drawing Tree for the network from the University of Washington Operations Center to Shore Station is shown in Figure 4.4-3.

4.4.2 Primary Infrastructure

The Primary Infrastructure is a major component of the RSN. It distributes power and communication from the land-based Shore Station in Oregon to sub-sea terminals at depths of up to ~3000 meters across the Juan de Fuca Plate. These sub-sea terminals called Primary Nodes have connection points for instrument platforms and their interconnection infrastructure to allow continuous, real-time interactive science experiments at the seafloor. The Primary Infrastructure will also include equipment used in the sub-sea telecommunications industry to capitalize on the high reliability needed to provide a system life of 25 years. Detailed specifications for the Primary Infrastructure are provided in the RSN document WetPlantRFPTechSpecs_RSN_2008-06-03_ver_1-00 and additional information is provided in the Wet_Plant_White_Paper_RSN_ver_1-04 and in the Technical Requirements document L4_Primary_Infrastructure_RSN_ver_3-00.

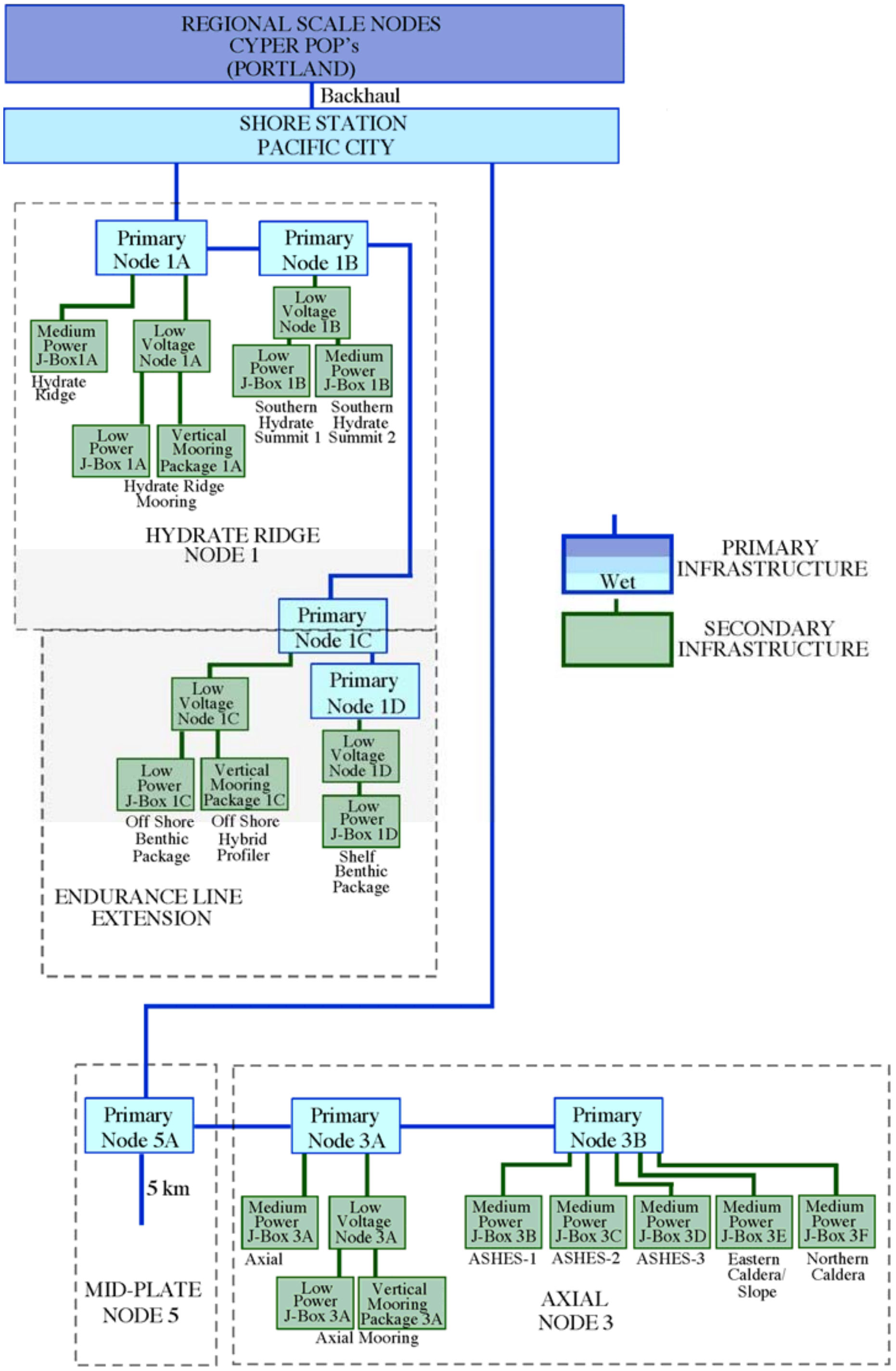

Figure 4.4-2. The high-level block diagram for the RSN Infrastructure and the Primary and Secondary Infrastructure associated with the CSN Endurance Extension Line.

The Primary Infrastructure subsystem of the RSN starts with the Backhaul System (Figures 4.4-1 and 4.4-2; Section 4.4.2.1) that provides Internet connectivity from a CyperPOP in Portland Oregon, to the Pacific City Shore Station (Section 4.4.2.2). Required infrastructure within the Shore Station is part of the RSN Primary Infrastructure, but the physical Shore Station facility is not part of this subsystem. The Primary Infrastructure includes power feed equipment (PFE) to convert utility power to regulated and controlled high voltage (10 kV) power for each of the sub-sea cables that terminate in that Shore Station. The Primary Infrastructure also includes the subsea line termination equipment (SLTE), which has the optical drivers and receivers for the sub-sea cables that terminate in the Shore Station and the electronics to convert the optical signals to network connections suitable for connecting to IP based interfaces.

The Primary Infrastructure includes the cable landing that provides a transition for the sub-sea cable from the ocean bed through conduits to the Shore Station. It includes the cable needed to reach all of the sub-sea terminals including any needed Repeaters to reach the required distance. Finally the Primary Infrastructure includes the sub-sea terminals called Primary Nodes that convert the High Cable Line Power Voltage (10 kV) to a lower (375 V) level and distributes it to science ports along with communications and timing signals. These science ports are the connection to the Secondary Infrastructure and Instrument Platforms.

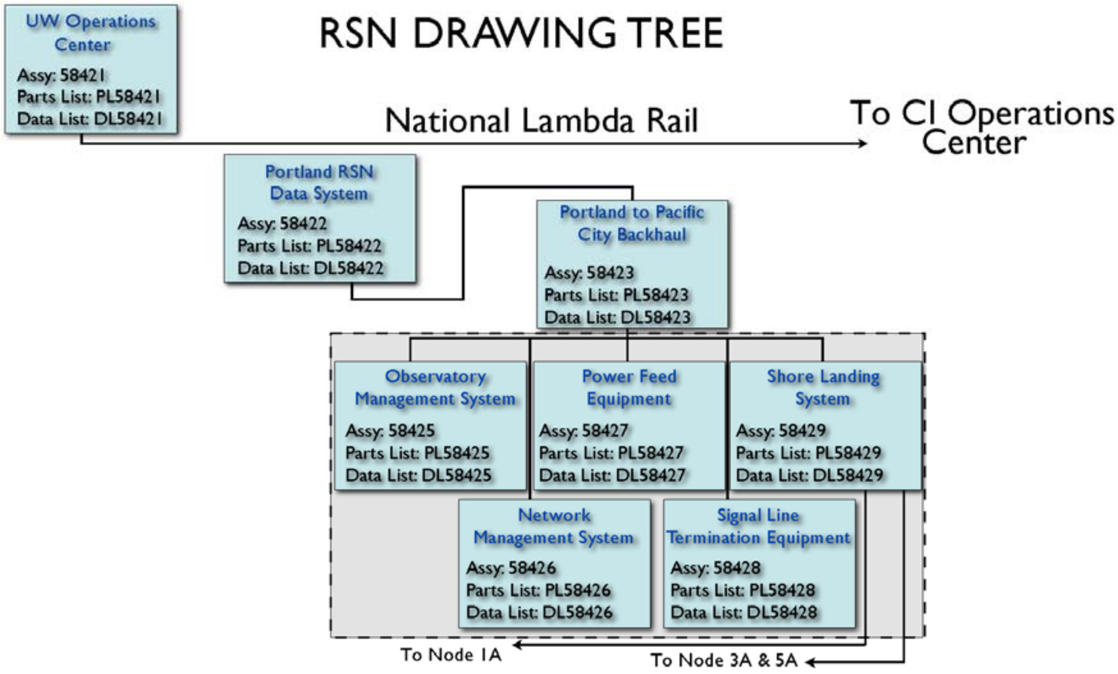

Figure 4.4-3. Drawing Tree for the RSN showing the network from the University of Washington Operations Center to Shore Station, with associated drawings for major components and references for Assembly, Parts List, and Data List drawings.

The entire Primary Infrastructure is monitored and controlled by a Network Management System (NMS). This system allows both the communication and power systems to be monitored for activity, status, utilization and to control allocations of resources across the system. The NMS can be accessed from the Shore Station or from remote facilities including the RSN Operations Center. The current Project Execution Plan calls for the entire Primary Infrastructure to be designed and implemented by a single Contractor. Having one contractor responsible for the Primary Infrastructure will reduce the number of interfaces that must be controlled between various parties and will reduce the overall risk of this critical and expensive part of the OOI.

4.4.2.1 Backhaul

There will be one Shore Station for the RSN system in Pacific City, Oregon (Figure 4.4-4). The shore station will have a dedicated high bandwidth link called the Backhaul, to a connection to the OOI CyberInfrastructure CyberPop in Portland.

It is anticipated that an existing backhaul system will either be leased or purchased. The system will include one or more dedicated fiber-optic links between the Shore Station and an interconnection panel in Portland, the termination equipment on either end of the fiber optic link, and any repeaters needed along the fiber optic path.

The backhaul system will have one link, POR-PC, between the Shore Station in Pacific City, Oregon (Figure 4.4-3) and the Pittock Building in Portland, Oregon. The initial capacity of the BH-PC backhaul system will be 10G b/s: the capacity of the Backhaul link is upgradeable by adding cards in the supplied terminal equipment in 10 Gb/s increments with no modification to the intermediate fiber or repeaters. The supplied terminal equipment will support an ultimate backhaul capacity on the BH-PC link of 40Gb/s, with the initial capacity of the backhaul system of 10Gb/s. The supplied terminal equipment will support an ultimate backhaul capacity on the BH-PC link of 40Gb/s.

4.4.2.2 Shore Station

The Shore Station in Pacific City, Oregon will have two cable landings serving the Hydrate Ridge, Axial, and Mid-Plate Primary Nodes. The Shore Station subsystem encompasses the physical building, the battery backup and power connection to the grid, and space for the Primary Infrastructure SLTE and PFE. The shore station is described in greater detail in the Shore_Stations_White_Paper_RSN_ver_1-02 document.

Figure 4.4-4. [redacted]

It is anticipated that parts of the existing Shore Station facility for the sub-sea cable system will be leased. Visitation of this facility shows it already includes many of the features needed to support the overall requirements of the system:

1. Connections to Reliable, High Capacity, Utility Power.
2. Battery Backup and Onsite Backup Generator Power Systems.
3. Access to rights of way for connections to beach cable landing sites.
4. Access to locations for ocean ground beds.
5. Security systems to ensure the physical safety of the equipment.
6. Reliable Heating and Air Conditioning equipment needed for safe operating of SLTE and PFE equipment.
7. Access to high-bandwidth terrestrial links to National Data Grids. Dark fiber or managed bandwidth to a city center.
8. Fire detection and suppression.
9. Space for all SLTE, PFE and NMS equipment.

The Shore Station will have access to 480 volt AC power to meet the needs of the RSN sub-sea cable system, and backup generators to meet the needs of the cable system should an AC power failure occur. The backup generators will be capable of powering the system for up to three days without refueling. The Shore Station will also have 24-hour remote security monitoring, including alarms for building intrusion and real-time video surveillance of the equipment room and external grounds. The Shore Station includes sufficient outdoor space for installing an Ocean Ground Bed, and concrete sub-surface Manholes that terminate the duct from the beach Manhole.

4.4.2.3 Backbone Cable

The RSN will rely on the telecom industry standard sub-sea cable to provide power (10 kV DC, up to 8 A) and communications (up to 40 Gb/s) via fiber-optics between the Primary Nodes (see Section 4.4.2.4) and the Shore Station. These cables are routinely deployed across ocean basins and margins for long lifetimes; they generally become obsolete before they fail (*Regional Scale Nodes Wet Plant Primary Infrastructure White Paper*; 20). The backbone cable will be deployed using a cable industry cable-laying ship. Technical requirements for this system described in greater detail in the WetPlantRFPTechSpecs_RSN_2008-06-03_ver_1-00 RSN Request for Proposals .

Backbone cables will run from the Shore Station to the Primary Nodes at Axial and Hydrate Ridge. Some of the Primary Nodes will be terminations, while others will pass power and bandwidth on to nodes further offshore, e.g. Primary Node 5 will send power and bandwidth on to Primary Node 3A. A backbone cable will also connect the Coastal Scale Nodes (CSN) Endurance Oregon Line to the RSN (Figures 4.4-1 and 4.4-2). Extension cables to Low Voltage and Medium Voltage Nodes are part of the Secondary Infrastructure and are described in Section 4.4.3. The selection of specific cable parameters is part of the Primary Infrastructure contract, therefore details will be available only after that contract's design phase. The request for proposals (RFP) for the Primary Infrastructure was issued in August 2008; negotiations are in progress.

4.4.2.4 Primary Nodes

Primary Nodes are the terminal points for the backbone cable and are contractor-supplied components (Figure 4.4-5). The main function of the Primary Nodes is to distribute power and bandwidth to the Secondary Infrastructure, and also to contain house-keeping functions of the system control, out-of-band communications, and engineering monitors. The Primary Nodes house the Medium Voltage Converters that convert the 10 kVDC primary level to the 375 VDC level and send that power on to the Low and Medium Voltage Nodes and Junction Boxes (Figures 4.4-5 and 4.4-6).

The Primary Nodes also have two science ports to allow power and full bandwidth connections to specific devices, such as high definition cameras. Primary Nodes also have one expansion port to send full power and bandwidth over long distances (>200 km) to other instrument locations. The design and implementation of the Primary Nodes is part of the Primary Infrastructure subcontract, therefore details will be available only after that contract's design phase.

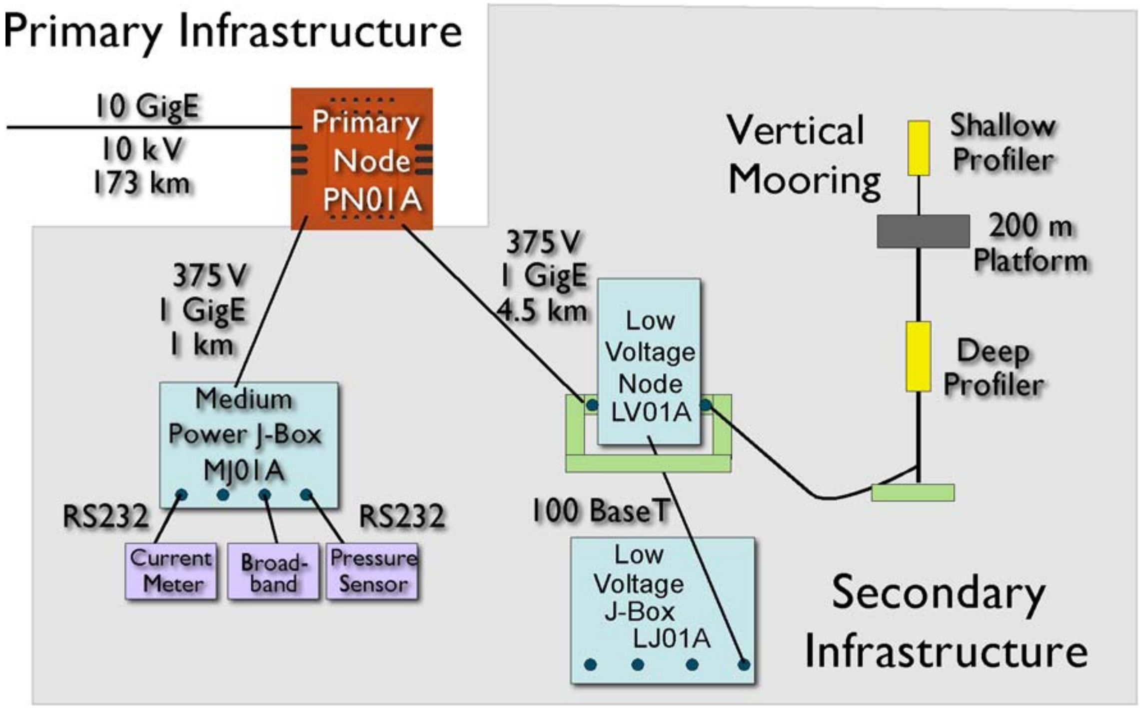

Figure 4.4-5. Simple schematic showing the relationship between the Primary and Secondary Infrastructure for part of the Hydrate Ridge system.

4.4.3 Secondary Infrastructure

The RSN's Secondary Infrastructure is shown schematically in Figure 4.4-5. The Secondary Infrastructure includes all extension cables, medium power and low power junction boxes, low voltage nodes, two water column moorings, and seafloor and mooring sensor packages. This infrastructure is linked to the Primary Infrastructure by connection to the Primary Nodes, which distribute low voltage (375 V) and data at a lower rate (1 GigE) to a group of Low and Medium Power Junction Boxes (J-Box) and Low Voltage Nodes (LV) clustered geographically around the Primary Node (Figure 4.4-2). The Low Voltage Nodes are connected to Low Power Junction Boxes (LP-JBox) at 48V and100BASE-T that provide the correct data and power interface to small groups of scientific instruments. This system is described in more detail in the Secondary_Infrastructure_White_Paper_RSN_ver_1-01.

In concert, this infrastructure will support (at least) three general scenarios:

1. Local area networks around a Primary Node (e.g., Axial Seamount);
2. Water column moorings at two of the Primary Node sites (Hydrate Ridge and Axial Seamount), which extend the science capabilities from the seafloor to the sea surface; and
3. Extended spatial arrays (e.g., Hydrate Ridge/Coastal Endurance Array).

4.4.3.1 Extension Cables

Extension Cables provide power and communication links between the Primary Infrastructure, Secondary Infrastructure and instruments. Extension Cables link Primary Nodes to LV Nodes to J-Boxes, and to instruments across the RSN. This cabling may be installed in various seafloor conditions from harsh areas (sharp rocks, inside the caldera of an active undersea volcano, across an active fault line) to benign areas, and will be powering different types of loads, therefore different types of cables are necessary. Primary Nodes are set at depths down to ~3000 m and extension cables link to elements along the bottom and from the bottom to near the surface. The requirements and additional details for the Extension Cables are described in the Technical Requirements RSN document L4_Extension Cables_RSN_ver_2-00 and in the Secondary_Infrastructure_White_Paper_RSN_ver_1-01. All extension cables have been documented in terms of their power/communications requirements, and in consideration of special environmental requirements. This includes various levels of armoring for deployments in volcanic areas such as the flanks and caldera of Axial Seamount. These are included in the block diagrams and budgeted appropriately.

Two fundamental characteristics of the OOI are the ability to expand the coverage area and number of sensors, and the ability to operate for over 25 years. To support this, ROV wet-mate connectors are used in many of the extension cable assemblies to allow for additional cables to be added to the system and for existing components to be temporarily removed from the system for maintenance.

Connectors and splices (Cable Termination Adapters, CTAs) are critical components in these cables assemblies as these are classic failure points in ocean systems. Several types of connectors will be necessary in this system, some combined with their cables at the factory, others on board ships in the field. Some will need to be wet-mateable via ROVs to avoid excessive weight and volume and prevent connection errors. Connectors will be made such that they are of compatible materials as they interface with different metals under the water surface. Connectors for each system have been evaluated and are shown in detail in the block diagrams. In general, there are three major types of connectors: E = Wet Mate Electrical Connectors, H = Wet Mate Hybrid Connector and D = Dry Mate Electrical Connector. These are indicated in the highlighted sections of block diagrams shown in numerous illustrations in the follow-on sections.

4.4.3.2 Medium Power Nodes, Low Voltage Nodes

The Initial RSN system will use two types of junction boxes (J-Box). The first type is a Medium Power J-Box (MP J-Box) that receives input voltage at 375 Volts DC and an input data link at 1 GigE (Figure 4.4-6). The MP J-Box will have one expansion port that passes on the 375 Vdc and 1 GigE data link. This port can be connected to another Medium Power J-Box, or to other specialized equipment that requires higher power or bandwidth, e.g., inductive power coupler systems in docking stations for charging batteries in mobile platforms, or high-definition cameras. In addition, the MP J-Box has eight instrument ports that provide 12 to 48 V and has 10/100BASE-T, RS232 or RS485 data links. There will be 13 Low Power and Medium Power Junction boxes on the system.

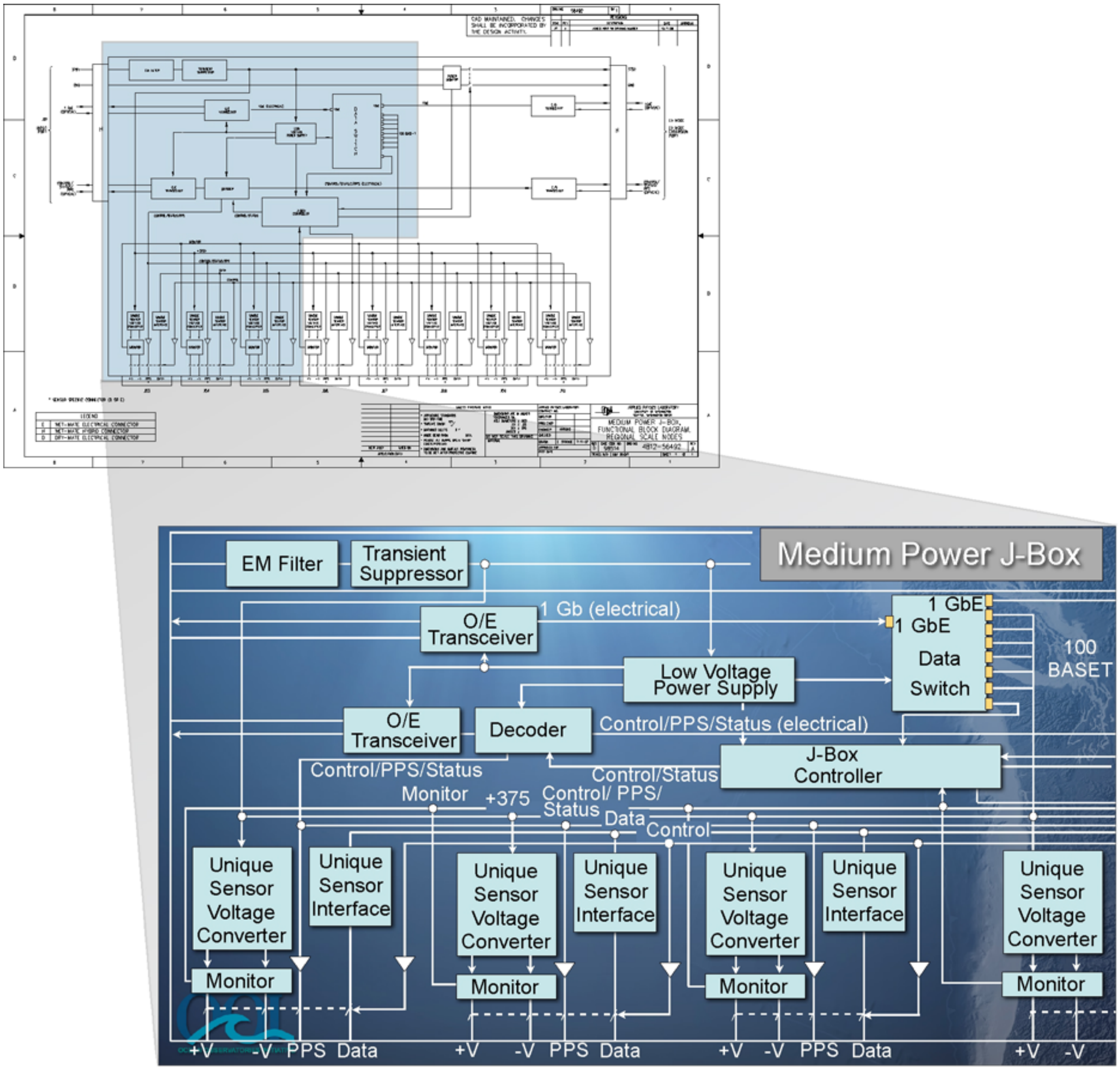

Figure 4.4-6. Expanded view of the Block Diagram for a Medium Power J-Box on the RSN.

The second class of junction box is the Low Power J-Box (LP J-Box) that receives input voltage at 48 Volts DC and an input data link at 10/100Base-T. The LP J-Box also has eight instrument ports that provide 12 to 48 V and has 10/100BASE-T, RS232 or RS485 data links. The junction boxes will include a pressure housing mounted on a frame with wet-mateable connectors. The ROV wet-mateable connectors will be on the outside of the frame for access by an ROV. Depending on what will be connected to a specific LVN and node location, not all of the possible ROV wet-mateable connectors may be populated. Depending on the distance from the J-Box, the J-Box is attached to a short (<100 m) cable with a wet-mate connector to plug into the junction box or it may just have a wet-mate connector on its frame that the input cable will be plugged into. If a sensor that is attached to the junction box is not attached its frame it may connect to the junction box through a wet-mate connector. Junction boxes are key to adapting the system to numerous types of sensors with a few standard infrastructure components. The initial RSN architecture will deploy junction boxes to support core instrumentation and sensors, with anticipation that more will be added during the 25-year life of the OOI to expand the coverage area and number of sensors on the network. Additional details and requirements for the nodes and junction boxes are provided in the Technical Requirements documents L4_JBox_RSN_ver_2-00 and L4_LVNode_RSN_ver_2-00 and the RSN White Paper Secondary_Infrastructure_White_Paper_RSN_ver_1-01.

The LV Nodes interconnect junction boxes and their associated instrument platforms to Primary Nodes. They are key to the expansion capability of the system by allowing a single input from a Primary Node to be distributed to multiple outputs. In the initial RSN architecture there will be approximately five LV Nodes deployed. The design allows the addition of more LV Nodes over the 25-year life of the OOI to expand the coverage area and number of sensors. Connections to LV Nodes are made using ROV wet-mateable connectors so that the LV Node can be brought to the surface for maintenance and repair without having to recover the cables or other attached infrastructure.

The nominal input voltage to the LV Node is 375 Vdc and the input data link is 1 GigE. There are two expansion ports that pass on the 375 Vdc and have a 1 GigE data link. These ports can either be connected to another LV Node for expansion, to a Medium Power J-Box, or to other specialized equipment that requires higher power or bandwidth, e.g., inductive power coupler systems in docking stations for charging batteries in mobile platforms, or high-definition cameras. In addition, the LV Node has four science ports that provide 48 Vdc and has 10/100BASE-T data links, which provide connections to Low Power J-Boxes. The inputs and outputs will also have a timing pulse per second link that is passed from inputs to outputs. This link will also have a low bandwidth out of band control protocol to talk to the node controller in case the In Band data path is not working.

4.4.3.3 RSN Sensors and Moorings

The instrument packages and sensors on the RSN provide the means to monitor and sample the water column (therefore sharing many functions with the CGSN mooring sensors) and they also include an extensive suite of geophysical and chemical sensors to examine plate tectonic, volcanic, chemical, hydrothermal, and biological processes. The architecture includes a set of core sensors, however, it also includes the capacity to increase the number and type of instruments over the life of the OOI to expand the coverage area and address new scientific questions.

The requirements, exemplar model, location and power and bandwidth requirements for each sensor are described in the following documents, as are profiler specifications:

- Core_Sensors_Design_RSN_2008-10-02_ver_1-06;
- Core_Mooring_Sensors_RSN_2008-10-02_ver1-03;
- Core_Seafloor_Sensors_RSN_2008-10-02_ver_1-01;
- Sensor_Maintenance_Plan_RSN_2008-10-01_ver_1-01
- L4_Instrument_Packages_RSN_ver_2-00;
- L4_Vertical_Mooring_RSN_ver_2-00;
- L4_Winches_Profilers_RSN_ver_2-00
- Winch_Profiler_Tech_Specifications_ver_2-00
- Deep_Profiler_Tech_Specifications_ver_2-00

The RSN infrastructure enables instruments to have cabled connections for power and 2-way communications (commands and data) to all elements 24/7/365. As described in the previous sections, the RSN sensors obtain power and communications from the Low Voltage Nodes, and Medium Power and Low Power J-Boxes via extension cables.

A wide variety of sensors are needed to provide required measurements. Commonly, these instruments need to be co-located and the data accurately timed. Sensors are grouped in instrument packages that are presented by functional measurements. To meet the Science Requirements there are 16 different types of core seafloor sensors and 17 core water column sensors, with a total of 108 sensors on the RSN system. As described in the RSN L4 Instrument Package Requirements Document, instrument packages include a Basic Core Seafloor Measurements Package (BCSM) (Table 4.4-2); Vertical Mooring Measurements Package (VMM) (Tables 4.4-6, 4.4-8, 4.4-10, 4.4-12), and a set of Site-Specific Measurements Package (SSM) with co-registered environmental and visual measurements at key plate locations that include:

•Zones of active magmatic activity
•Zones of hydrothermal flow
•Zones of subduction and sedimentary wedge formation
•Water Column Measurements
•Benthic Boundary Layer Measurements
•Horizontal Context Measurements
•Zones of gas hydrate formation and methane seeps

4.4.3.4 Basic Core Seafloor Measurements Package (BCSM)

The Basic Core Seafloor Measurement packages are located at Primary Nodes 1A and 3A on the backbone in areas that are environmentally benign (Figures 4.4-1 and 4.4-2). Basic Core Seafloor Measurement packages at these locations provide measurements key to understanding seismic activity at zones of crustal formation, and along subduction zones. They also provide an off-shore, complementary component to the EarthScope array and Pacific Northwest Seismic array. The BCSM sensors, exemplar models, [redacted], and location are shown in Table 4.4-2 and example block diagram is shown in Figure 4.4-7. Associated power and bandwidth requirements are summarized in Table 4.4-3.

Table 4.4-2. Basic Core Seafloor Measurements Package (BCSM)

Measurement	Example Sensor	REDACTED	Location
Global/regional seismic events, subduction earthquakes, slow quakes	Broadband Triaxial Seismometer & Accelerometer		Buried in caissons in sediment; accelerometer mounted externally
Regional/local seismicity,	Short Period Seismometer		In array placed in cement seismonuments
Local currents, background ocean temperature	Current Meter + Temperature		On <1 m mooring near hydrothermal site
Tidal Pressure on Seafloor	Pressure		Mounted on Ti-stand, pressure housing
Secondary reception of P-waves, cetacean vocalization, wind, rain	Hydrophone		Mounted on stand

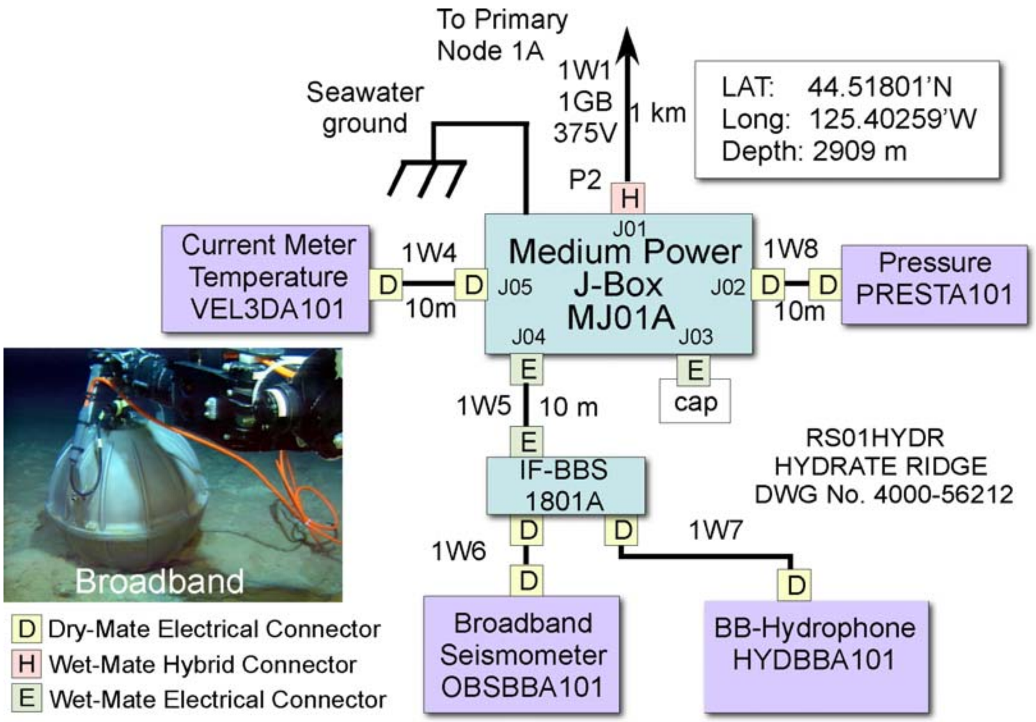

Figure 4.4-7. A subset of the Site 1, Hydrate Ridge Functional Block Diagram (4000-56212) showing the layout for the Basic Core Seafloor Measurements Package that will be installed at two of the Primary Nodes. These packages are located 1 km away from the Primary Nodes. Also shown is a broadband sensor in a titanium housing just prior to deployment by a remotely operated vehicle.

Table 4.4-3. Power and Bandwidth Requirements for Basic Core Seafloor Measurements Package (Reference Document: RSN Power and Bandwidth V 1.0)

Sensor	Average Power	Voltage	Bandwidth	Interface
Current Meter	345 mW	12-15 Vdc	<400 b/s	RS232
Broadband	1.8 W	12 or 48 Vdc	4800 b/s	RS232
Hydrophone	1.2 W	12-15 Vdc	4 Mb/s	ethernet
Pressure	192 mW	6-16 Vdc	9600 b/s	RS232/485

4.4.3.5 Site-Specific Instrument Packages

Sensor arrays are included at key experimental sites that commonly address linkages across geological, biological and chemical processes both on the seafloor as well as in the water column. The site-specific instrument packages in aggregate meet the requirements outlined in the OOI Science Requirements and the data to come off these arrays are tightly coupled to the development of Education Requirements linked to Ocean Literacy Principles (See Section 4.5). Seafloor sensor arrays are distributed around Medium and Low Voltage J-Boxes on extension cables that typically range from 10 m to 250 m in length. To optimize serviceability and performance with respect to operations and maintenance requirements, the sensors are connected to the junction boxes via dry- and/or wet-mate connecters. Vertical moorings include a seafloor package, in addition to a suite of sensors on a deep profiler, 200-m platform, and on a profiling winch. The following sections describe the site-specific instrument packages, their environment of deployment and associated vertical mooring components.

4.4.3.6 Hydrate Ridge

Hydrate Ridge 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). RSN infrastructure at this site includes two Primary Nodes (Hydrate Ridge and Southern Hydrate Ridge: Figures 4.4-1, 4.4-2, and 4.4-8, 4.4-9) and a full water column mooring at the base of the slope (Figure 4.4-10).

This site also provides high power (10 kv) and bandwidth (10 Gb/s) capabilities to the Endurance Array Oregon Line through Primary Node 1C. Sensors at this site meet requirements outlined in the the OOI Science Requirements documents for A-1 Global Biogeochemistry and Carbon Cycling, A-4 Fluid Rock Interaction and the Subseafloor Biosphere, A-5 Plate-Scale Seismology and Geodynamics, A-6 Gas Hydrates, A-7 Climate Variability and Ecosystems, A-8 Ocean Mixing and Rough Topography, and support requirements outlined in A-3 Ocean Circulation, Mixing, and Ecosystems, A-9 Coastal Ocean Dynamics and Ecosystems- Hypoxia on Continental Shelves, A-10 Coastal Ocean Dynamics and Ecosystem Shelf/Slope Exchange. To meet these requirements 10 different types of seafloor sensors are hosted at the southern summit Hydrate Ridge sites, as well as those on the water column mooring (as described in Sections 4.4.3.7 hosted at the base of the margin. This site has strong geological, chemical and physical oceanographic linkages that also allow understanding of processes operative upslope and monitored by the CGSN Endurance array (Figure 4.4-8).

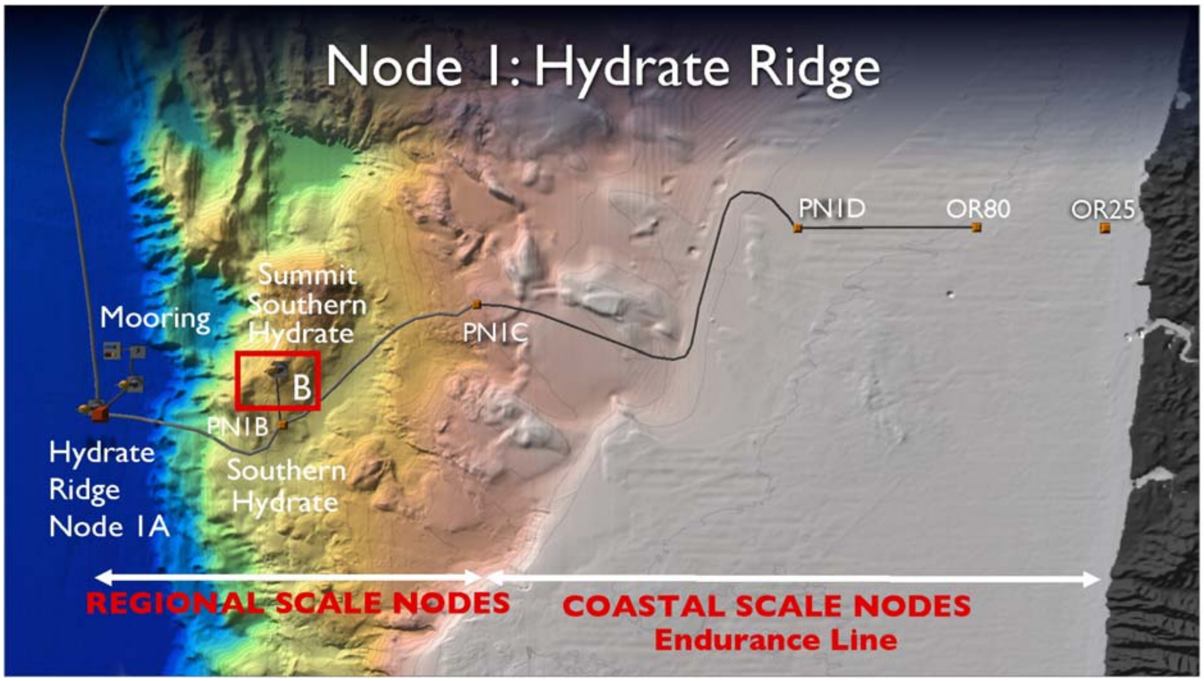

Figure 4.4-8. Location of the backbone cable and extension cables for Primary Node 1A-1C of the RSN along the Hydrate Ridge network and the CSN Endurance Array Oregon Line (Node 1C-1D). A full water column mooring with profiling capabilities will be located near Node 1A. RSN and CSN share the node at 500 m. The CSN at 500 and 80 m will host moorings connected to the cable through extension cables. RSN site-specific sensors (red box) are

located ~ 10 km north of the Node 1B (Southern Hydrate Ridge) at the summit of southern Hydrate Ridge at a water depth of ~ 700 m. The sensors are shown below in Figure 4.4-9.

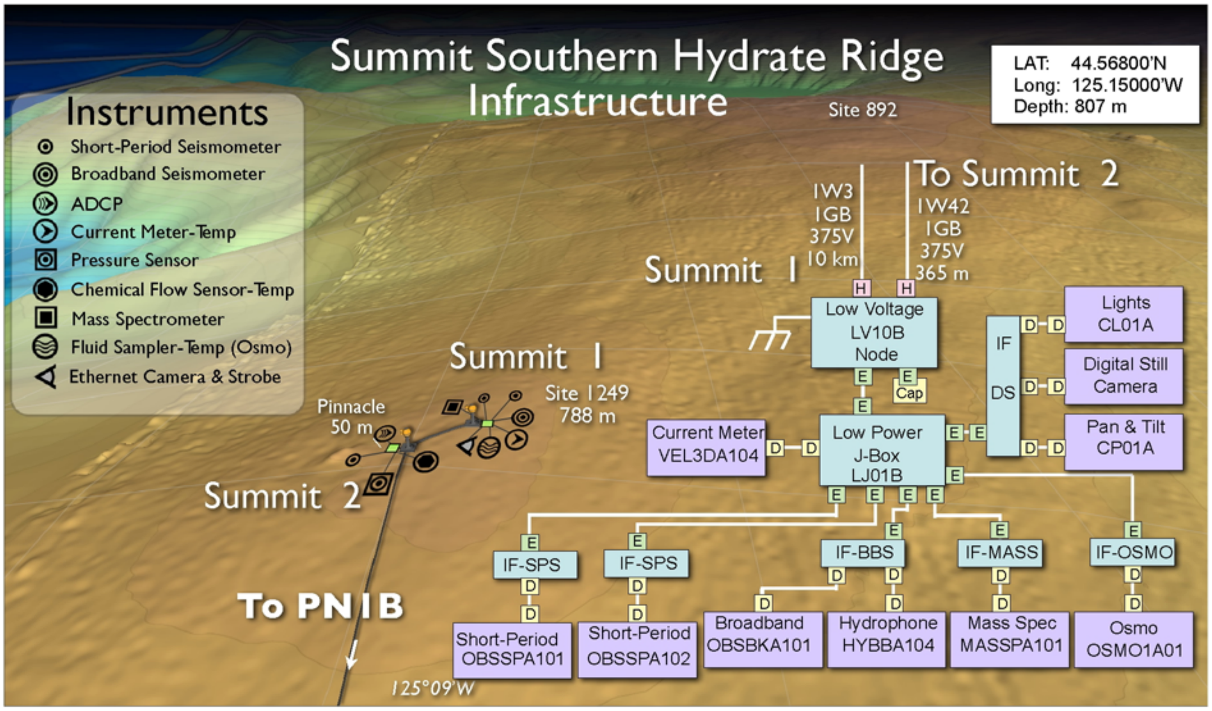

Figure 4.4-9. Sensors at the southern Hydrate Ridge Summit 1 and Summit 2 sites. The block diagram is shown for the Southern Summit 1 site.

Table 4.4-4. Specific Sensors at the Southern Summit of Hydrate Ridge Sites

Measurement	Example Sensor	REDACTED	Location
Global/regional seismic events, subduction events, slow quakes	Broadband Triaxial Seismometer & Accelerometer		Distal to methane seep site
Secondary reception P-waves, cetacean vocalization, wind, rain	Hydrophone		Mounted on stand
Regional/local seismicity, hydrofracturing	Short Period Seismometer		In array distal to seep sites
Plume structure, velocity profile through water column	75 kHz Bottom Mounted upward-looking ADCP		On stand on seafloor within seep footprint
Local currents, background ocean temperature	Current Meter + Temperature		On <1 m mooring near seep
Tidal Pressure on Seafloor	Pressure		Mounted on Ti-stand, pressure housing
Flow through sediment-water	Flow meter		Base is coupled to seafloor, sensors in frame in seep

Measurement	Example Sensor	REDACTED	Location
interface (0.1 to >500 m/yr			
Dissolved volatiles in seep fluids	Mass Spectrometer		Intake extends from seep to TI-housing on stand
Major/Trace element chemistry of seep fluids	In situ Time Series Osmotic Water Sampler + temperature		Seafloor frame
Digital still imagery of vents, diffuse flow, seeps, and macrofauna	Seafloor High Res Camera W strobes		On frame with pan and tile capabilities, lights

Table 4.4-5. Power and Bandwidth Requirements for Sensors at the Southern Summit of Hydrate Ridge (Reference Document: RSN Power and Bandwidth V 1.0)

Sensor	Average Power	Voltage	Bandwidth	Interface
Broadband Triaxial Seismometer	1.8 W	12 or 48	4800 b/s	RS232
Hydrophone	1.2 W	12-15 Vdc	<400 b/s	Ethernet
Short Period Seismometer	5 mW	'+/- 5Vdc (+/- 7.5Vdc I14max to analog sensor) - 48V (logger)	1/s	RS422 –future (100baseT)
75 kHz ADCP	1 W	'20 to 50V battery 42V (new), 28V (depleted)		RS-232
Current Meter + Temperature	6.5 W		1 Hz	RS232/485 USB
Pressure	192 mW	6-16 V V	<16 b/s	RS232/RS485
Flow Meter	1 W max	5.5-18 V	256B at 0.7 to 210 s intervals	RS232
Mass Spectrometer	72W	24 Vdc		RS232/ethernet
Osmo Fluid sampler	<1 W	12 Vdc	0.5 Hz	RS232
High Res Camera W strobes, Pan and Tilt	5.5 W	12 Vdc	0.765 Gb/s	100BASET/TX

4.4.3.7 Profiling Moorings at Hydrate Ridge and Axial Seamount

Ocean conditions surrounding the RSN are bracketed on the pelagic or open-ocean end by the OOI global site at Ocean Station Papa, and on the coastal end by the Endurance Array. The RSN resides in a complex system of currents, where wind- and tide-forced motions lead to turbulent mixing that aids transport of chemical and biological species. The Pacific Northwest is one of the most biologically productive regions of the world, hypoxia, ocean acidification, and harmful algal blooms are observed with increasing frequency. These complex physical, biological and chemical processes are all intertwined, and respond to forcing on a wide range of spatial and temporal scales. The water column moorings at Hydrate Ridge and Axial (Figure 4.4-10) are well suited to resolve these processes, and the system's response to changing forcing conditions resulting from climate change. The unprecedented power (375V) and bandwidth (Gb/s) capabilities of these moorings allow for a broad suite of sensors that include real-time digital imaging and acquisition of high bandwidth sonar and hydrophone data for biological applications.

Though both moorings are in about 3000 m of water, they have very different oceanographic foci. The mooring at Hydrate Ridge is situated adjacent to the coastal continental slope at the end of the Endurance Oregon Line, and in concert with the northern Endurance Washington Line, provides a unique opportunity for investigating a variety of interdisciplinary coastal studies (Figure 4.4-8). The coastal region of the Pacific Northwest is a classic wind-driven upwelling system. However, the presence of the Columbia River plume and the range of trajectories with which it can impinge on the ocean, and the strong variability of the width of the continental shelf, all play strong roles in setting the system's response and behavior. In addition, the aforementioned large-scale systems affect the coastal region by modulating the pycnocline, nutricline and oxycline depths and offshore pressure gradients, which in turn affect the onshore transport of physical, biological and chemical quantities. The presence of internal waves driven by waves and tides, their interaction with the larger-scale currents, and their eventual breakdown into turbulence, are also vital to setting properties in the coastal region. All of these are expected to change strongly over time, but will be well resolved by the measurements at Hydrate Ridge, the Endurance Array, and supporting shipboard work.

In contrast to the margin setting of Hydrate Ridge, Axial Seamount is far from the continental shelf and hence represents an open-ocean or pelagic site in the continuum of observing scales represented in the OOI's cabled system. Here, large-scale currents including the North Pacific Current, the subpolar gyre and the northern end of the California Current interact. These currents transport heat, salt, oxygen, and biota, all of which are crucial to the region's ecosystem. However, their variability arises from forcing as varied as tides and wind (0.5--5 day timescales) to interannual (El Niño) to decadal (Pacific Decadal Oscillation) timescales. Examples of relevant science questions represented in the OOI Science Requirements include 1) Internal tides are ubiquitous vertical motions formed by tidal currents flowing past bottom features such as Axial Seamount. How, and how strongly, do they break down into turbulence, and what are the feedbacks on the large scale current system? 2) What is the impact of long- and short-term forcing changes on the structure and transports of the large-scale current system – and what are their effects on the ecosystem? Together with the mooring at Ocean Station Papa, these processes can be studied with observing platforms in the water column at these two sites. The following subsections describe the sensor packages on the Hydrate Ridge and Axial Moorings.

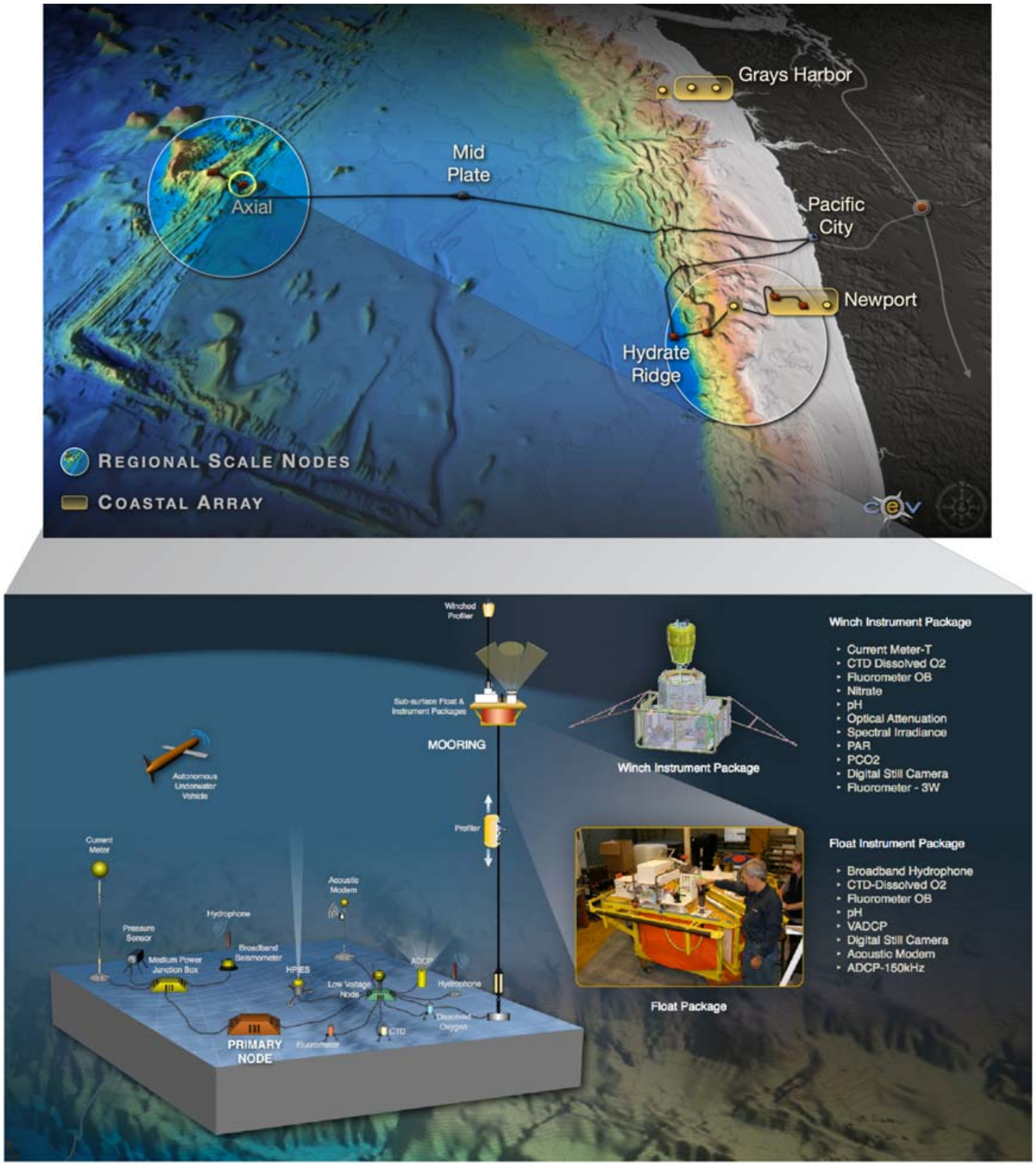

Figure 4.4-10. Location of high power and bandwidth moorings with profiling capabilities on the RSN. One mooring will be placed at the base of Axial Seamount, providing measurements key to examining flow over rough topography, El Nino and La Nina events, and the Pacific Decadal Oscillation. A second mooring will be located at the base of the accretionary margin outboard from Hydrate Ridge. This mooring forms an array with three surface and three subsurface (two of which are cabled to the RSN) moorings that are part of the Coastal Scale Endurance Array.

4.4.3.8 Vertical Mooring Measurement Package (VMM)

The Vertical Mooring Measurement Package (VMM) is located at two sites, one ~4.5 km east of Node 1A (Hydrate), and one ~4.5 km northwest of Node 3A (Axial). The VMM consists of a Basic Core Seafloor Mooring Measurements package (BCSMM, Table 4.4-6) located tens of meters from the base of the vertical mooring assembly, a Profiler Instrument Package that is located on a profiler that traverses from just off the seafloor to the base of a platform located at 200 m beneath the sea surface, a Float Instrument Package located on the 200 m subsurface platform, and a Winch Instrument Platform located on a winch that travels from the 200 m platform to just beneath the surface (Figure 4.4-11). The complete VMM is described in the following sections, as are the individual instrument packages. More detailed information on the moorings is provided in the Technical Requirements L4_Vertical_Mooring_RSN_ver_2-00 and L4_Winches_Profilers_RSN_ver_2-00 with specifications provided in Winch_Profiler_Tech_Specifications_ver_2-00 and Deep_Profiler_Tech_Specifications_ver_2-00.

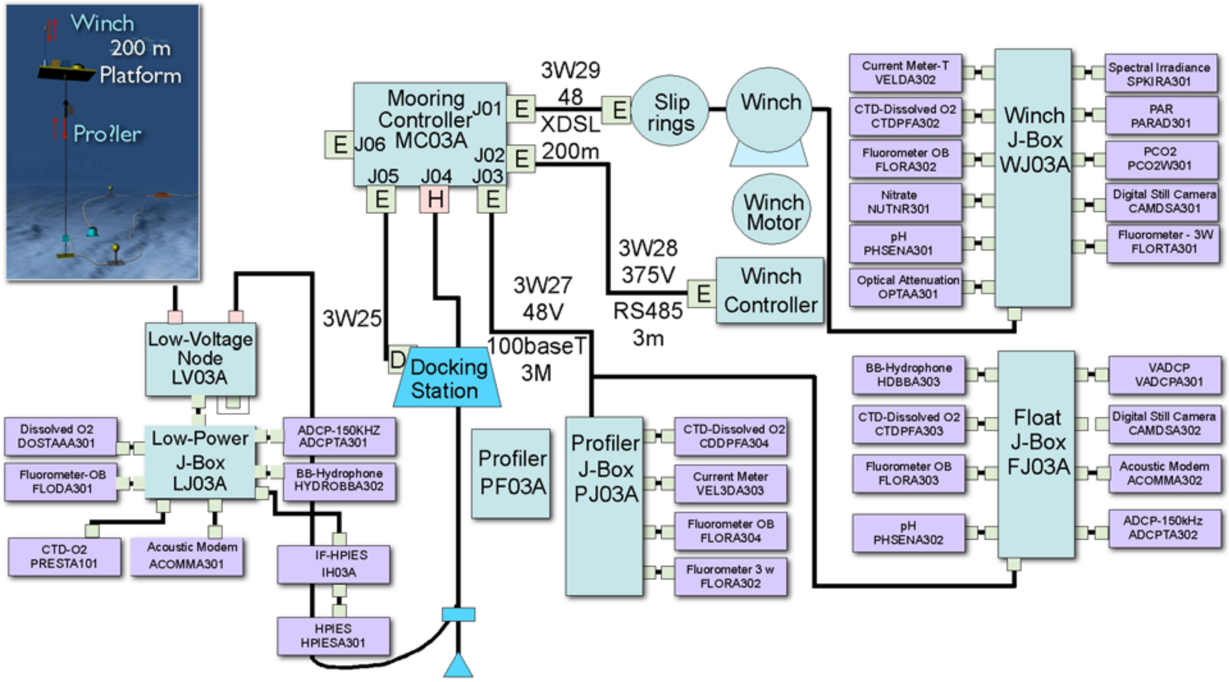

Figure 4.4-11. Block Diagram for all components of the Water Column Moorings. One mooring will be at Node 1A near the base of the accretionary margin near Hydrate Ridge and another at the base of the eastern flank of Axial Seamount on Primary Node 3A.

4.4.3.9 Basic Core Seafloor Mooring Measurement Package (BCSMM)

The Basic Core Seafloor Mooring Measurement Package includes seven instrument packages for measurement of physical oceanographic and chemical processes near the seafloor through the entire vertical ocean water column. One of these packages will be near the base of each of the two RSN moorings. Sensors such as the broadband hydrophone provide tracking of cetacean vocalization and are important assets for geophysical experiments to measure secondary reception of primary waves from seismic events. The BCSMM sensors, exemplar models, manufacturer and location are shown in Table 4.4-6 and example block diagram is shown in Figure 4.4-12. Power and bandwidth requirements are summarized in Table 4.4-7.

Table 4.4-6. Basic Core Seafloor Mooring Measurement Package (BCSMM)

Measurement	Example Sensor	REDACTED	Location
Secondary reception of P-waves, cetacean vocalization, water current	Broadband Hydrophone		Mounted on stand
Conductivity, Depth, Temperature, Ocean mixing, biological potential	CTD-dissolved O2		CTD-O2 coupled and mounted on junction box.
Turbidity by light absorption, chlorophyll	Fluorometer-Optical Backscatter		Mounted on Ti-stand, pressure housing
Movement of water mass above the seafloor	ADCP-150 kHz		Mounted on bottom stand
Gravest mode average water currents of the water column, horizontal electric field	HPIES*		On own stand 500 m from LVNode
Communication and navigation	Acoustic Modem		Mounted on bottom stand

* Horizontal Electric Field and Pressure Inverted Echo Sounder

Table 4.4-7. Power and Bandwidth Requirements for Basic Core Seafloor Mooring Measurements Package (Reference Document: RSN Power and Bandwidth V 1.0)

Sensor	Average Power	Voltage	Bandwidth	Interface
Hydrophone	1.2 W	12-15 Vdc	<400 b/s	RS232
CTD Dissolved O2	3W, 60 mW	7-16, 6.5-24 Vdc	6-768 kS/s	ethernet
Fluorometer-Optical Backscatter	96 mW	7-15 Vdc	<96 b/s	RS232/485
ADCP-150 kHz	60 (xmit), 4 avgW	6-16 Vdc	9600 b/s	RS232/485
HPIES	1 W	12 Vdc	16 kBaud	RS232
Acoustic Modem	10 W	5-15 Vdc	<5400 bps burst	RS232 or bus

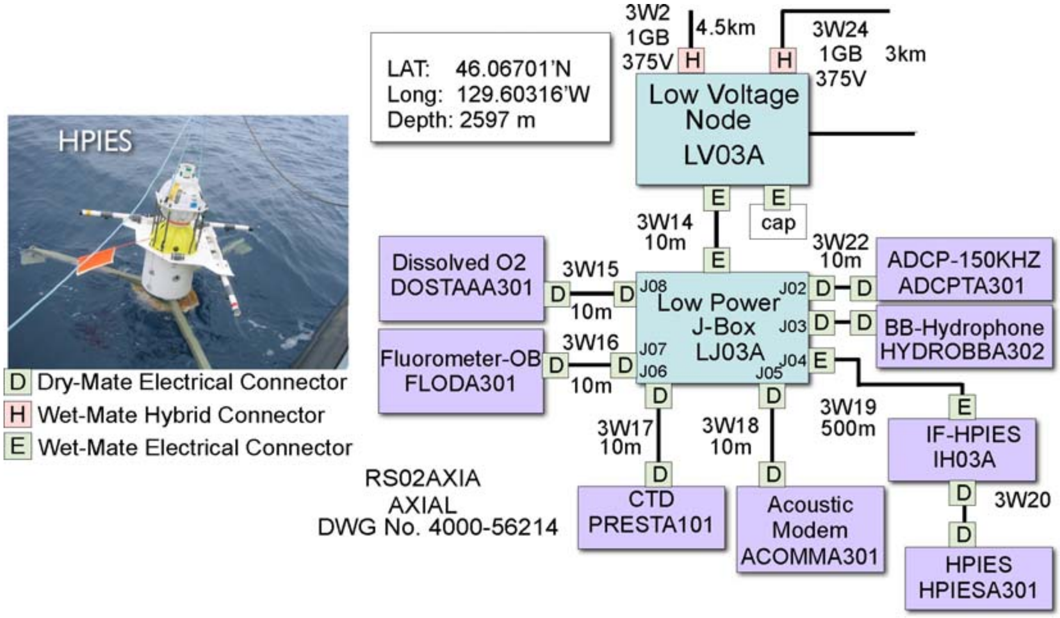

Figure 4.4-12. A Block Diagram for the Basic Core Seafloor Mooring Measurements Package for the water column mooring located 4.5 km NW of Primary Node 3A near the base of Axial Seamount. The image to the left shows a Horizontal Electric Field and Pressure Inverted Echo Sounder (HPIES) instrument package being deployed.

4.4.3.10 Profiler Instrument Package Sensors

The Profiler Instrument Package includes five sensors mounted on a profiler that traverses from just above the seafloor to just below the 200-m float where it couples to a Docking Station (Figure 4.4-13). One of these packages will be on each of the two RSN moorings. The five instrument packages are required for measurement of physical oceanographic and chemical processes near the seafloor through the entire vertical ocean water column. These sensors are profiler-mounted to provide temporal and spatial measurements over nearly the entire ocean depth. The Profiler Instrument Package Sensors, exemplar models, manufacturer and location are shown in Table 4.4-8 and example block diagram is shown in Figure 4.4-13. Power and bandwidth requirements are summarized in Table 4.4-9. Additional information on the profiler requirements and design is provided in Deep_Profiler_Tech_Specifications_ver_2-00.

Table 4.4-8. Sensors on Profiler Instrument Package

Measurement	Example Sensor	REDACTED	Location
Conductivity, Depth, Temperature, Ocean mixing, biological potential	CTD-dissolved O_2		CTD-O_2 coupled and mounted on Profiler.
Turbidity by light absorption	Fluorometer-Optical Backscatter		Mounted on Profiler
Velocity	Current Meter + Acoustics- 3Dwave		Mounted on Profiler.
Chlorophyll a, CDOM, fluorescence, optical backscatter, biological activity	Fluorometer-3 wave length		Mounted on Profiler

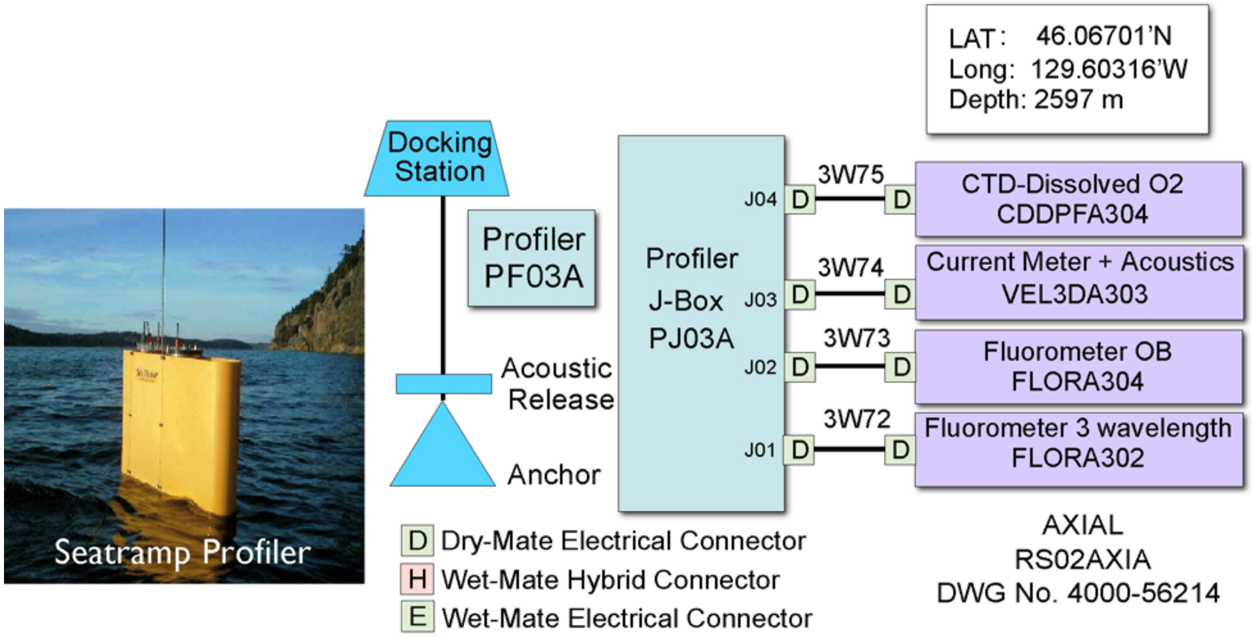

Figure 4.4-13. A Block Diagram for the Profiling Instruments Package for the water column mooring located 4.5 km NW of Primary Node 3A near the base of Axial Seamount. The image to the left shows Seatramp Profiler being deployed as an example profiler.

Table 4.4-9. Power and Bandwidth Requirements for Sensors on the Profiler Instrument Package (Reference Document: RSN Power and Bandwidth V 1.0)

Sensor	Average Power	Voltage	Bandwidth	Interface
CTD Dissolved O2	3W, 60 mW	7-16, 6.5-24 Vdc		RS232
Fluorometer-Optical Backscatter	96 mW	7-15 Vdc	<96 b/s	RS232/485
Current Meter + Acoustics	420 mW	7-24 Vdc	<5 Hz, 80 b/s	RS232/485
Fluorometer-3 wave length	1.08 W, 960 mW sleep	7-15 Vdc	<50 b/s	RS232

4.4.3.11 Float Instrument Package

The Float Instrument Package includes nine sensors mounted on a Float Package below the euphotic zone (Figure 4.4-14). One of these packages will be on each of the two RSN moorings. The nine instruments are required for measurement of physical oceanographic, chemical and biological processes in the upper water column. Mounted on the platform, these sensors provide co-registered measurements at high temporal resolution, making optimum use of the power and bandwidth supplied by the RSN cabled network. The Float Package sensors, exemplar models, manufacturer and location are shown in Table 4.4-10 and example block diagram is shown in Figure 4.4-14. Power and bandwidth requirements are summarized in Table 4.4-11.

Table 4.4-10. Sensors on Float Instrument Package

Measurement	Example Sensor	REDACTED	Location
Marine mammal and fish, wind, rain, seismic t-phases	Broadband Hydrophone		Mounted on Platform
Conductivity, Depth, Temperature, Ocean mixing, biological potential	CTD-dissolved O_2		CTD-O_2 coupled and mounted on Platform
Spectral backscatter and chlorophyll	Fluorometer-Optical Backscatter		Mounted on Platform
Ocean acidity	pH		Mounted on Platform
Profiles of turbulence	VADCP		Upward-looking on platform
Imaging of biology (fish), profiler platform, maintenance engineering	High Res Camera Ethernet W strobes, Pan and Tilt		Upward-looking on platform
Communication with surrounding sensors, extend spatial footprint	Acoustic Modem		Mounted on Platform
Medium range velocity profiles	150 kHz ADCP		Upward-looking on platform

Table 4.4-11. Power and Bandwidth Requirements for Sensors on Float Package (Reference Document: RSN Power and Bandwidth V 1.0)

Sensor	Average Power	Voltage	Bandwidth	Interface
Hydrophone	1.2 W	12-15 Vdc	<400 b/s	ethernet
CTD Dissolved O2	3W, 60 mW	7-16, 6.5-24 Vdc	6-768 kS/s	RS232
Fluorometer-Optical Backscatter	96 mW	7-15 Vdc	<96 b/s	RS232
pH	84 mW	6-24 V	<16 b/s	Analog to CTD
VADCP	310 mW op., 0.8 mW sleep	12-15 V	10 Hz	RS232
High Resolution Camera Ethernet W strobes, Pan and Tilt	5.5 W	12 Vdc	0.765 Gb/s	100BASET/TX
Acoustic Modem	10 W Xmit, 80 mW Rcv	5-16 Vdc	<5400 bps burst	RS232
150 kHz ADCP	60 W xmit 4W avg	20-50 V		RS232

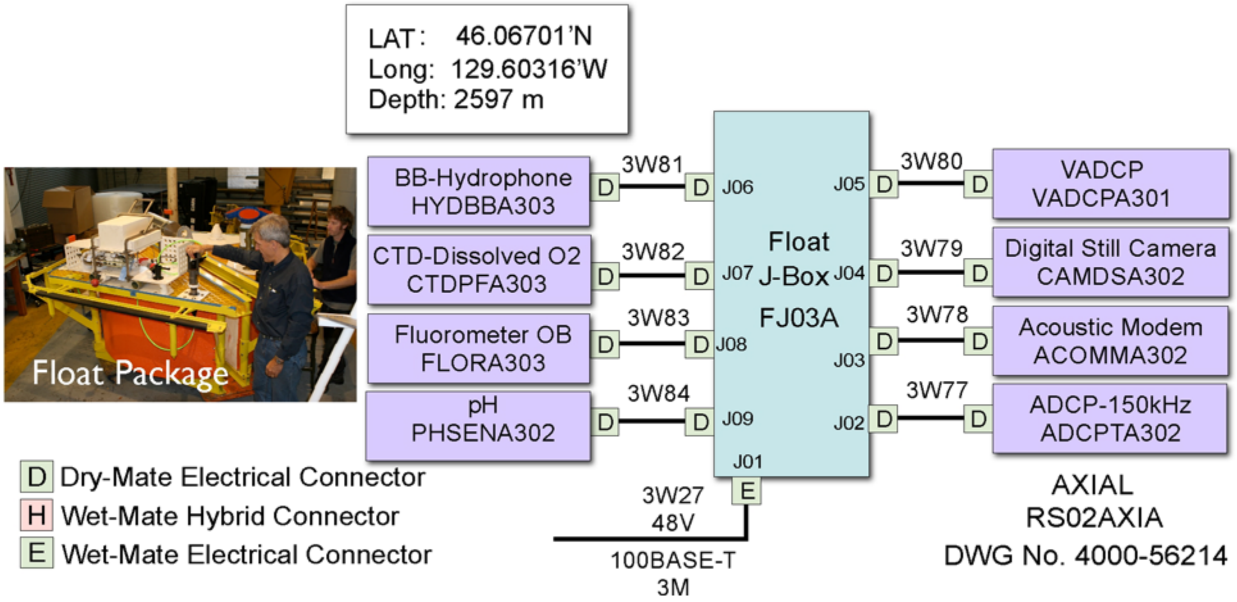

Figure 4.4-14. Block Diagram for sensors on the Float Instruments Package for the water column mooring located 4.5 km NW of Primary Node 3A near the base of Axial Seamount. The image to the left shows a float platform prior to its deployment in Puget Sound.

4.4.3.12 Winch Instrument Package

The Winch Instrument Package includes 12 sensors mounted on the Float Package Winch Instrument Platform (Figure 4.4-15). One of these packages will be on each of the two RSN moorings. The 12 instruments are required for measurement of physical oceanographic, chemical and biological processes throughout the ~ 200 m upper water column to the surface. Mounted on the platform, these sensors provide co-registered measurements at high temporal resolution, making optimum use of the power and bandwidth supplied by the RSN cabled network. The Winch Instrument Platform sensors, exemplar models, manufacturer and location are shown in Table 4.4-12 and example block diagram is shown in Figure 4.4-15. Power and bandwidth requirements are summarized in Table 4.4-13. Specifications and additional information is provided in the RSN Winch_Profiler_Tech_Specifications_ver_2-00 document.

Table 4.4-12. Sensors on Winch Instrument Package

Measurement	Example Sensor	REDACTED	Location
Velocity	Current Meter + Acoustics- 3Dwave		Mounted on Winch Float
Conductivity, Depth, Temperature, Ocean mixing, biological potential	CTD-dissolved O_2		CTD-O_2 coupled and mounted on winch float
Spectral backscatter and chlorophyll	Fluorometer-Optical Backscatter		Mounted on Winch Float
Biologically important nutrients	Nitrate		Mounted on Winch Float
Ocean acidity, climate change	pH		Mounted on Winch Float
Optical Attenuation	Optical Attenuation		Mounted on Winch Float
Visible Light Penetration into the water column	Spectral Irradiance		Mounted on Winch Float
Photosynthetically active radiance, biological processes	PAR		Mounted on Winch float
Dissolved carbon dioxide, ocean acidity, climate change, biological processes	pCO2		Mounted on Winch float
Imaging of biology (fish), profiler platform, maintenance engineering	High Res Camera Ethernet W strobes, Pan and Tilt		Mounted on Winch float
Chlorophyll a, colored dissolved organic matter, fluorescence, optical backscatter, biological processes	Fluorometer-3W		Mounted on Winch float

Figure 4.4-15. [redacted]

Table 4.4-13. Power and Bandwidth Requirements for Sensors on the Winch Instrument Package (Reference Document: RSN Power and Bandwidth V 1.0)

Sensor	Average Power	Voltage	Bandwidth	Interface
Current Meter + Acoustics	420 mW	7-24 Vdc	<5 Hz, 80 b/s	RS232/485
CTD Dissolved O2	3W, 60 mW	7-16, 6.5-24 Vdc	6-768 kS/s	ethernet
Fluorometer-Optical Backscatter	96 mW	7-15 Vdc	<96 b/s	RS232
Nitrate	6.5 W	6-18 V (Non-isolated) 19- 75 V (Isolated input) 1 - 36 V (Optional isolated input)	1 Hz	RS232/485 USB
pH	84 mW	6-24 V	<16 b/s	Analog into CTD
Optical Attenuation	0.85@12V	10-16 Vdc	6 scan/s nominal	RS232/485
Spectral Irradiance	25 mA @ 12 Vdc	6-22 Vdc 12 nom	7 Hz, 24 Hz opt.	RS232/485
PAR	10 mA@ 12 Vdc	PC serial port	9600 baud	RS232
CO_2	250mA@14.5 Vdc	8-14 Vdc	9600-15200 baud	RS232
High Res Camera Ethernet W strobes, Pan & Tilt	5.5 W	12 Vdc	0.765 Gb/s	100BASET/TX
Fluorometer-3 wave length	1.08 W, 960 mW sleep	7-15 Vdc	<50 b/s	RS232

4.4.3.13 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 4.4-16). It is the only place in the world's oceans where long-term measurements have been made on the subsurface biosphere, examining changes in microbial communities linked to changes in fluid chemistry following an eruptive event. This site also has a long history of monitoring through NOAA's NEMO Observatory program that had a moored instrument array here with real-time monitoring capabilities.

Instrumentation at this site will provide critical measurements/quantification of carbon dioxide emissions and other volcanic gases into the hydrosphere. Only discrete measurements at any submarine volcano have been made to date, preventing accurate flux measurements to be made. Infrastructure at the summit of Axial Seamount and on the full water column mooring support requirements described in OOI Science Requirements documents: A-1 Global Biogeochemistry and Carbon Cycling; A4 Fluid-Rock Interaction and the Subseafloor Biosphere; A-3 Ocean Circulation, Mixing, and Ecosystems; A5-Plate Scale Seismological and Geodynamics; A-4 Fluid Rock Interaction and the Subseafloor Biosphere; A-5 Plate-Scale Seismology and Geodynamics; A-7 Climate Variability and Ecosystems; and A-8 Ocean Mixing and Rough Topography.

Infrastructure at Axial Seamount includes a Primary Node 3A located in a benign area roughly 20 km down slope in Thompson Basin at the base of the eastern flanks and a Low Voltage Node (LVO3A) (Figure 4.4-16; Tables 4.4-14 and 4.4-15). The LV Node supports the Basic Core Seafloor Mooring Measurement Package and a full water column mooring with its full contingent of sensors, and a profiler and winch. Primary Node 3A also supports a Medium Power J-Box (MJO3A) that provides communication to the common suite of Basic Core Seafloor Measurement packages. Meter scale resolution bathymetry, direct seafloor imaging and a 3.5 kHz sonar survey of this area show that this area is flat and heavily sedimented.

A 40-km long cable connects Primary Node 3A to Primary Node 3B, which is located on the southeast portion of the summit at eastern edge of the caldera. Primary Node 3B provides power and communication to five Medium Power J-Boxes that allow access to the Ashes vent fields and to the north central portion of the caldera. Primary Node 3B will also host a broadband and short-period seismometer, a hydrophone, as well as a bottom pressure recorder and tilt meter (Figure 4.4-17). A suite of chemical, physical oceanographic, and biological sensors will be located in and near vigorously venting chimneys and diffuse vent sites at the Ashes Vent Field. Three Medium Power J-Boxes and ~ 3 km long armored extension cables provide access to this site. Additional short-period seismometers and coupled pressure sensors and tilt meters will also be placed at these sites. An additional cable provides power and communication (10 Gb) to stereo high definition cameras located at the ASHES 3 site. A 5 km long extension cable extends up the center of the caldera to provide access to a Medium Voltage Node that supports two short-period seismometers and a coupled pressure sensor and tilt meter.

Figure 4.4-16 (following page)**.** A) Axial Seamount is the most magmatically active portion of the Juan de Fuca Ridge, significant CO2 degassing occurs during volcanic events, and it hosts three hydrothermal fields within its central caldera. B) A full water column mooring with an instrumented profiler and winch provide vertical measurements with 7 and 4 cycles/day, respectively. This system could capture a megaplume event in real-time, something never before achieved. C) An diverse suite of sensors within the ASHES vent field, including stereo HD cameras provide direct measurements for examining the connections between volcanism and life.

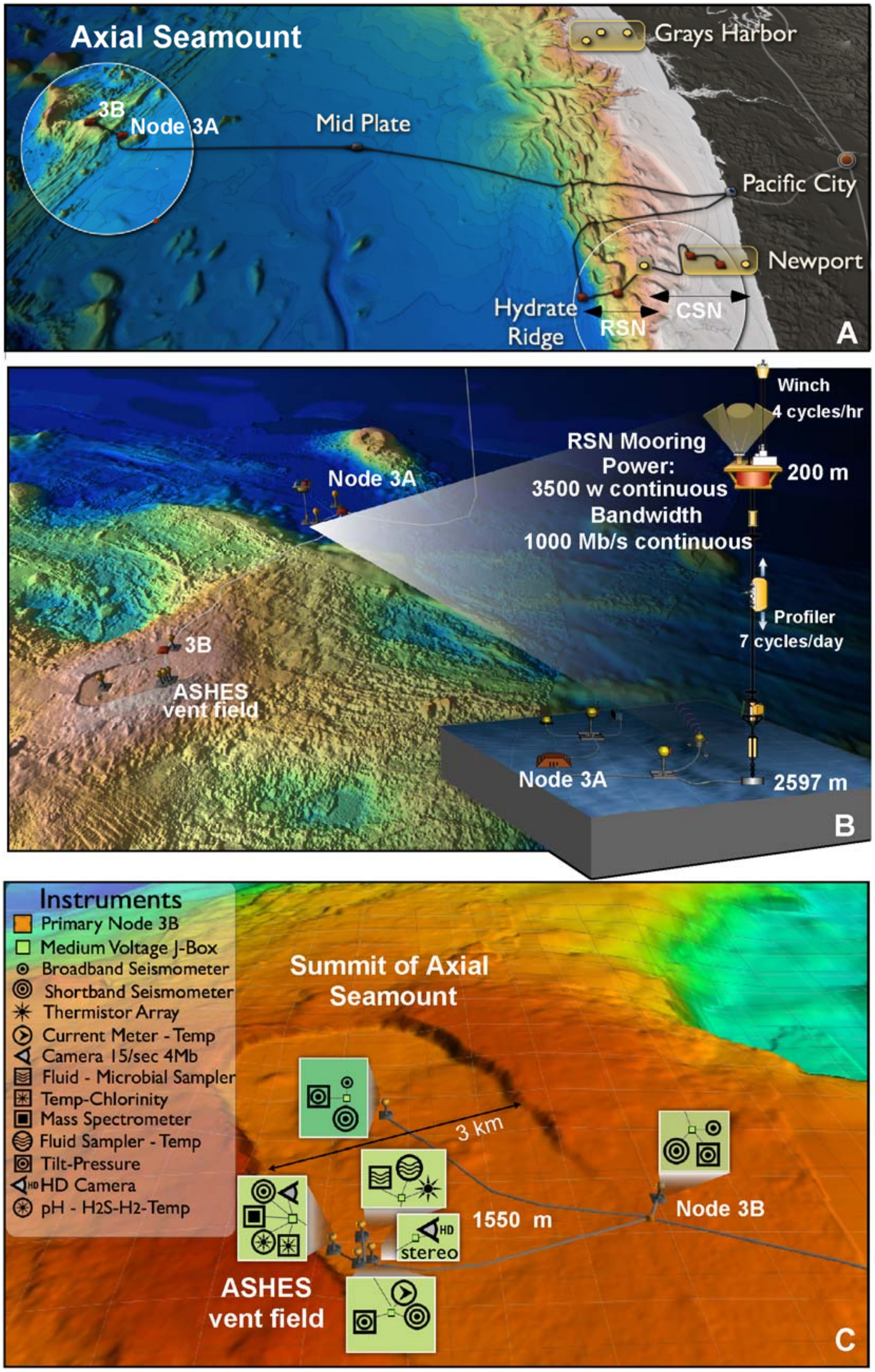
Axial Seamount
Grays Harbor
3B
Node 3A
Mid Plate
Pacific City
Newport
Hydrate Ridge
RSN
CSN
A
Winch
4 cycles/hr
RSN Mooring
Power:
3500 w continuous
Bandwidth
1000 Mb/s continuous
200 m
Node 3A
3B
ASHES vent field
Profiler
7 cycles/day
Node 3A
2597 m
B
Instruments
Primary Node 3B
Medium Voltage J-Box
Broadband Seismometer
Shortband Seismometer
Thermistor Array
Current Meter - Temp
Camera 15/sec 4Mb
Fluid - Microbial Sampler
Temp-Chlorinity
Mass Spectrometer
Fluid Sampler - Temp
Tilt-Pressure
HD Camera
pH - H2S-H2-Temp
Summit of Axial Seamount
3 km
1550 m
HD
stereo
Node 3B
ASHES vent field
C

Table 4.4-14: Axial Seamount Core Measurements, Sensors, and Locations

Measurement	Example Sensor	REDACTED	Location
Global/regional seismic events, harmonic tremor	Broadband Triaxial Seismometer & Accelerometer		On outer south-eastern portion of summit/flank, buried in caissons in sediment
Secondary reception of P-waves, cetacean vocalization, wind, rain	Hydrophone		Mounted on stand
Regional/local seismicity, hydrofracturing	Short Period Seismometer		In arrays within 250 m to ~3 km from hydrothermal fields, placed in coreholes in basalt or in cement seismonuments
Temperatures of diffuse flow across seafloor	Thermistor Array		Linear array across seafloor
Local currents, background ocean temperature	Current Meter + Temperature		On <1 m mooring near hydrothermal site
Tidal Pressure on Seafloor	Pressure		Mounted on Ti-stand, pressure housing
Dissolved volatiles vent fluids	Mass Spectrometer		Intake extends from venting site to TI-housing on stand
Major/Trace element chemistry of diffuse flow fluids	In situ Time Series Osmotic Water Sampler + temperature		Seafloor frame with intake extending into diffuse flow site
Digital still imagery of vents and macrofauna	Seafloor High Res Camera W strobes		On frame with pan and tile capabilities, lights
Black smoker fluid temperature, hydrogen	Temperature Resistivity-H_2		Sensor tip placed within black smoker orifice, logger in Ti-housing on stand
Black smoker fluid temperature, hydrogen, hydrogen sulfide, and pH	pH-Hydrogen Sulfide-Temperature-hydrogen		Sensor tip placed within black smoker orifice, logger in Ti-housing on stand
Digital still imagery of vents, diffuse flow, and macrofauna, flow velocity calculations	Stereo High Definition Camera		On frame with pan and tile capabilities, lights
Inflation and deflation of seafloor due to magmatic processes	Bottom Pressure Tilt Recorder		Ti-housing, stand, leveled
Major/trace element chemistry of diffuse flow fluids, co-registered temperature, hydrogen sulfide, pH	Remote Access Fluid Sampler		Mooring with extension to vent
Microbial community in diffuse flow systems	Particulate DNA Sampler		Mooring with extension to vent

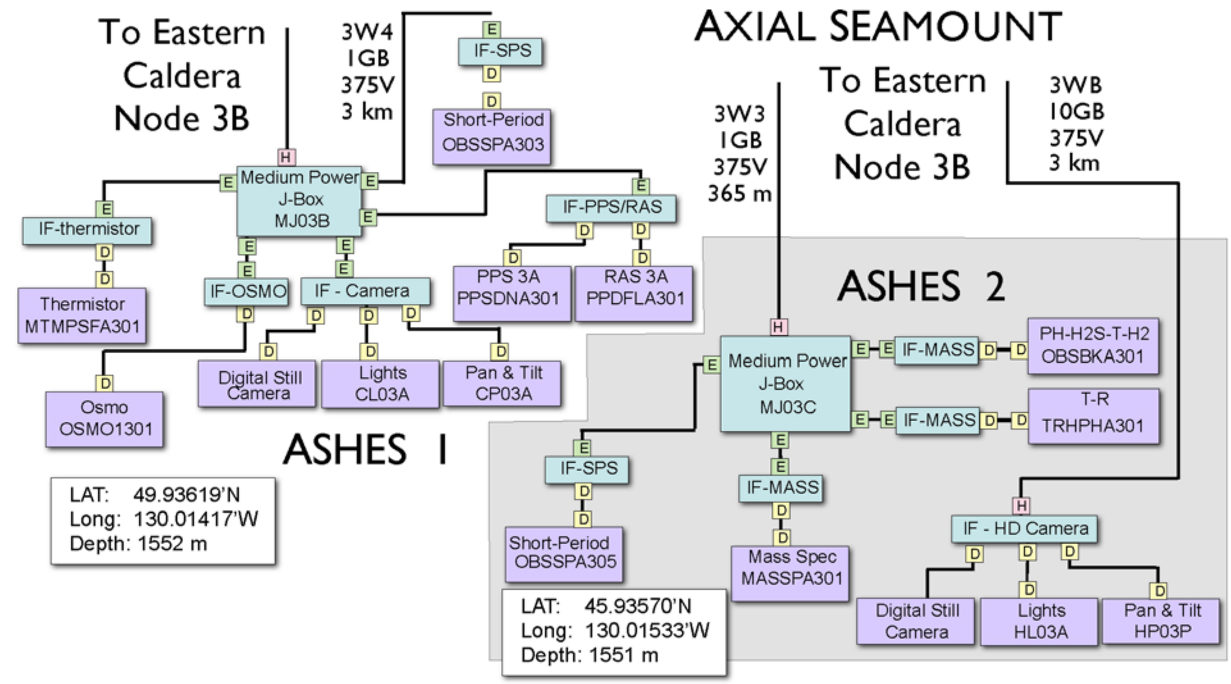

Figure 4.4-17. Block diagram of Secondary Infrastructure at the ASHES 1 and ASHES 2 hydrothermal sites in the caldera of Axial Seamount. Three other Medium Power Junction Boxes in the caldera and near its rim provide power and communication to a suite of geophysical sensors.

Table 4.4-15. Power and Bandwidth Requirements for Sensors on Axial Seamount Measurement Package (Reference Document: RSN Power and Bandwidth V 1.0)

Sensor	Average Power	Voltage	Bandwidth	Interface
Broadband Triaxial Seismometer	1.8 W	12 or 48	4800 b/s	RS232
Hydrophone	1.2 W	12-15 Vdc	<400 b/s	ethernet
Short Period Seismometer	5 mW	'+/- 5Vdc (+/- 7.5Vdc I14 max to analog sensor) - 48V (logger)	1/s	RS422 –future (100baseT)
Thermistor Array	96 mW W	7-15 Vdc	<96 b/s	
Current Meter + Temperature	345 mW op, 8.1 mW sleep	12-15Vdc	<400 b/s	RS-232
Pressure	7-28Vdc & +6-16Vdc	<2 Hz	RS-485/-232	7-28Vdc & +6-16Vdc
Mass Spectrometer	72W	24 Vdc		RS232
Osmo Fluid sampler	<1 W	12 Vdc	0.5 Hz	
Seafloor High Res Camera Ethernet W strobes PAR	5.5 W	12 Vdc	0.765 Gb/s	100BASET/TX
Temperature Resistivity-H_2	~5 mW			RS232
pH-Hydrogen Sulfide-Temperature-hydrogen	~5 mW			RS232

High Definition Camera	Camera: Pan/Tilt: <110 W, Light: 200 W	Camera: Pan/Tilt: 12-32 Vdc Light: 80-185 Vdc	Camera: Pan/Tilt: low rate commands, Light: N/A	RS-485/-232
Bottom Pressure Tilt Recorder	LILY: 360mW Pres: 192 mW	7-28Vdc & +6-16Vdc	<2 Hz	RS-485/-232
Remote Access Fluid Sampler	5.2 W	31.5 Vdc	50 Samples	RS-232
Particulate DNA Sampler	9 Ah (battery, intermittent)	31.5Vdc	physical samples	

4.4.3.13 Mid Plate

The Mid-Plate Primary Node (Figure 4.4-1), located between Axial Seamount and the Pacific City Shore Station, is important because it provides one of the few mid-plate sites that will enable future study of stress propagation through the plate as well as intraplate deformation and its relation to plate boundary failure. The site will not be equipped with core sensors when first installed. This site serves as an important engineering connection to the Axial Seamount site because of the long connecting cable distance from the Shore Station to Axial Seamount. As such, is serves in a similar fashion as a “Repeater” that provides power and bandwidth to the Axial Seamount site. It provides the capability for future support of requirements as described in OOI Science Requirement document A5-Plate Scale Seismological and Geodynamics. The Mid-Plate Primary Node will be installed with a nearby cable extension of approximately 5 km (or sufficient length to enable pick-up by a ship) to allow for the option of expansion to establish additional node and/or science sites (should opportunity and funds become available after construction).

4.5 Education and Public Engagement

4.5.1 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 led to development of on-line platforms for instruction that engages students in active scientific inquiry (27), incorporates computer simulations of real-world phenomena (28 and 29), and involves collecting and analyzing data (30 and 31). The OOI brings that potential closer to reality for ocean education.

As the OOI develops and deploys transformative tools necessary to pursue our national research priorities it must also enable the "effective translation of results into readily understandable information usable by decision-makers, resource managers, educators, and potential workforce participants" (4). The education goals and the key science questions that frame the OOI infrastructure are tightly coupled; the science questions provide the interdisciplinary context for effective marine education that, in turn, develops the intellectual capital needed to build research capacity and a literate and engaged public. Building this capacity and engaging the public will require sustained educational efforts targeted at multiple audience levels.

The ability to engage and serve a range of education providers and communities and to encourage partnerships between them will be a critical contribution of OOI infrastructure, one that is enabled both by both OOI cyberinfrastructure and by OOI educational infrastructure designed to provide educators with the tools and resources required to make unique educational contributions. These efforts will help ensure that national and international policy and science priorities are simultaneously addressed at a variety of scales (global to local) and tailored to account for differences in geographic regions, cultural diversity, digital capabilities, as well as different ocean uses, interactions, and phenomena within these areas. The OOI will participate in a nationally "coordinated effort to develop and promote a comprehensive education message about the ocean and its role in the Earth System, and to enable the use of ocean-observing data for management and educational purposes" (4).

Capitalizing on the burgeoning fields of information and visualization technology and the increasing power of the Internet, OOI Education and Public Engagement (EPE) 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 ocean science EPE programs of unprecedented technical sophistication that serve the entire ocean science education community.

4.5.1.1 Vision

The OOI has the potential to seed widespread public appreciation of the oceans and ocean science and technology. OOI science will provide the interdisciplinary context for inspirational and effective marine education, which in turn develops the intellectual capital needed to build research capacity and a literate and engaged public. The OOI will allow users to go places they have never been, and see things they have never seen. It will allow them to track dramatic planetary events, or multiple simultaneous events, while they are happening. By enabling Education and Public Engagement applications as part of the wider investment in infrastructure and programs, the discoveries of the OOI will be made immediately accessible, compelling, and important to educators, the public, and policy makers. Support from these audiences is critical to healthy funding for long-term observatory operations, research, and education. 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 cumulative history of OOI EPE planning can be summarized as the Ocean Observatories Initiative education and public engagement program will connect people to 21st century ocean science and technology through integration of OOI science and education.

The vision for OOI Education and Public Engagement:

> *Education providers will have the tools, services, and resources to deliver compelling ocean education experiences accessing observatory data and scientists. These will enable them to develop new approaches that maximize the unique and transformative science and engineering capacities of OOI*.

Education programs associated with the OOI, or created using OOI resources and infrastructure, will:

- Emphasize the creative opportunities enabled by the novel aspects of the OOI (e.g. near real-time data, the virtual ability to control/configure sensors and mobile assets, high-bandwidth infrastructure for images, powerful cyberinfrastructure and links to the scientific community);
- Have an impact on a nationwide scale, in particular through partnerships with existing ocean education enterprises;
- 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;
- Enhance the size, intellectual scope, diversity and sophistication of the ocean education user community;
- Develop explicit and continuous goals around reaching underserved audiences; 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 can be fully developed.

4.5.1.2 Goals

Two broad goals have been established to attain the OOI vision. Use of the OOI's EPE infrastructure will:

- Increase public engagement, 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.

These EPE goals stem directly from the community consensus established at the first OOI workshop in Puerto Rico and in the former OOI Education and Public Awareness Committee (3) as well as from PDR panel recommendations and a 2008 OOI EPE Drivers Workshop. They are well aligned with National Science Board (NSB) priority recommendations for an NSF Science, Technology, Engineering, and Mathematics (STEM) education roadmap (21; see box below), directly addressing priorities two and three and providing support for investigations into the efficacy of cyber-enabled teaching and learning (32).

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.

A National Action Plan for Addressing the Critical Needs of the U.S. Science, Technology, Engineering and Mathematics Education System (National Science Board, October 2007)

Detailed specifications of target audiences for education infrastructure that will enable achieving these OOI EPE goals are discussed in detail below.

4.5.1.3 Audiences

Recognizing that it is beyond the scope of the OOI EPE infrastructure to reach all possible audiences, the *ad hoc* Working Group, in consultation with NSF program officers, used the following criteria for selecting target audiences. Audience focus must 1) complement and leverage, rather than duplicate, existing ocean education activities and programs (e.g. the Centers for Ocean Sciences Education Excellence program, COSEE); 2) 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; 3) cultivate future generations of OOI scientist users; and 4) leverage and build on the wider OOI cyberinfrastructure. To date, most of funding for ocean science education has been directed toward formal K-12 learning (e.g. COSEE) and K-12 teacher professional development. Far fewer resources have been dedicated to informal or free-choice learning and post secondary education. Furthermore, all areas of science education are increasingly taking advantage of the Internet, Internet resources and the growing expectation that a wide range of information and services can be accessed online. As a result, the OOI EPE infrastructure development will focus primarily on:

- Supporting "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.
- Supporting online post-secondary career, technical and educator training programs, with a focus on increasing participation and diversity in ocean science and technical careers.

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. While narrowing the possible range of audiences for the initial EPE activities, this selection is strategic in that it allows for long-term development that will reach a wider range of audiences. For example, by including teacher professional development as part of the post-secondary audience, it is anticipated that pre-college audiences will be reached as the next generation of educators engages more fully in the use on online resources.

Education infrastructure that will empower the requisite access, tools and services is key to reaching the goals and audiences articulated above. It is also crucial to establishing the OOI as the foundation on which to create education programs of the breadth, depth and sophistication implicit in the OOI vision. The MREFC investment in Education and Public Engagement infrastructure provides the opportunity to build on the OOI cyber- and marine infrastructures to establish this enabling infrastructure.

Essential elements of education infrastructure envisioned for OOI include:

- A clear focus on providing access to the actual execution of oceanographic research, not just describing it;
- A system(s) that bridges the gap between cyberinfrastructure services and what education professionals need to reach target audiences;
- A suite of data visualization tools, products, services and audience-appropriate user interfaces;
- Capacity for engaging non-scientist users;
- Open access to educational and scientific content and services; and
- Collaboration with the marine and cyberinfrastructure IOs so that education infrastructure strategically leverages the OOI infrastructure and capabilities.

These elements will naturally build on the OOI cyberinfrastructure as articulated in the CI Work Breakdown Structure, the CI User Requirements, and the CI-EPE Interface Requirements documents.

4.5.1.4 Progress since Preliminary Design Review

The key panel recommendations from the December , 2007 Preliminary Design Review Report (15) included the following:

"***A fourth IO for Education and Public Engagement (EPE) will be added*** *… a program structure that will help realize the education goals, and support efforts to engage members of underrepresented groups in ocean science.*"

"***OOI must develop a set of education drivers****, with external community input, to direct and integrate the Education and Public Engagement effort, just as science drivers are integrated throughout the IOs and program management structure."*

To address panel concerns and advance EPE planning, an *ad hoc* EPE Planning Group comprising the EPE representatives from each IO and key personnel at OL met weekly in the 9 months after PDR to devise strategies that address the panel recommendations and move the EPE IO closer to fruition. Strategies already executed include:

- Convening a community workshop to develop a set of high level Education Drivers and Education Requirements
- Collaborating with the CI design team to integrate education with CI, specifically in the development of Education Requirements (i.e. those that serve as the basis for the work of the EPE IO) and a draft list of CI/EPE interface requirements that will serve as the foundation for a future EPE/CI IO interface requirements
- Creating a draft RFP for a fourth IO dedicated to EPE
- Developing examples of the integration of science and education using OOI science themes and Ocean Literacy Principles as the framework
- Working with management to ensure integration of education with science occurs throughout the OOI network.

4.5.2 Drivers and Requirements

4.5.2.1 Development of EPE Drivers

The Education and Public Engagement (EPE) Working Group hosted an EPE Drivers Workshop to engage the science education community in developing education drivers for the OOI, from which the Planning Group could develop Requirements. This workshop was convened in Portland, Oregon, June 18-19, 2008, and followed immediately on the OOI Cyberinfrastructure (CI) Education Requirements Workshop. The goal of the EPE workshop was to bring together recognized experts from a variety of science education disciplines to collaborate in developing EPE drivers (i.e., top-level requirements) and to map those high-level education drivers into a set of EPE Requirements, i.e., the requirements defining the technologies to support those drivers. Workshop participants were educators and scientists with expertise in web, virtual community, data visualization, and gaming knowledge. Their experience included K-20 ocean education, free choice and inquiry-based learning, oceanographic research, and cyberinfrastructure architecture.

The drivers and requirements formed the basis of a draft *Education and Public Engagement Request for Proposals* (33) to establish the EPE Implementing Organization for the OOI Network, and provide the framework for designing the infrastructure to support OOI 21st Century ocean education. The drivers listed below are the primary outcome of the workshop and define the overall focus of the OOI education effort. They do not represent a list of expectations to be met by the EPE IO alone; they also describe the expectations for the OOI Network, affirming and highlighting the need for creating the EPE IO.

OOI Education and Public Engagement Drivers:

1. The OOI will enable communication, education, and public engagement efforts that tightly interweave the key OOI science themes with the essential principles of ocean literacy.

2. The OOI will support online post-secondary training programs with a focus on increasing participation and diversity in ocean science and technical careers. It will also support "free choice" learning in a variety of both physical and virtual settings with a focus on increasing public engagement with ocean science and technology.

3. The OOI will enable multiple forms of access to and engagement with the development path and construction history of the OOI enterprise in order to support innovative engineering and technology education.

4. The OOI will have the capacity to engage and respond to audiences of diverse cultural or economic backgrounds, or who may traditionally have been underserved in ocean education.

5. The OOI will enable multiple forms of interaction and collaboration that assist in the formation of ocean policy at both national and international levels.

6. The OOI will support enhanced field experiences for students engaged in OOI activities including construction, operation, maintenance, and research.

7. The OOI will enable multiple forms of interaction and collaboration that facilitate networked community access among scientists, engineers, and educators.

8. The OOI will enable open access to EPE data products, visualizations, and other educational materials developed as part of the OOI effort for a wide range of users.

9. The OOI will be developed in collaboration with, and support of, the national community of marine education providers, in order to leverage the unique contributions of the OOI and to more effectively reach a broad audience.

4.5.2.2 EPE Requirements

The implemention of OOI EPE infrastructure will require design, development, construction, testing/piloting 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 and tailored specifically for use in an educational context. While the CI will provide basic functionality for the researcher, another layer or bridging system of infrastructure is envisioned for use in reaching the target audiences. This layer will constitute the EPE infrastructure.

Requirements statements are intended to describe a singular documented need of what a particular product or service should be or do, i.e., it is the enabling capability to be furnished to the user. Like all OOI user, system, and design requirements, the EPE User Requirements will be managed and tracked in the OOI Requirements Database (the DOORS application - Dynamic Object Oriented Requirements System). The DOORS database will facilitate tracking, analysis, and linkages for multi-level traceability, testing, and reporting.

A set of *top-level requirements* was derived from the EPE Drivers above and is articulated in the L2 Education (EPE) Requirements (DCN 1122-00000). These *top-level requirements* are binned as follows: general EPE requirements for the OOI network; requirements defining the audiences and general descriptions of required services; data services; networking services, and requirements to provide remote field experiences.

A set of specific *EPE User Requirements* (i.e., education users, EUR) address the technologies identified by the workshop participants as needed to meet the top-level EPE requirements (articulated in detail in the EPE Requirements document; 34). These requirements are binned into the following five initial subsystems: Tools; Resource Storage, Archiving, and Retrieval; Virtual Participation; People Resources; and Pubic Engagement. Under each of these categories are requirements pertaining to education users (EUR) that the EPE infrastructure, to be developed by the EPE IO, must address.

4.5.2.2.1 Subsystem - Tools

4.5.2.2.1.1 Web-based Interfaces

The EPE IO will provide intuitive web-based user interfaces for audiences to browse and access relevant CI services and resources. OOI data, being digital in nature, will be most widely accessed online. Users will have a wide range of familiarity with data and graphical interpretations of data, from very sophisticated to quite elementary. The web-based user interface will need to be easy to use and navigate to allow access to OOI resources in many formats, from raw data to ready-to-use templates. This requirement implies interaction with the CI IO to collaboratively develop a user interface for identified target audiences.

The EPE IO will provide interfaces that allow product developers to access and use relevant CI services and resources. Educational product developers may want to access OOI content to use in a wide variety of applications. Some developers will require raw data to manipulate; others will seek archived model runs to illustrate particular science themes. For example, a museum exhibit developer creating an interactive display may wish to show real-time data flows mapped to the point of origin on the ocean floor, and also provide archived model runs or other data illustrations that show particular earth system attributes interacting. This requirement implies EPE interaction with the CI IO to develop a coordinated user interface for educational product developers.

4.5.2.2.1.2 Visualization

The EPE IO will develop education-specific user interfaces supporting interactive visualization of selected data streams. Education users will want the option of looking at data in various visual formats from which they can select for their preferred playback format. The choice of which kinds of data streams might be viewed in this way will be determined by expert groups including both education specialists familiar with the range of educational settings, and involved scientists familiar with the range of visual formats designated for use within the science enterprise. This requirement implies interaction with all IOs to leverage the suite of visualization tools available for educational purposes.

The EPE IO will provide interfaces to live video from remote sites, where available. Some of the observing sites will have mounted cameras, whose output would be useful to educators to illustrate ocean phenomena such as hydrothermal vents and organism behavior etc. A simple interface would allow educators to view archived or live video feeds. The choice of formats of the live video feeds shall be determined by a combined group of EPE specialists working with all IOs to identify the instrumentation, data formats, and bandwidth available.

4.5.2.2.1.3 Interactions with Models, Simulation Runs

The EPE IO will modify and simplify existing oceanographic models for education purposes. The simplified models shall include the ability to adjust a limited number of parameters and change the visualization output. The preference among educators is for simplified versions of models which do not lose the overall purpose of the model, but dispense with much of the detail. In the simplification process, key parameters should be selected to remain interactive in order to help illustrate the model's output and variability, and where feasible, several options for visualization should be provided. The requirement implies collaboration with all IOs to select and repurpose the suite of models and simulation runs that will best serve educational purposes.

4.5.2.2.1.4 Digital Merger with non-OOI Databases

The EPE IO will ensure that EPE infrastructure is compatible with both OOI and related but non-OOI science data sources as practicable. Educators might seek to use data from a variety of sources, including non-OOI research efforts, to populate a web page or simple database they are constructing for a particular use. The ability to download and interpret data from databases such as those of NASA or NOAA, for example, would greatly enhance the comprehensiveness of education messages and options. This requirement implies collaboration with CI IO to identify and make available such data sources.

4.5.2.2.1.5 Educational Modules

The EPE IO will support education developers by 1) providing access, tools and templates to develop educational modules for key audiences; and 2) providing access and tools to modify, tune, and share educational modules and their parameters. Education developers and users will bring many levels of sophistication to their use of OOI data. Some user/developers may start with using ready-made but modifiable templates with data and interpretive material already integrated, but also linked to the OOI real-time and archived data (e.g., to illustrate earthquake, tsunami, etc). Others will wish to access raw data in order to build their own modules. This spectrum of needs will demand prototype examples that can be ready for immediate use, as well as a database of web tools and products offering ideas for OOI-based teaching opportunities, and a rating system for each module allowing users to critique each other’s work. This requirement implies collaboration with CI IO to identify and provide appropriate interactive web tools.

4.5.2.2.2 Subsystem - Resource Storage, Retrieval and Archiving

4.5.2.2.2.1 Educational Resource Database

The EPE IO will provide an easy-to-navigate database of educational resources and sample solutions. The database shall include education-relevant OOI numerical models and model executions; fields that map OOI data resources to ocean literacy concepts; and fields and metadata that identify education-relevant materials and their sources. All OOI data resources across disciplines and observatories will be searchable by users, but an education-user database will provide a focused, non-technical user interface and key words that will allow educators to match resources with specific education goals and concepts (as per Ocean Literacy), as well as tracking their provenance. In addition, the database will house those models and archived model runs with particular value to illustrating education drivers and concepts. This requirement implies collaboration with CI IO on archiving selected education-relevant numerical models, model executions and work flows.

The EPE IO will develop a review and reporting system for collecting feedback on the usefulness of educational solutions. The database of educational resources and solutions will be dynamic. To enable this, usage analysis will be conducted continuously by the CI IO with EPE IO input, and this analysis will inform the addition of new educational resources and applications to the OOI infrastructure.

4.5.2.2.2.2 Library of Cultural Formats

As resources allow, the EPE IO will integrate needs of underserved audiences into EPE infrastructure, and shall enable the development of culturally diverse formats of OOI-based educational data products. The OOI will design user interfaces and directories to EPE products that recognize cultural diversity and provide access to underserved audiences. This could include: website choices designed for minimum bandwidth usability, pilot studies that encourage collaboration between schools, science centers, and natural community-based activities. Role models from these audiences participating across OOI will be highlighted throughout the design, construction and operation of OOI. The EPE IO will enable the design of educational solutions that deliberately target breadth of cultural diversity.

4.5.2.2.3 Subsystem - Virtual Participation

This infrastructure element will support virtual laboratories and work environments. The EPE IO will enable science missions from planning through control and execution to be tracked through the use of web-based tools. Users will be able to follow science missions as they are planned and carried out. An example would be planning and tracking cruise paths for research vessels. Simulators -- repurposed for educational settings -- would allow users to learn about the variables involved in all stages of science missions. Web-based tools will allow development of virtual access to a limited number and type of remote sites. An example might be stored seawater samples taken from different levels of the water column or different sites. Users could view the data pertaining to available samples from whatever site and depth they select. Another example might be virtual “control” of an unmanned vessel, to provide a sense of designing and implementing a data-gathering mission, and an understanding of the engineering components of OOI.

The EPE IO will develop a database of shore-based science and engineering activities that will be captured, archived and catalogued and can be accessed by educators. Many science and engineering activities that are not solely related to data streams will be taking place in a variety of venues and on varying timescales. Examples include live video links to science centers or classrooms. A selection of these events, identified in collaboration with IOs involved, will be captured for future use by educators.

4.5.2.2.4 Subsystem - People Resources

This infrastructure element will support networking capability among the scientist, educator, and student. The EPE IO will provide access to social networks, two-way video links, video archiving and other communication technologies that allow educators and scientists to interact beyond current boundaries, in real or virtual settings. These might be as simple as e-mail connections, video connections, or chat rooms, but ideally would include collaborative online communities with work spaces in which tools, templates, and ideas could enable active development of educational activities. Tools are customized to support the network's common interests (OOI data access, scientist-educator-learner interaction, flexible growth of new tools that are driven from within). Video conferencing would be scheduled/managed interactions, not permanently available dial-a-scientist access. Such sessions would subsequently be archived for reuse by multiple audiences and individuals.

4.5.2.2.5 Subsystem - Public Engagement

The EPE IO will ensure that all the materials developed under EPE guidance shall be made available to the public as part of the general OOI web presence. The EPE IO will also include EPE IO personnel on the team advising on design and execution of OOI web presence. OOI program-wide web presence should be designed intentionally to take advantage of the transformative education and science infrastructure built by OOI. The EPE effort, managed by EPE IO and its partner IOs, needs to participate fully in designing this web presence for maximum effectiveness.

4.5.2.3 Integration of CI and EPE

The Education User Requirements will guide the EPE IO in creation of essential education infrastructure needed to build capacity for engaging non-scientist users and providing open access to educational and scientific content and services. The educational components of the OOI will be built on the cyberinfrastructure backbone and delivered to the EPE audience through portals analogous to those for the science users - essentially “learning laboratories” or “research classrooms” tailored to non-science user groups. Therefore, although it will naturally work closely with all IOs and their project scientists, the EPE IO will have its closest working relationship with the CI IO.

Recognizing that the EPE IO will develop system(s) and tools that will bridge the gap between the technologies the Cyberinfrastructure IO will deliver and the ability to design products for EPE audiences, the EPE Working Group has collaborated closely with the CI Architecture and Design Teams. Two key activities establish the integration between the EPE and CI: 1) the CI user requirements elicitation workshop held in Portland OR just prior to the Education Drivers Workshop; and 2) the collaborative formulation of an Interface Requirements Agreement between CI and EPE Implementing Organizations.

4.5.2.4 CI Education User Requirements Elicitation Workshop

The CI education user requirements elicitation workshop was focused on specifying key deliverables from CI IO, as specified by domain education and outreach professionals, who were mainly online ocean science education product developers. Workshop goals were:

- Elicit requirements from domain education/outreach professionals and science translators who are actively engaged in technology-based observatory-related activities
- Provide an opportunity for exchange between the CI IO and the types of education professionals who could be involved in the future EPE IO
- Provide the CI engineering team with further detailed insight into educational programs, and provide insight into current teaching/public outreach projects
- Identify and elicit new user requirements for the CI from the view of this specific community
- Validate, refine and prioritize existing user requirements
- Refine and consolidate the basis for further requirements elicitation and domain modeling in subsequent workshops and in ongoing requirements and architecture design work.

The workshop outcomes resulted in the following sets of generalized requirements that eventually were integrated into the final CI User Requirements document.

CI short-term support:
- Data available in standardized forms
- Simplified navigation through metadata
- Ability to subset data based on lat/long (GUI preferred) and other parameters
- Real-time data transfers
- Reliable data set access

CI mid-term support:
- better data visualization,
- repository of tools to browse, transform and visualize data
- improved data accessibility and organization
- real-time data transfer to foster “real science” applications
- intuitive interactivity with the integrated observatory

CI long-term support
- flexible data use through web 2.0 and succeeding tools for browsing through datasets using several visualization styles, and designing/conducting scientific research in classroom or free choice settings
- producing ready-to-use material for websites (e.g., plots)
- processing data in various formats (GMT, GIS, ASCII for Flash, XML)
- geospatial transformations
- interoperability with other observatories across disciplines/directorates.

4.5.2.5 CI/EPE Interface Requirements

There is broad overlap between the outcomes of the CI elicitation workshop and the EURs derived from the drivers and high-level requirements. Understanding the need to define the intersection of the CI IO and the EPE IO, the Working Group conferred with the CI Architecture and Design Team and established an initial Interface Requirements Agreement that articulates mutual responsibilities in building the EPE infrastructure:

The CI IO's EPE and Integration teams shall collaborate with EPE IO's development team to address the needs of the EPE community for the fulfillment of the CI User requirements, the EPE User requirements, and the EPE-CI interface agreements.

The EPE IO shall collaborate with the CI IO to provide derived requirements for the development of CI user interfaces that support the education community and general public.

The CI IO shall provide live and recorded video feeds from remote sites to support the development of EPE applications by the EPE IO.

The EPE IO shall provide derived requirements to the CI IO for accessing/ embedding/ interfacing video streams with the EPE applications.

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The EPE IO shall identify external education-relevant datasets such that the CI can make them available to the integrated observatory users.

The CI IO shall provide educator access to selected archived numerical models, model executions, and workflows for reuse and modification.

The EPE IO shall provide online help and guidance to educators seeking to use OOI user interfaces, datasets, and data products.

The EPE IO shall identify educational data products for culturally diverse users and audiences and support their maintenance and prominence in the CI user interfaces.

The EPE IO shall identify education-relevant observation planning, mission control, and engineering simulators representing the deployment and scheduling of OOI infrastructure.

4.5.2.6 Integration of OOI Science and Education

In fostering and highlighting the integration of the Education and Science goals and activities of OOI, the EPE Working Group has chosen the Ocean Literacy Principles (OLP) (http://www.cosee-ne.net/about/documents/OSLbroch.pdf) as a set of pre-vetted, fully developed and refined principles. These principles (see below) are overarching ideas that do not neatly fall within a particular discipline. As a result, there are many fundamental concepts that illustrate more than one principle.

The principles are as follows:
1. The Earth has one big ocean with many features.
2. The ocean and life in the ocean shape the features of Earth.
3. The ocean is a major influence on weather and climate.
4. The ocean makes the Earth habitable.
5. The ocean supports a great diversity of life and ecosystems.
6. The ocean and humans are inextricably interconnected.
7. The ocean is largely unexplored.

The OLP principles have been widely distributed, and are accepted as central guidelines in many settings across the country. For example, the NOAA Environmental Literacy (NOAA's Education Strategic Plan 2008-2028; 35) and NSF COSEE grant programs require applicants to align their proposed work to it, and at least three states are using it to infuse more ocean sciences into new standards, frameworks and guidelines for K-12 schools. Science centers and museums are using the OLP as the basis for exhibit design and for program development. Thus the OLP provide an accepted starting place for integrating education drivers with science themes in the OOI EPE effort.

As can be seen conceptually in Figure 4.5-1, there is clear reciprocity between science themes and education drivers. Table 4.5-1 shows a partial set of relationships between Key Science Questions and Education Drivers.

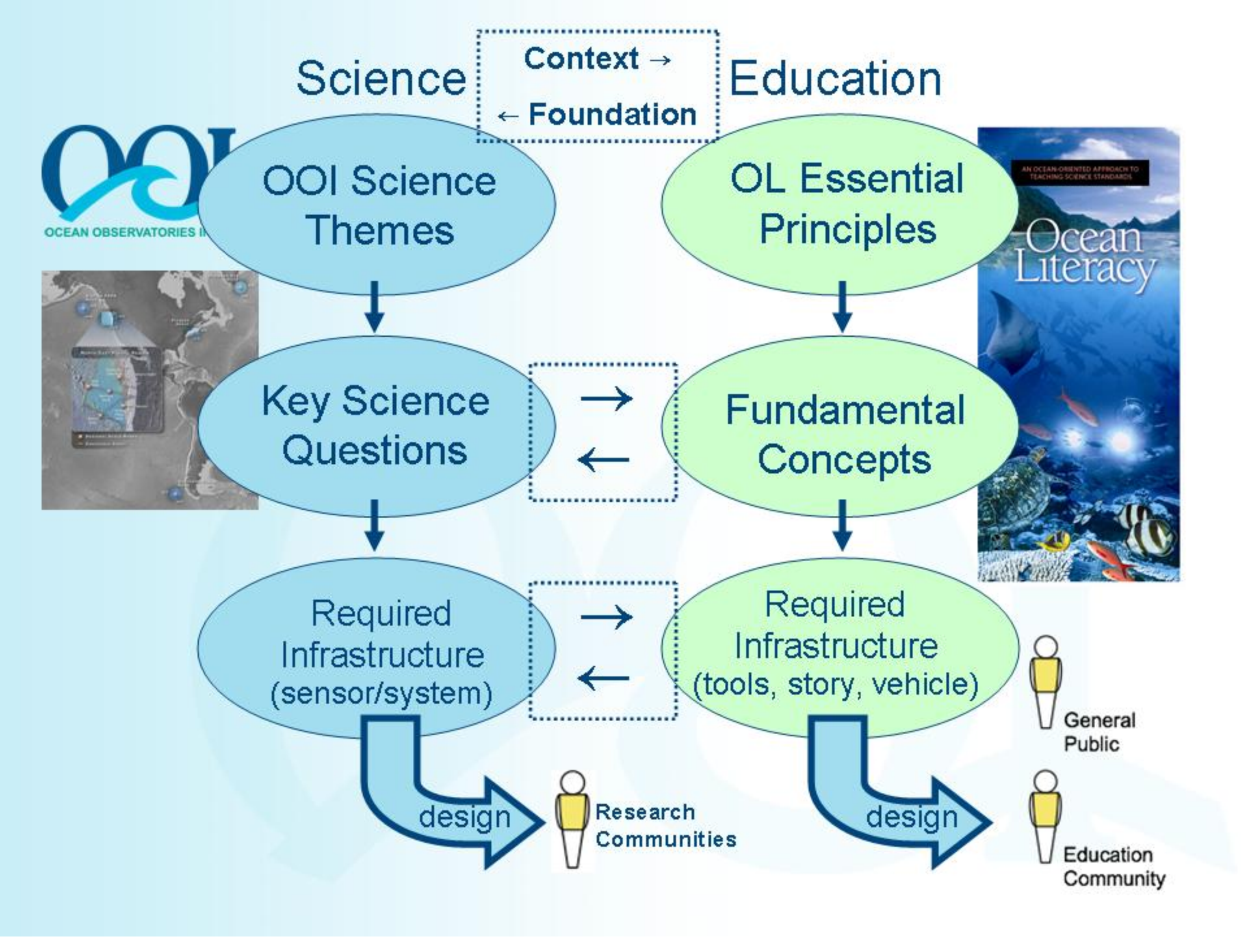

Figure 4.5-1. Science themes and education drivers are integrated throughout the OOI enterprise, from high-level requirements through each story, and across all research components. The science and education drivers have a similar relationship to the OOI core infrastructure which enables users to successfully accomplish their goals using cutting edge observations that transform the way that we can understand the earth. The OOI infrastructure does not, in itself, pursue the science or education enterprise, but it represents tremendous potential to make new discoveries, test hypotheses, and integrate education at every step of the way.

Table 4.5-1. Sample relationships between Key Science Questions and Ocean Literacy Principles (OLP) Fundamental Concepts.

SCIENCE QUESTION	OLP Fundamental Concept	EXPLANATION
How important are extremes of surface forcing in the exchange of momentum, heat, water, and gases between the ocean and atmosphere?	The ocean is a major influence on weather and climate (and vice versa).	The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain. Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.
What is the ocean's role in the global carbon cycle?	The ocean is a major influence on weather and climate (and vice versa).	The ocean dominates the Earth's carbon cycle. Half of the primary productivity on Earth takes place in the sunlit layers of the ocean and the ocean absorbs roughly half of all carbon dioxide added to the atmosphere. The ocean controls weather and climate by dominating the Earth's energy, water, and carbon cycles.
How does plate-scale deformation mediate fluid flow, chemical and heat fluxes, and microbial productivity?	The earth has one big ocean with many features.	An ocean basin's size, shape and features (islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all in the ocean.
	The ocean supports a great diversity of life and ecosystems.	Most life in the ocean exists as microbes. Microbes are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.

SCIENCE QUESTION	OLP Fundamental Concept	EXPLANATION
What are the forces acting on plates and plate boundaries that give rise to local and regional deformation and what is the relation between the localization of deformation and the physical structure of the coupled asthenosphere-lithosphere system?	The earth has one big ocean with many features.	An ocean basin's size, shape and features (islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all in the ocean.
How important are extremes of surface forcing in the exchange of momentum, heat, water, and gases between the ocean and atmosphere?	The ocean is a major influence on weather and climate (and vice versa).	The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain. Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

4.5.3 Approach to Implementation

4.5.3.1 Request for Proposals for a “Design-Build” Strategy

Against the backdrop of the specific restrictions on use of MREFC funds, the drivers and requirements from the activities above form the basis for a draft Request for Proposals (RFP) to identify the EPE Implementing Organization for the OOI Network. Ocean Leadership, with NSF/OCE’s concurrence, will take the approach of procuring a Design-Build subaward for the EPE infrastructure. This means that the exact solution of what to build will be determined by the chosen EPE IO after that organization undertakes a design phase following from a careful analysis of the EPE Education User Requirements and other program documents.

The RFP will provide the education drivers and the Education User Requirements (EUR) as background to respondents. The specific requirements listed in the RFP for creating the EPE IO derive directly from the EUR, and in turn motivate Statement of Work. Respondents are asked to frame their proposed work plan around these requirements, and also must provide a project management plan that addresses interface requirements between CI IO and EPE IO. The chosen EPE IO will design and develop infrastructure subsystems that correspond to the five EUR areas described in Section 4.5.2.2 above. The approach to design, develop, conduct demonstration tests of, and commission the subsystems, in addition to the organization’s domain expertise and the initial concept submitted for the subsystems, will be part of the evaluation of the proposals. More information can be found in the OOI Education and Public Engagement Implementing Organization Request for Proposals (DCN 7001-00000).

4.5.3.2 EPE IO Major Tasks

Pending approval by NSF, the RFP will be issued in Year 1 of the construction phase (i.e., the MREFC phase) . The chosen IO will become rapidly integrated into the development of the wider OOI Network. Maintaining a high-level Work Breakdown Structure similar to the other IOs, the EPE IO will operate in the following task areas:

1. Project Management
2. Systems Engineering and Integration
3. Subsystem Design and Development
4. Implementation

The EPE IO will be responsible for project management activities during the period of contract performance. EPE IO project personnel will cover key required areas, including project management, systems engineering, and skill sets incorporating knowledge of educational infrastructure, software development, and educational program development. A Project Execution Plan will be developed that will address the EPE IO’s planned approach for the design, development, implementation, testing, and initial operation of the OOI EPE infrastructure. The EPE infrastructure, together with the cyberinfrastructure implemented by the CI IO and the marine infrastructure implemented by the RSN IO and CGSN IO, comprise the OOI integrated observatory network, with Ocean Leadership serving as the systems integrator. The EPE IO will conduct the design, development, implementation, and commissioning of the EPE infrastructure in accordance with the OOI Systems Engineering Management Plan, including, but not limited to, change management.

Starting from an analysis of the Education User Requirements, the EPE IO will derive subsystem requirements for the EPE subsystems. The EPE IO will support and establish interface requirements and Interface Control documents (ICDs) between the EPE and the CI, CGSN, and RSN infrastructures. Interface requirements will include all relevant interoperability, dependencies, constraints, and performance requirements between the OOI infrastructures. The documents will include Interface Milestones to facilitate schedule coordination, where relevant. The EPE IO will attend interface meetings, conference calls, or other activities to ensure that effective and complete interfaces are established. All interface documents shall be agreed and approved by the interfacing parties and by OL, who will resolve any conflicts between IOs. The EPE IO will work closely with the other Implementing Organizations as the components of the OOI are brought on line, and will coordinate with OL and the IOs on adjustments to the Integrated Master Schedule to ensure that the EPE development is appropriately timed with the development of the other observatory infrastructure elements.

The EPE IO will also define two demonstration tests that will show that the developed subsystems provide the required functionality. The two demonstration tests will address the two target audiences: 1) online post secondary education and technical training programs with a focus on increasing participation and diversity in ocean science and technical careers, and 2) "free choice" learning environments, both physical and virtual, with a focus on increasing public engagement with ocean science and technology. An initial concept for these demonstrations is requested with the proposal. Final definition of the demonstration tests will be a deliverable under the systems engineering Task and is subject to approval by Ocean Leadership. The tests will be then carried out under the Implementation task area.

4.5.3.3 MREFC Funding Constraints

NSF/OCE has advised that $5M of the total MREFC capital investment for the OOI be used to develop infrastructure specifically focused on an education and public engagement effort, “within the restrictions on the use of MREFC funds.” Although NSF’s Large Facility Manual (May 2007: NSF07-38) does not define or address “education infrastructure”(p.4), it does state that to be eligible for consideration for MREFC funding, each candidate project should represent an outstanding opportunity to enable research and innovation, as well as education and broader societal impacts. The NSF/OCE Division in consultation with the Large Projects Office has offered additional guidance to OL that education infrastructure would be something that depreciates over time and needs to be bought, developed, and/or maintained.

Education infrastructure is in many ways analogous to, and commonly overlaps with, the OOI cyberinfrastructure, because they both require the design, development and prototyping of intangible assets that reside in the online environment. Education infrastructure can include 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 EPE users. The focus is specifically on *enabling* education-relevant projects, not on *doing* them, which will occur during the O&M phase. The EPE IO will develop and test EPE infrastrcture that will serve as new models to take advantage of the cutting edge technology and combined science and education vision of the OOI. These tools, once developed, will lay the foundation for future OOI EPE endeavors by a wide user community.

As with the rest of the MREFC funds, human resources to design, build and test the education infrastructure are appropriate expenditures. Follow-on EPE efforts that use the education infrastructure would be funded by external programs. NSF/OCL Education Program Officers anticipate significant support for competitive education awards that use the education infrastructure to utilize and disseminate knowledge, data, and products from the OOI Network.

The size of the MREFC investment in EPE-specific infrastructure is mandated from the NSF. NSF has also advised the Project Office to provide a small amount of “base funding” from this number to the CI, RSN, and CGSN IOs, so these groups can maintain a liaison function during the MREFC project with the Education and Public Engagement IO. Therefore the planned ceiling for the EPE solicitation is approximately $3.4M, with an additional $1.5M to support liaisons from the cyber and marine IOs over the approximate 5-year duration of the MREFC. Additionally, Ocean Leadership will provide a part-time resource (Education Coordinator) from its MREFC budget. The draft RFP for the EPE IO states that institutional contributions may strengthen a proposal, so responders are free to incorporate these if they deem appropriate. In crafting the EPE User Requirements and the RFP, the planning group gave significant thought to whether an effective EPE infrastructure could be developed for the resources available. The funding constraint guided the content and prioritization of the User Requirements and the formulation of the Tasks. The group also researched funding levels for similar EPE efforts such as Rutgers University’s COOL Classroom (http://www.coolclassroom.org) and University of Washington’s PRISM initiative (http://www.prism.washington.edu) to determine whether a significant return could be realized for this funding level. After consideration of all these views, the planning group is confident that NSF’s investment, even though limited, will be used effectively via the design-build competition for an EPE infrastructure. It should be noted that the EPE infrastructure can be expanded if additional resources are identified.

4.5.3.4 Coordinating and Leveraging EPE Investments at the Implementing Organizations

The planned EPE Implementing Organization will join the three existing IOs as an integral part of the OOI integrated project team, and an equal partner with all other IOs under the central management of Ocean Leadership. Each IO has an EPE team and has made a commitment to supporting OOI EPE through a combination of institutional matching funds, in-kind contributions, and personnel time, as well as through existing EPE partnerships. Once the EPE IO is identified, it will become part of the OOI EPE community. Ocean Leadership supports a part time resource (0.5 FTE) as Education Manager for the overall OOI EPE effort. In addition to developing the EPE infrastructure, the EPE IO will have a special relationship with the Project Office in coordinating and leveraging educational activities with project scientists and research scientists from the other IOs as well.

Each IO partner has strong connections within the ocean education community (e.g. Centers for Ocean Sciences Education Excellence or 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/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 National Science Foundation and other federal agencies. The new COSEE Networked Ocean World will perform a needs assessment of educational products from ocean observing systems, which can inform the OOI education effort. All of these assets and partnerships can be brought to bear on OOI EPE. 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, Deep Earth Academy, 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: 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 (Cyberinfrastructure, Pioneer Array, Endurance Array, Global sites, Regional Scale Nodes).

- Establish regular meetings/teleconferences 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.

Table 4.5-2. Summary of the anticipated institutional contribution areas for the cyber- and marine infrastructure IOs and the OOI Project Office during construction phase.

CI IO	RSN IO	C/GSN IO	Project Office
Scientist training	Education-oriented research cruise	Visualizations and animations	EPE IO Management and Coordination
Visualizations and animations	Visualizations and animations	Outreach to Policy Community	Media Coordination
Educational Prototypes	Partnerships with TV learning channels	K-12 Online learning environments	Outreach to Lawmakers
OOI CI Education Web Portal	Science center and museum partnerships	Science center and museum partnerships	Synergy with other ocean education and diversity activities

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