OOI CYBERINFRASTRUCTURE
NSF OCEAN OBSERVATORIES INITIATIVE

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OOI – CyberInfrastructure

Ocean Observing Programs Requirements Workshop Woods Hole Oceanographic Institution, Woods Hole, MA May 13-14, 2008

Workshop Report

Michael Meisinger, Alan Chave, Elizabeth Rosenzweig

CANDIDATE

August 2008

NSF

CONSORTIUM FOR Ocean Leadership
DISCOVERY • UNDERSTANDING • ACTION

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Document information

Project	Ocean Observatories Infrastructure (OOI) CyberInfrastructure (CI)
Document Custodian	OOI CI Architecture & Design Team (ADT)
Approval	Report: Alan Chave (Woods Hole Oceanographic Institution), OOI CI IO System Engineer User Requirements: Frank Vernon (UCSD), OOI CI IO Deputy Director
Created on	May 15, 2008
Last Changed on	August 13, 2008
Document Status	CANDIDATE

Document History

Date	Version	By	Description of Changes
2008-05-15	0.1	M. Meisinger	Initial workshop report from notes and previous workshop report structure
2008-06-13	0.2	M. Meisinger	Added presentation and session summaries, agenda, participants, science background, conclusion. Scenario summaries from Elizabeth integrated.
2008-06-20	0.3	M. Meisinger	Scenario summaries reworked
2008-06-22	0.4	A. Chave	High level review of version 0.2
2008-06-26	0.5	M. Meisinger	Scenario summaries rework completed, finished presentation summaries, workshop summary, review comments addressed. Reviewed introduction
2008-07-31	0.6	A. Chave	Review of candidate draft
2008-08-05	0.7	M. Meisinger	Review comments addressed, final polishing, added exported requirements list from DOORS, changed status to CANDIDATE.
2008-08-20	0.8	M. Meisinger	Minor corrections and modifications

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OOI - CyberInfrastructure

Ocean Observing Programs
Requirements Workshop at WHOI, May 2008
Outcome and Summary

1 Executive Summary

In an effort to further the understanding of user requirements and expectations for the planned Ocean Observatories Initiative (OOI) CyberInfrastructure (CI), the OOI CyberInfrastructure Implementing Organization (IO) is holding a series of topic oriented workshops with scientists and other future users of the CI. These workshops are important steps in refining and complementing the requirements and design documentation that was one cornerstone for the successful completion of PDR in December 2007.

The workshop described in this report was targeted towards ocean observing programs and was held May 13-14, 2008 at the Woods Hole Oceanographic Institution (WHOI) in Woods Hole, MA. This workshop was the third in the series and succeeded two prior requirements workshops held in July 2007 and January 2008 (see [CI-RWS1], [CI-RWS2]).

Physical oceanographers, marine geologists, other scientists and engineers from ocean observing communities as well as from the Regional, Coastal and Global Observatories of the OOI were invited to the workshop. The workshop goals were CyberInfrastructure science user requirements elicitation and documentation, the validation of existing requirements, as well as an outreach effort to future CI user communities. WHOI provided the venue for a 2 day workshop that covered introductions to the planned CI and the OOI program, oceanographic science presentations, technology background, CI requirements elicitation and validation sessions, domain modeling and use case scenario development sessions as well as feedback opportunities.

The workshop outcome and results include

- CI user requirements elicited from ocean observing community members
- Refinement and validation of existing user requirements
- Partial prioritization of existing user requirements
- Domain models elaborated during the workshop
- CI use case scenarios for ocean observing
- Aggregated workshop presentation materials on the OOI CI Confluence web site [CI-OOP-WEB]
- Questionnaires for requirements elicitation (extended and short versions)
- Completed participant questionnaires

2 Introduction

2.1 Goals and Background

In order to provide the U.S. ocean sciences research community with access to the basic infrastructure required to make sustained, long-term and adaptive measurements in the oceans, the National Science Foundation (NSF) Ocean Sciences Division has initiated the Ocean Observatories Initiative (OOI). The OOI is the outgrowth of over a decade of national and international scientific planning. As these efforts mature, the research-focused observatories enabled by the OOI will be networked, becoming an integral partner to the proposed Integrated and Sustained Ocean Observing System (IOOS; www.ocean.us). IOOS is an operationally-focused national system, and in turn will be the enabling U.S. contribution to the international Global Ocean Observing System (GOOS; http://www.ioc-goos.org) and the Global Earth Observing System of Systems (GEOSS; www.earthobservations.org). Additionally, the OOI will provide an ocean technology development pathway for other proposed net-centric ocean observing networks such as the Navy's proposed Littoral Battlespace and Fusion Integration program (LBSFI). Additionally, the global community spanning Canada, Asia, and Europe are also developing new ocean networks which all contribute to the GEOSS. Developing a robust capability to aggregate these distributed but highly linked efforts is key for their success.

The OOI comprises three distributed yet interconnected observatories spanning global, regional and coastal scales that, when their data are combined, will allow scientists to study a range of high priority processes. The OOI CyberInfrastructure (CI) constitutes the integrating element that links and binds the three types of marine observatories and associated sensors into a coherent system-of-systems. 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 everything from seafloor cables to water column fixed and mobile systems. Junction boxes that provide power and two-way data communication to a wide variety of sensors at the sea surface, in the water column, and at or beneath the seafloor are central to these observational platforms. The initiative 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, beginning at the science community, with 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 of facility resources, and operational activities, along with the opportunity to seamlessly collaborate with other scientists, institutions, projects, and disciplines.

A conceptual architecture for the OOI CyberInfrastructure was developed and published by a committee established by JOI in 2006 (see http://www.orionprogram.org/organization/committees/ciarch) [CI-CARCH]. It describes the core capabilities of such a system. Initial requirements were derived from similar cyber-infrastructure projects.

In May 2007, a consortium led by SIO/UCSD, including JPL/NASA, MIT, MBARI, NCSA, NCSU, Rutgers, Univ Chicago, USC/ISI and WHOI, was awarded a contract to be the Implementing Organization (IO) for the development of the OOI CI. The first six months of the design phase has focused on architecture and design refinement and consolidation, and an initial science user requirements analysis and community involvement effort. In December 2007, the preliminary CI design [CI-PAD] was successfully reviewed in a PDR (Preliminary Design Review) by a panel of independent experts appointed by NSF, who provided very positive review comments.

Current activities are targeting the Final Design Review (FDR) in November 2008, where all requirements and design documentation, operations management plans together with cost estimates and feasibility analyses will be reviewed. Major activities towards FDR focus on completing a baseline set requirements at all levels of the OOI and CI, covering user, system and subsystem requirements, with clear tracing to OOI science objectives [SCIPROSP] and user community expectations. Further activities target advancing the CI design and that of its subsystems to the next level to be ready for the start of OOI MREF construction. During all OOI design and construction activities, the validation of any previously elicited and documented user and system requirements through the community will remain a primary concern. Direct involvement of prospective CI user communities is of paramount importance to the success of the program. The requirements elicitation and management process is planned to be an ongoing activity in close collaboration with the user communities involved throughout the design and construction phases.

Earlier science user involvement occurred during the first CI requirements workshop (RWS1), July 23-24, 2007 at Rutgers University and the second CI requirements workshop (RWS2), January 23-24, 2008 at UC San Diego. For each of these workshops, the outcomes were summarized in the form of publicly available reports [CI-RWS1, CI-RWS2].

This report covers the outcome of the third requirements workshop on Ocean Observation Programs (OOP). The workshop took place May 13-14, 2008, at WHOI in Woods Hole, MA. It was the third in a series of CI architecture and design team organized workshops to identify and elicit requirements from domain users. The first two workshops were targeted mainly at the numerical ocean modeling communities. Later workshops covered data product generation, integrated observatory management and education and public engagement topics.

Goals of the ocean observing programs workshop described in this report were:

- Capture knowledge from field scientists in longitudinal and objective-driven ocean observing programs
- Provide the CI engineering team with detailed insight into ocean observing programs and into current research projects
- Identify and elicit user requirements for the CI coming from this specific community
- Validate, refine and prioritize existing user requirements
- Develop a thorough domain understanding through direct collaboration with domain scientists in order to increase language tangibility, and document this understanding in the form of domain models
- Refine and consolidate the basis for further requirements elicitation and domain modeling in subsequent instances of this workshop and in ongoing requirements and architecture design work
- Provide an opportunity for interchange between the CI and the OOI marine observatory IOs
- Advance the common understanding across the individual OOI teams

2.2 Science Background

The community over the last decade has identified high priority science needs, and the OOI has been designed to quantitatively address these questions. This is especially critical as the oceans are changing in our lifetimes, and developing a quantitative understanding of relevant processes is crucial to understanding the possible trajectories of these changes and potential impacts on human society. The OOI will provide scientists a sustained presence in extreme ocean environments, enabling fundamental discoveries. Given the need to develop a quantitative picture of the ocean, scientists require spatial time series spanning many scales across a range of marine biomes. The OOI will accomplish this by deploying a distributed but linked infrastructure in regions that are disproportionately important relative to their geographic size. This distributed infrastructure will enable the collection of data that will allow fundamental processes to be characterized across a range of marine systems. The spatially distributed full OOI network will be required to quantitatively test our understanding of the high priority science questions.

Given this, there is a need to develop a robust cyber-infrastructure to allow all of the distributed assets to be coordinated in an integrated manner. These assets will be used to address many scientific questions reflecting the scientific diversity of the earth system science community. As an example, we highlight one of the high level science questions that is driving the OOI.

What is the role of the oceans in the ocean carbon cycle?

The Problem: The oceans represent one of the major sinks for CO_2 on Earth; however, there is uncertainty about how much carbon is/can be absorbed, how the carbon moves through the atmosphere-earth-ocean system and where the carbon is sequestered. This uncertainty is unsettling, as we know a significant fraction of atmospheric carbon associated with the last few centuries of industrialization has been absorbed by the ocean, and this is changing its chemistry (for example, CO_2 uptake is acidifying the oceans). Therefore, it is imperative to understand carbon cycling in the ocean before we can begin to understand the feedback pathways between the ocean, atmosphere and land.

The Need: Carbon cycling in the ocean is spatially and temporally variable, reflecting circulation patterns and biological activity. Improved understanding could be tied to deeper insight in three key areas. We require understanding in the major regions where CO_2 is absorbed from the atmosphere into the ocean. We require understanding of carbon sequestration processes in the oceans. Finally, we require a synoptic view of how carbon is transformed in the ocean. These challenges will require a simultaneous view from the atmosphere to the seafloor, and the full OOI network allows us to directly tackle these scientific challenges.

The OOI approach: The OOI has proposed the deployment of infrastructure at deep ocean high latitude sites that are crucial to understanding carbon transport from the atmosphere into the ocean. The range of sites enables assessment of the variability of the processes where many of the ocean's major water masses are formed and then transported globally. The OOI coastal networks provide information on how carbon is transported, transformed, and sequestered on narrow and wide continental shelves that are critically important, as they represent one of the largest carbon sinks on Earth and are sensitive to a growing human presence. As most of the uncertainty in coastal carbon biogeochemistry is related to the shelf morphology, it will be comparison between narrow and broad continental shelves that will provide scientists with the picture required to understand how the carbon cycle is regulated in shallow waters (<200 meters deep). Finally, the transformation and transport of carbon from the atmosphere requires a regional and full water-column perspective provided by fixed and mobile assets spanning the north Pacific through the northwest waters off Canada and the United States. This will provide any scientist data with a regional perspective that is required to study and separate the transport and transformation signals in the water column, complemented by the first opportunity to assess whether hydrothermal venting, methane hydrate beds or earthquakes can be major sources for the global carbon cycle. Finally, the combined OOI-enabled understanding will assist the global carbon cycle modeling community, allowing them to conduct numerical experiments that can be validated with streaming data from the sea.

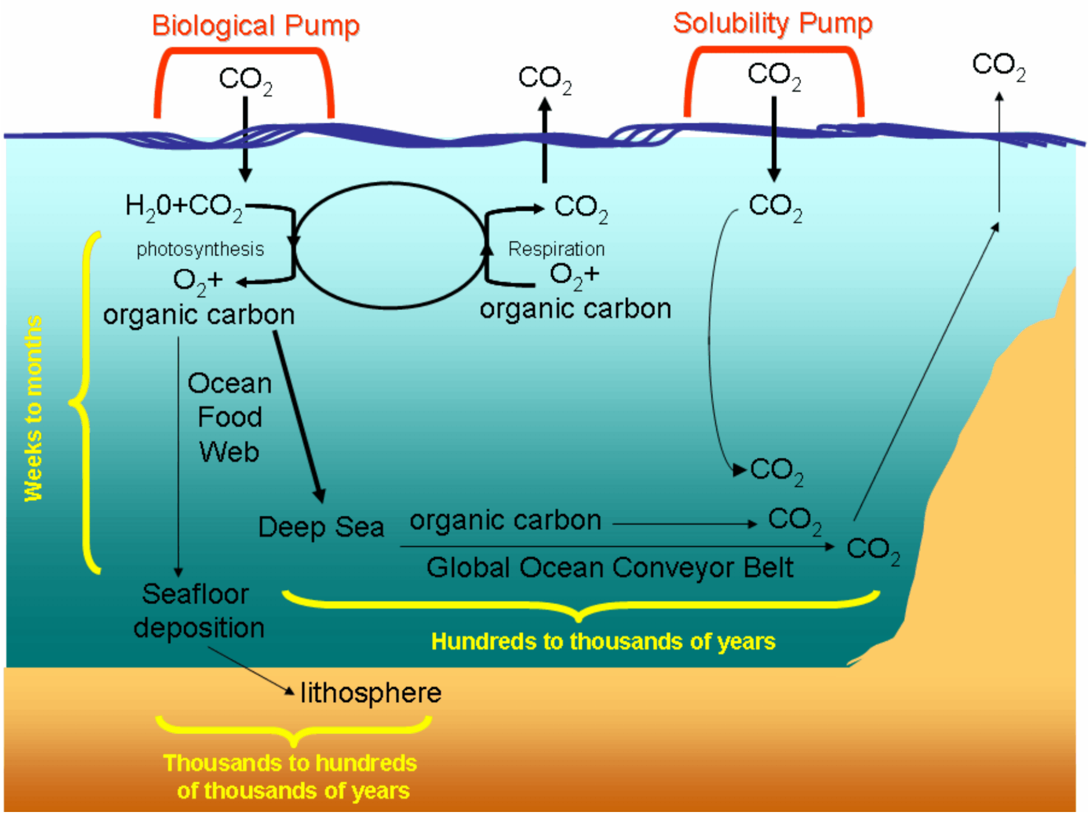

Figure 1: Ocean Carbon Cycle

2.3 Outline

The remaining parts of this report are structured as follows: Section 3 summarizes the presentations given at the workshop and places them into the context of the scientific background. Section 4 documents the direct workshop outcomes, such as discussions, domain models, elaborated scenarios and prioritized requirements. Section 5 lists the science user requirements for the OOI CI originating from this workshop. Section 1 documents participant feedback and provides conclusions from the organizers. The appendices contain further details about the workshop organization and background materials.

2.4 Preparation

The CI Architecture Design Team (ADT) has refined and adapted the previously existing questionnaire with relevant questions for user requirements elicitation that was structured into selected categories. A shortened and tailored version of the questionnaire was sent to the workshop participants. The scientists were asked to provide answers to the questions prior to the workshop. Appendix A of this report documents the participant questionnaire.

Each scientist was asked to prepare an overview presentation covering projects, research interests and relevant background information related to the OOI CI. The presentations were supposed to address the main topics covered by the questionnaire. The presentations covered approximately 15-20 minutes each, including questions.

2.5 Acknowledgements

This report was developed by the OOI CI ADT; it contains input from many sources, such as the workshop presentations by the organizers and invited science users, the completed participant questionnaires, the CI preliminary architecture and design, OOI science background information from the project scientists, and notes taken by Igor Klacansky, Michael Meisinger and Elizabeth Rosenzweig. This report contains summarizing and general statements extracted from meeting materials by the organizers.

We profoundly thank the participating scientists for their time and efforts during the workshop, and their valuable contributions to the OOI CI requirements elicitation process. Furthermore, we would like to thank them for their efforts in filling out the participant questionnaire and providing further materials after the workshop, and for reviewing and validating this report.

2.6 Disclaimer

The contents of this report reflect the understanding and analyses of the CI ADT based on written workshop notes and general background. Errors in transforming them into this report are the responsibility of the CI ADT. No statements in this report are verbatim quotations of participants; there were no audio recordings of the discussions taken during the workshop.

3 Presentations

3.1 OOI CI User Requirements Elicitation Process

Alan Chave (Woods Hole Oceanographic Institution), OOI CI System Engineer, welcomed the workshop participants and described the process for science user requirements elicitation. The OOI project is preparing for final design review in November 2008. A set of important activities covers completing and refining user requirements for the OOI integrated observatory with the cyber-infrastructure component as its "face". This workshop's goal is the collection of new requirements and validation of existing user requirements by science users involved with ocean observing programs. There will be other requirements workshops focusing on different topics.

Chave presented the requirements elicitation process (see Figure 2) and described the purpose of systematic and iterative requirements elicitation efforts involving multiple user communities over the course of the OOI CI project.

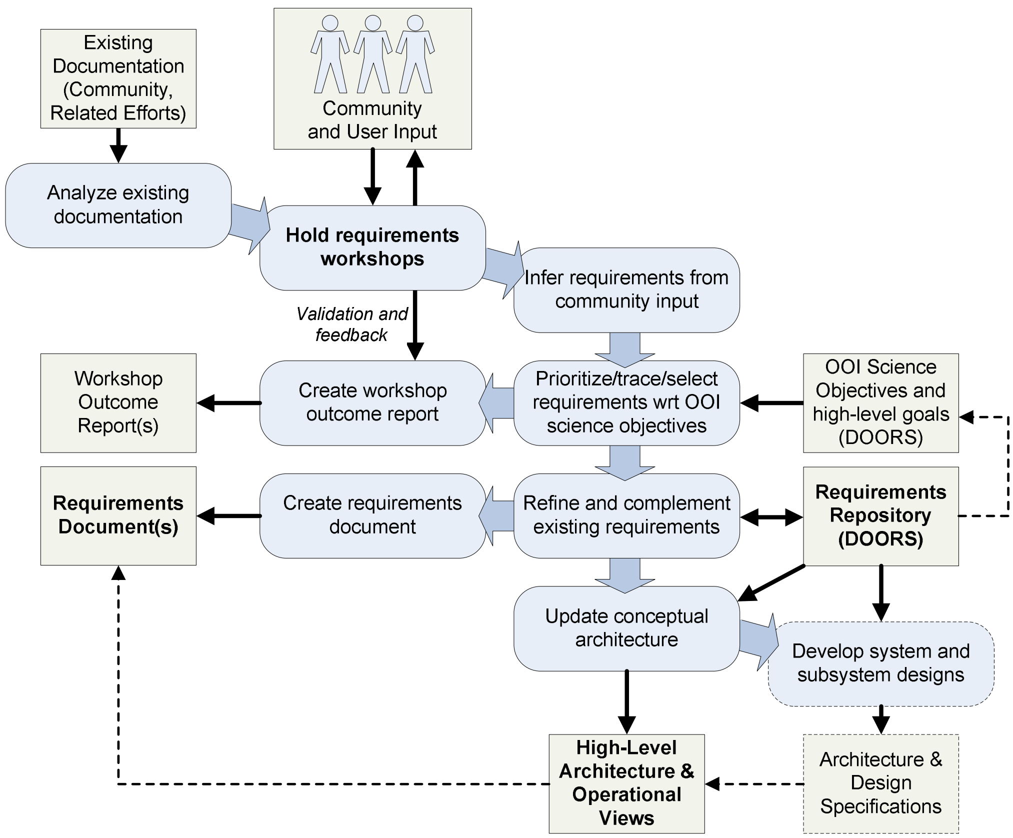

Figure 2: CI user requirements elicitation process

3.2 CI Overview, Requirements, Architecture

Matthew Arrott (UCSD/Calit2), OOI CI Project Manager, provided an overview of the OOI cyber-infrastructure. The main goal of the CI is to support the three main research activities of observing, modeling and exploiting knowledge through a set of well-rounded resources and services. The CI infrastructure will be distributed across the country, and will have points of presence at the sites of the main OOI observatory components on the east and west coasts.

The design process involves several iterations that advance the understanding of requirements and design. Previous design cycles led to the conceptual architecture, the UCSD-led proposal for the OOI CI [CI-PROPOSAL] and refinement for Preliminary Design Review (PDR) in December 2007. The current iteration emphasizes further refinement of requirements and design for FDR.

One goal of this workshop is defining and elaborating (1) direct access to instruments through commands sent to and data received from them in native form, (2) interaction between instruments and instrument resource agents through observation plans, and (3) more general abstract interaction patterns between the infrastructure and any kind of resource. The principal community of interest is the OOI marine observatory; each of the observatories and their resources need to act as capability containers to manage membership, resources, storage and computation, yet operate as elements of a system of systems.

3.3 Project and Research Overview: Dave Fratantoni

Dave Fratantoni (WHOI) provided background information related to glider technology research and projects at WHOI's Autonomous Systems Laboratory (ASL). The goal is to explore physics and biology on scales inaccessible with traditional tools.

Gliders "fly" through the ocean on defined paths, following a vertical saw-tooth motion. They exploit gravity and buoyancy to transform vertical forces into forward motion without any active propulsion. Gliders typically avoid the surface between communication intervals; during communication times, they use radio and satellite networks to transmit small digests of data to shore and use GPS to acquire a position fix. Gliders keep full mission logs of all measured data on local disks that are recovered upon retrieval of the glider. Gliders surface typically every 6 hours and are deployed for 1.5 months. During each surface interval, the navigation path and configuration parameters can be controlled though commands relayed by the shore station.

WHOI has developed GODS, the Glider Operations and Data System, a shore-side controller system. It provides a common command structure for all vehicle variants using a web-based interface.

Specific statements:

- WHOI's ASL has built an integrated observatory together with MBARI as a closed-loop experiment in 2003 during AOSN. A similar adaptive sampling experiment was repeated in 2006.
- Gliders are slow mobile instrument platforms
- Communication with gliders is low-bandwidth. Underwater, it is limited to acoustic communication with short range (up to 10 km) and data rates up to 30 kbps. Satellite communications is intermittent, expensive and slow.
    - Real-time data transfer is limited to 100-200 kB/day at ~2000kbps data rate; data collected and stored on disk is at MB to GB scale, depending on payload sensors.
- Gliders surface on their own schedules. A synchronization of surface times would be very difficult, so they don't even try
- Deployment is easy but recovery is challenging, and most available ships are not optimal platforms for recovering gliders.
- Adaptation of long-term measurements in favor of short-term objectives has an opportunity cost: the quality and regularity of long-term measurements can be diminished.
    - Adaptive sampling can make long-term models less valuable in certain aspects of the measurements; e.g. time series can get interrupted or sensor calibrations can get changed so that long-term trend information can be lost

    - Adaptation of a sampling plan can be beneficial and lead to (statistically) optimal sampling of a domain
    - Adaptive sampling can result in large quantities of heterogeneous data products; it requires complex models to detangle and interpret such data.
- The onboard computing platforms are sufficiently powerful for navigation and data storage, but not much more
- Gliders are autonomous systems. Communication and shore-side platforms play a support and enabling role only.
- There is no intrinsic advantage to distributed intelligence on vehicles for coordinated behaviors: the shore-side control system can autonomously coordinate the fleet. The system consists of the fleet and the shore-side control system.
- Coordinated control / adaptive sampling requires quality models of both the environment and vehicle performance
- It is easy to generate large amounts of data of uncertain scientific quality
- Not all researchers apply the same calibration and QC standards. This results in data of different quality. It is not possible to archive all data assuming a common quality level. The problem is not so much the quality of a particular platform, but the intermingling with data from other sources. Differences between two types of measurements are significant. Result is "data stew".
- Currently there are 5 varieties of gliders available from 3 vendors. Most of the gliders are conceptually similar.
- The enabling technology for gliders is satellite communications rather than glider engineering or power sources.
- Sensors deployed on gliders include CTD, fluorometers, optical backscatter, par, low-frequency passive acoustics, dissolved oxygen
- Gliders provide intrinsic measurements, such as slab velocity, surface velocity, wind direction through observation and inference from environmental influences (e.g. comparison of expected vs. actual position).
- Example applications include repeated transects, grid surveys, synthetic moorings (provide approximated vertical profiles at fixed locations), gateway platforms.
- There are certain applications where gliders are not the optimal choice, for instance coastal waters with strong tidal flows, where gliders could get lost.
- A strategy to cover longer distances is to deploy more gliders.
- Post-processing of glider data:
    - While a glider is deployed, following each contact, generate profiles and time series, apply real-time quality control, export data to users (generally ASCII or NetCDF) for use in visualization tools, models, etc.
    - Upon recovering the vehicle, generate profiles and time series, apply final quality control and intercomparisons, archive science/engineering data for future analysis (internal format is Matlab)
- Real-time data quality control can be performed by short-term comparison of data. Data can be flagged as good or bad; it should be possible to reflag data. This supports a self-organizing quality control.
- The CI should consist of a layer well-removed from actual operations and should not impact the PI's ability to make continual improvements/changes. Many topics are active areas of research and should not be controlled by OOI.
- Not all researchers are related to the OOI. OOI should not impose modifications of specific systems to comply with OOI standards, but instead should adapt to existing systems.
- Do not engineer the CI system to control the individual instruments
- Exemplary standards in domain: NODC (National Oceanographic Data Center) standards/formats for hydrographic data archiving

- Current impediments in glider technology are:
    - still first-generation technology
    - massive data generation, but data generally not at a quality level appropriate for archival ingestion and future public use without QC flags or other descriptive metadata
- References
    - The Scripps Argo system is at the forefront of real-time QC, within a very defined scope
    - Consult the Argo profiling float community for general info on large-scale automated hydrographic data collection, processing, archiving, etc.
    - WHOI ASL gliders page: http://asl.whoi.edu
    - SIO gliders page: http://spray.ucsd.edu
    - UW/APL seaglider page: http://iop.apl.washington.edu/seaglider

3.4 Project and Research Overview: Dana Yoerger

Dana Yoerger (WHOI) provided background on vehicles for deep submergence science. AUVs (Autonomous Underwater Vehicles) are mobile platforms containing instruments with autonomous navigation and decision-making capabilities. Such vehicles are used, for instance, to map seafloor bathymetry in a systematic manner and locate sites of interest, such as vents.

One successful observation pattern uses a phased approach. An application is finding and characterizing a seafloor hydrothermal vent, with the goal of finding it in one dive by making all the necessary observations and decisions. After initial ship-based characterization of the ocean environment of interest, the AUV follows a coarse rectangular observation pattern at medium elevation over the sea floor that covers a broad area in a reasonable time. Measurements include temperature, salinity, optical backscatter and vertical velocity. A manual analysis of the collected data by scientists follows, typically during the daily downtime of the vehicles. The following AUV deployment specifically targets the identified areas of interest with a much finer pattern and at a lower elevation (e.g. 50m above seafloor). After a further analysis and decision-making step, the AUV is deployed for highly detailed observations of the vent site of interest.

John Delaney has posed a challenge for the observing community: to get 100x100 km near bottom surveys, with each dive having a projected 100 km long track, 400m swath width, 40 km^2/dive and 250 dives/site. Current AUV operations do not come close to satisfying these requirements of resolution and coverage. This problem is hard but achievable; it will be costly and take time. The general way to go in the future is to break the day-rate structure of current vehicle operations. Once people get off the clock cycle, the economics become manageable. All the elements that break the day life cycle are not included in the costs associated with the vehicles above. Furthermore, moving toward an economy of scale can be achieved through commercial products and higher volume production.

Specific statements:

- Currently, AUVs are individually operated and not yet configured for observatory use. Significant experience is required to operate the vehicles and interpret observations.
- The observing community currently advances their knowledge of performing automated observations. It’s an active research area.
- Moving towards observatory-based, automated AUV-based observations will be a big step. It cannot be expected that the existence of the OOI and an adaptive sampling CI will immediately change the field.
- Pre-site data available for an AUV deployment include water column maps, bathymetry maps, and photos. Studying the maps is currently not an automated process.
- Within the phased observation approach, it is not always clear ahead of time what the strongest clue to follow up for the next phase is

- AUV measurements are an order of magnitude better than ship based measurements. Although AUV range is lower and observations take a longer time, the improvement in observed data is greater than proportional.
- One AUV dive lasts about 1 day. This is a full cycle, involving several different crews and individuals. The area covered is about 2 sq km.

3.5 Project and Research Overview: John Delaney

John Delaney (University of Washington) provided science background and motivation for the transformative nature of the integrated OOI observatory.

One significant objective of the OOI concerns the real complexity of the ocean. Each scientist brings in his/her own deep expertise and understanding. The availability of an integrating CI will eventually enable the community to understand the interdependency of oceanic processes. One key element is interactivity. The seafloor labs should provide similar interactive remote observation capabilities as operating theaters in a hospital already provide today.

Enabling technologies are power and bandwidth at the point of observation, such as within the regional cabled observatory. It is a mesoscale (i.e. the scale of an oceanic eddy field, or up to a few hundred km) observatory situated on the Juan de Fuca tectonic plate. This site was chosen partly because it is a complete (mid-ocean ridge to subduction zone) plate but also because many processes are going on. These processes occur similarly across the planet. Understanding one location very well will further the understanding of much of the planet.

Delaney provided a visionary example. Hydrate ridge site is near a subduction zone where two continental plates meet. Cabled sensing infrastructure placed in its vicinity will provide ongoing observations of physical, chemical and biological processes, relayed back in real-time to the shore station. When one of the frequent earthquakes occurs, tons of microbes that live below the seafloor are brought out into the water column. Sample capsules located on the seafloor will take physical samples that are automatically ejected to the surface and immediately picked up by drones and dropped of at shore-side labs, where the samples are analyzed. The data from the cabled observatories as well as physical sample analyses are immediately made available to the interested public through a data distribution network.

Delaney suggests looking beyond the immediate future and considering the vision over the next 10-15 years. For instance, frustration with some aspects of expeditionary science will lead to new approaches. This will enable significant progress beyond what was achieved before. Any science question breaks down to individual observations. These questions are captured in the traceability matrices of the OOI Science Prospectus [SCIPROSP]. The outcome of the OOI design phase needs to be developed software and hardware strategies enabling the community to achieve the visions such as that sketched above.

3.6 Project and Research Overview: Al Plueddeman

Al Plueddeman (WHOI) presented research and projects of the Upper Ocean Processes Group at WHOI, with experience in this field dating back more than 20 years. Such research focuses on physical processes at the air-sea interface and within the ocean surface boundary layer, such as air-sea interaction, the oceanic response to surface forcing, the structure of the oceanic surface boundary layer and bio-physical interactions. Further areas of investigation include Arctic shelf processes and shelf-basin exchange, internal waves, fronts and oceanographic instrumentation and observing techniques. This is research focusing on a fraction of the scope that John Delaney has laid out.

The means to make observations leading to a deepened understanding of such processes include deep ocean moorings, climate reference stations and volunteer observing ships. The group has experience with

40+ deployments of deep ocean moorings, focusing on marine meteorology and upper ocean vertical structure. Moorings are deployed in remote locations with multi-year turnarounds and unattended operation. Climate reference stations focus on high-quality air-sea fluxes. Particular sites are occupied for multiple years. Three long-term sites exist that have produced more than 20 buoy-years of data since 2001. Such stations provide in-situ validation for numerical models and satellite fluxes, and offer telemetry (inductive and acoustic) of subsurface data. Volunteer observing ships (commercial ships) provide research-quality marine meteorology data. Multiple ships on different routes in the Atlantic and Pacific were supported over more than 8 years. However, such ships are typically too fast for specific situational observations.

Specific statements:

- Process studies are weeks to months long focused field campaigns, which typically involve multiple PIs and multiple platforms. One example is CBLAST-Low, involving cables, towers, buoys, ships, aircraft, models and remote sensing.
- Coastal hydrography focuses on remote and/or difficult to access environments (e.g., Arctic) using AUV technology.
- One example of moorings are Arctic drifters, which are ice-tethered "moorings" deployed for months to years in multi-year pack ice. 44 buoy-months of data from 2 deployed and refurbished buoys were collected between 1992 and 1998.
- The harsh environment and very remote platforms require robust, redundant technology and mechanisms. It is pushing the limits of mooring and buoy technology. Low available power and data rates increase the difficulty. So do requirements to refurbish these platforms in such environments.
- Examples for remote platforms in harsh environments are MLML (4 months at 60N in the Atlantic), CLIMODE mooring (1 year in Gulf Stream), CLIMODE drifter (2 weeks in Gulf Stream), the "Horizontal Mooring", and the Chalk-Ex patch dispersion experiment
- The roots of the individual observation platform trace back to expeditionary programs. Each program and data management system was different. The migration from expeditionary to longitudinal programs creates "feature freezes" and more stable processing and instrumentation environments. Today it is a mixture of custom and common environments.
- The OOI's challenge will be to support both worlds. Change need to be managed, but evolution should be permitted at a pace that is not too fast.

3.7 Technology Background: Arjuna Balasuriya

Arjuna Balasuriya (MIT), lead of the CI subsystem Planning&Prosecution, provided background technology information on cluster autonomy. This work includes among others Henrik Schmidt as PI and Mike Benjamin. In his presentation, he described concepts of operations for distributed sensing, as for instance applied in the ROADNet program. In particular, he described a vehicle autonomy architecture based on the backseat driver paradigm. One key principle in such autonomous systems is the separation of vehicle control and autonomy modules. The backseat driver paradigm captures this idea. One benefit is the controlled interface between the vehicle control and autonomy modules: Environmental status information such as position, bearing, and speed goes in and vehicle commands such as change direction, acceleration etc. go out of the autonomy module. This keeps such modules exchangeable. The MOOS architecture and as the central piece MOOS-DB provide the processing and communication environment for individual autonomous platforms.

3.8 Technology Background: Mike Benjamin

Mike Benjamin (MIT) provided further background on an autonomous navigation and decision making system using the MOOS process IvP Helm. The IvP-Helm technology is based on interval programming. Individual objectives as part of an autonomous system deployment are represented by objective functions over domain variables, yielding utility values for a common decision space that shares variable such as heading, speed and depth with defined precision. Examples for behaviors are waypoint coverage, obstacle avoidance, loitering patterns, return to base, etc. Behaviors are enabled and disabled based on certain environmental and mission control conditions. The autonomy control process retrieves utility functions (discrete linear functions) for each of the enabled behaviors at regular intervals; the IvP-Solver process then combines the behaviors and determines an autonomous navigation solution by optimizing overall utility.

Specific statements:

- The computing power available now on remote vehicle enables applications that go beyond current individual vehicle observations.
- Acoustic communication (ACOMMS) makes collaboration easier
- Use of objective functions is a significant deviation from other behavior decision systems
- Goal of the MOOS developments in the context of ROADNet and classified materials by ONR is to develop a system not dominated by proprietary software but built on individual components
- On the MIT website, a core set of MOOS modules are available under GPL license
- The goal is to motivate researchers to contribute their behaviors to the pool to establish an autonomy infrastructure.
- One goal for OOI could be to capitalize on existing public modules and behaviors and make them available within the OOI context.

3.9 Technology Background: Steve Chien

Steve Chien (NASA JPL) provided technology background on the CI Planning&Prosecution candidate technologies ASPEN and CASPER, developed by NASA JPL. ASPEN is a mission planning tool providing activity scheduling for available resources under given constraints for an upcoming mission, such as scientific ocean observation involving fixed and mobile resources. ASPEN is intended to run at a shore-based control station in batch mode. CASPER is the embedded version of the mission planning tool that can be placed on mobile assets such as AUVs and gliders in order to support autonomous operations. CASPER runs continuously and keeps track of temporary objective inconsistencies and risks or changing environmental and control conditions.

CASPER can complement autonomous vehicle navigation and decision making using the MOOS/IvP-Helm system. MOOSDB provides the communication conduit between shore-based, external vehicle and on vehicle mission planning and control processes. In a future OOI scenario, CASPER-MOOS-IvP can be embedded on mobile assets for autonomy control if the instrument owner chooses to do so, while ASPEN provides shore-side resource management for the OOI, with input from event detection through the modeling component of the OOI CI.

Specific statements:

- CASPER/ASPEN were developed for the EOS1 satellite mission.
- CASPEN currently runs in spacecraft with limited processing power, such as 4 MIPS, with 128 MB memory.
- The software is also used on satellites with 3-5 ground contacts a day of 10 minutes length each.
- ASPEN/CASPER is intended to be an open system but has in its current state a steep learning curve
- It is not required that CASPER runs on a mobile instrument. Providing communication with shore-stations can be established frequently, all mission planning and control can also be done on shore. Sub-networks of 20-30 sensors need to have planning capability, but for individual sensors it is not necessary.

- A long term observation scenario, such as tracking underwater volcanic eruptions over more than one year with combined fixed and mobile sensors that can detect and alter observation programs during specific events has not been done so far. Similar observations occur when targeting and tracking particles from Gobi/Sahara dust storms coming down to the US.
- An infrastructure such as the one proposed could be a solution for this scenario. Combining observing assets with sufficient tracking capabilities and a planning system is enabling to support such a scenario.

4 Workshop Outcome

4.1 Questionnaire Response Analysis

The CI ADT received substantial input from participating scientists through the questionnaires that were handed to them prior to the workshop. The input from the questionnaires was analyzed and led to new requirements as well as refinement and validation of existing science user requirements. Selected statements are listed in the individual scientist background sections.

4.2 Existing User Requirements Discussion

4.2.1 Requirements Walk-Through and Prioritization

The workshop participants discussed a subset of the list of existing CI science user requirements, as documented in the second requirements workshop report [CI-RWS2]. The goals of the walk-through were a validation and prioritization of these requirements. Comments made in this session led to updated science user requirements as documented below in Section 5.2. Changes include refinements to the requirements and their explanations, as well as subsumed and dropped requirements for documented reasons.

The participants discussed and rated some science user requirements in the form documented in [CI-RWS2] using the following attributes:

- Critical (product unacceptable unless existent),
- Essential (required for core operation),
- Conditional (would enhance the product),
- Optional (may or may not be worthwhile),
- Reject (should not be considered as requirement)
- Rephrase (in this form not ratable)

R-ID	RWS1 Requirement	Importance
RWS2-R1	The CI shall notify registered users and applications when new resources are added to the system.	Essential (Clarify)
RWS1-R3	The CI shall be extensible to allow the addition of new resources and applications to the OOI infrastructure.	Critical
RWS1-R9	The CI shall provide a catalog listing all resources under CI governance.	Critical
RWS1-R9A	The CI shall enable users to discover observatory resources together with their metadata based on resource characteristics and user-defined search criteria.	Critical
RWS1-R11	The CI shall catalog physical samples in the CI resource catalog.	Critical
RWS1-R12	The CI shall support cross-referencing from CI governed resources to external resource catalogs and metadata.	Essential
RWS1-R16	The CI shall bind metadata to all resources under CI governance throughout the resource life cycle.	Critical
RWS1-R18	The CI shall provide standard OOI metadata descriptions that include, but are not limited to, a complete description of resource behavior, content, syntax, semantics, provenance, quality, context and lineage.	Critical
RWS1-R19	The CI shall allow the discovery of all information resources that are based on a given original information resource.	Essential
RWS1-R20	The CI shall provide information resource subscribers automatic and manual fallback options with similar characteristics in case the original resource becomes unavailable.	Conditional
RWS1-R26	The CI shall provide notification of resource state change to all resource sub-	Critical

	scribers.	
RWS1-R33	The CI shall collect and provide resource access statistics.	Essential
RWS1-R21	The CI shall be capable of archiving all data and data products associated with an OOI observatory or other CI-governed information resource.	Critical
RWS1-R22	The CI shall support the publication, distribution and archiving of different versions of the same data product.	Essential
RWS1-R23	The CI shall ensure the integrity and completeness of all data products throughout the OOI life cycle.	Conditional
RWS1-R24	The CI shall ensure that all archived data products can be restored in their complete and most recent state.	Critical
RWS1-R30	The CI shall publish new data products resulting from processing of existing data products.	(Rephrase)
RWS1-R31	The CI shall enable users and applications to subscribe to information resources in the form of data streams.	Essential
RWS1-R47	The CI shall provide a topic-based (publish-subscribe) data distribution infrastructure that supports real-time and near real-time delivery, guaranteed delivery, buffering and data streaming subject to resource availability.	
RWS2-R2	The CI shall interface with, ingest and distribute data from external data sources, databases, and data distribution networks of related scientific domains.	Optional
RWS2-R3	The CI shall provide interactive and automated data quality control (QC) tools.	Critical (Rephrase)

4.3 Domain Analysis and Modeling Sessions

4.3.1 Domain Analysis: Longitudinal Observing Programs

The goal of this session was discussion of the past and present situation for longitudinal observing programs. What works well, what can be improved, what are the current technologies and what are the biggest challenges?

Specific statements:

- Present day longitudinal observations work well because they are driven by robustness. For instance, communication with instruments is always initiated in low power use and low bandwidth mode. This makes it more likely to establish a link with the instrument in adverse conditions.
- During the deployment phase of assets, many important measurements are taken by ships.
- Automating resource planning is possible. There has been no push in this direction yet. Is it possible to develop automatic programs that capture/relay observations? An example is a profiler that comes to the surface except during bad weather conditions. In some cases, such an "algorithm" can be developed, in other cases not.
- Mission files for instruments provide a schedule for resource operation, parameter changes etc. Such files are often presented in the native language of instruments, which tends to be a unique language. It is possible to run mission files on a simulator. Behavior files can be loaded onto AUVs
- A layer can be developed above the proprietary language of instruments. This supports a mail box drop strategy of communicating with the instruments.
- Raw data is always archived but not propagated to publicly output data streams
- The QC processing of data from instruments depends on the project. For specific projects, the heads-up decision is made by one of the technical people based on experience; this is a less automatic process.
- Data modelers typically do not want to deal with QC flagged data. The general rule from experience is: if data are not good enough, don't give them out.

- Typical data quality levels are raw data, QC'ed flagged data, public use data (conservative QC, high level)
- The understanding of what high quality data for sensors and data streams are typically increases and evolves over time. It is necessary to publish new versions of the entire public data product based on this better understanding.
- Particular interesting events that were originally flagged as outliers will be detected once data are analyzed, leading to updated data products.
- Adopting MMI proposed metadata standards through the OOI will advance the open question of standard formats
- There exists a leap-frog scheme for managing and evolving equipment, following the physical update cycle

4.3.2 Domain Analysis: Objective-Driven Observing Programs

The goal of this session was discussion of the past and present situation for objective-driven observing programs. What works well, what can be improved, what are the current technologies and what are the biggest challenges?

Specific statements:

- The OOI CGSN will utilize both AUVs and gliders. Gliders are higher in number. AUVs are critical assets of the OOI for quick measurements.
- The design of CGSN currently relies mostly on surfacing of mobile assets for higher bandwidth communication. In the future, an increased range for acoustic underwater communications might lead to a network of acoustic presence in a an area of 100x100km at a manageable cost.
- Improving the precision of position determination for AUVs is of high importance, because many objective function evaluations are based on position.
- Underwater navigation of mobile assets can be addressed with ADCP sensors in combination with GPS fixes during regular surfacing cycles. This leads to a 0.1% accuracy (0.2-0.3% demonstrated in field tracks) of position fixing. The ADCP provides velocity relative to the water which can be integrated to give position, corrected by GPS readings when surfaced
- For real-time communication with shore-stations, satellite-connected surface vehicles and AUVs can collaborate using acoustic communication connections. This can lead to swarm-based patterns of mobile asset deployment.
- Docking stations are required for recharging and high bandwidth data communication with mobile assets. Such docking stations are being designed. They will provide physical connections for power and communications.
- To observe episodic events, questions that need to be solved include how to task gliders and AUVs to observe a storm. Airplanes can drop profiling floats. There should be about 3-4 days lead time to find and analyze all available data on CI, deploy assets to areas of interest and have them execute a mission.
- Episodic event observation requires: detection, a quick response and deployment of resources accordingly
- Example episodic event observation scenario: tracking the 4D effects of a large storm passing by.
- The pattern of behavior for response to a storm can be captured in advance (parameterized by number of assets). Adjustments may be necessary for storm track and autonomous vehicle capabilities.
- The Mars rover is an example of an autonomous observation system that takes commands in the form of "take a picture at time X from sky location Y". The rover systems break this command down into down into smaller tasks and activities, and calculates a detailed observation plan.

- There is an opportunity cost for performing redeployment of instruments due to episodic events. This impacts long-term observations. The observation and deployment decision is made by policymakers at a high level.
- This decision process will lead to continuous tension between scientists interested in the different types of observations. A better option is to have core instrument capacity for basic measurements with extra resources available for episodic measurements.
- This decision process will require social engineering and daily discussion as well as informed, automated decision making processes.
- Another example is the Hubble space telescope. There is a queue of prioritized public requests and available time blocks for certain research topics.
- One possibility is installation of a voting system: Researchers get a number of tickets (chits) within a time frame to do something. This is a way to assign resources. It is a proven method to build consensus. It drives people to reach common areas of interest instead of daily arguments, but also requires a limited number of people and chits.
- Science events include meteorological, seismic and biological events. The time frame for observing such events ranges from days to weeks, but sometimes only minutes. Certain events cluster in certain times of the year (seasonal events). The duration of events can be short, but preparation to observe them can take much longer.
- Observation plans and assets need to be flexible enough to follow opportunities. There is a trade-off between the use of fixed platforms at known re-occurrence locations and very fast assets.
- The CI needs to support the decision making and social process: Technologies and models for decision making exist (see chit system), but policies to be defined and enforced.
- In the future, NSF might choose to make unused resources available to external users for a fee.
- How does one account for the excess capacity needed to support future OOI use scenarios?
- The OOI needs to provide a way to capture use cases of behavior, for instance in the form of "what if" questions on resources, such as battery life.
- Platforms need to be able to express the capabilities available to them to the community.
- Marine IOs need to have the ability to constrain their capabilities.
- The capacity and capability of resources can change over time. The marine IOs need to be able to communicate these changes to the CI's observation planning systems
- A virtual platform for observation planning is needed such as a representation of a mooring system. The usefulness of such resource planners exceeds that of virtual ocean models.

4.3.3 Domain Analysis: Observation parameters and variables

The question posed to the audience in this working session was "define key parameters and variables that characterize an observation. Assume you have to make an observation request using an automated system".

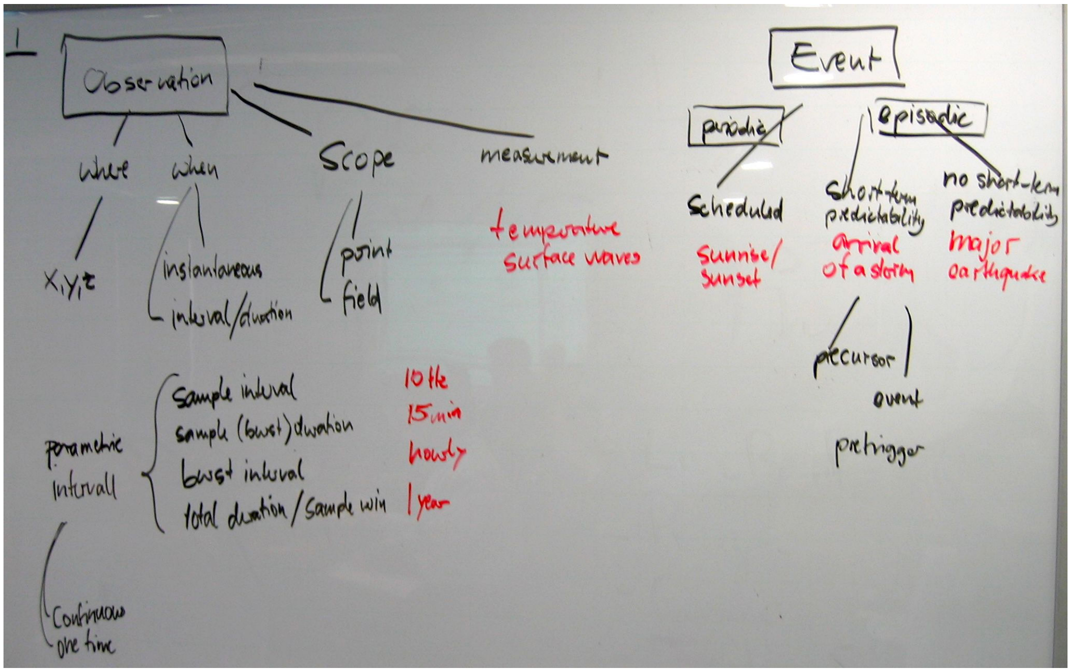

Figure 3: Observations and events whiteboard snapshot

The basic findings together with some example values are captured in the domain model displayed in Figure 4. It was clear from the discussion that the nomenclature might not be the same for all participants in the workshop. A clear need to define a standard vocabulary was identified.

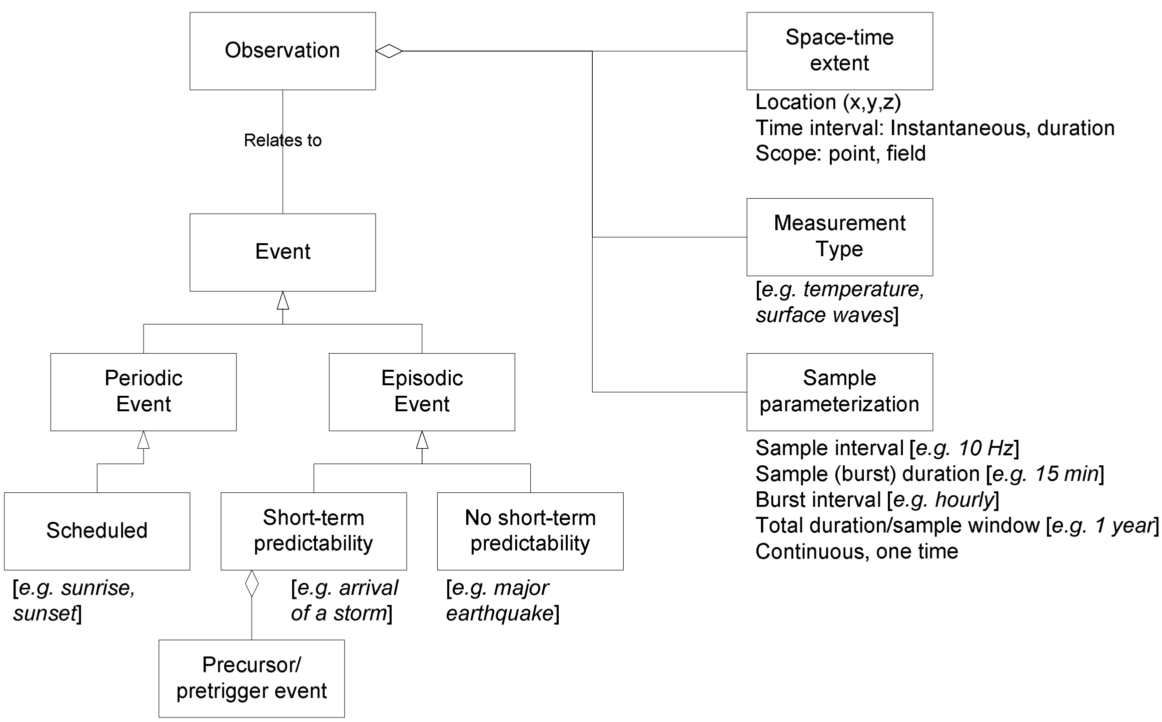

Figure 4: Observations and Events Domain Model

Findings:

- A *burst* is a cluster of samples. It can also describe clustering of phenomena, and hence has two meanings.
- There are many possibilities for measurement intervals. In some cases, you might need to combine two types of schedules: one is purely on a regular basis and the other is event-driven, hence is triggered by something in the environment.
- Episodic/adaptive events, such as the arrival of a storm or an eruption, can be predicted by "precursor behavior".
- A pre-trigger ring buffer can continuously store data for a short period so that event detectors can scan for anomalies. Event trigger algorithms react to events and extract the relevant data from the ring buffer.

4.3.4 Domain Analysis: Roles and Responsibilities in Ocean Observing

The goal of this working session was identification of any roles and responsibilities in ocean observing programs.

General findings:

- One individual can act in several different roles, depending on the project.
- Typical roles
  - Director of Marine Operations
  - Scientist
  - Engineer
  - Technician
  - Logistics Coordinator
    - Finds out what scientists need, who is going on a mission, gets instruments, can go to sea, can operate instruments, carries out mission at sea
  - Marine crew
  - Operations manager

Rutgers LEO-15 operations (see Figure 5):

- Director of Marine Operations
  - Approval of observation plans (by scientist and her)
- Scientist with support engineers
  - Contact Director of Marine Ops
  - Provide documentation:
    - Observation plan
    - Implementation plan
  - Provide sensors
  - Prepare mission files
- Technician
  - Work with simulator, plug in sensor ahead of time
  - Make sure it works
  - Knowledge of instruments
    - Configuration
    - Power usage, sample rate, continuous or profiling event
- Logistics coordinator
  - Logistics plan
  - Arrange for vessel time and divers

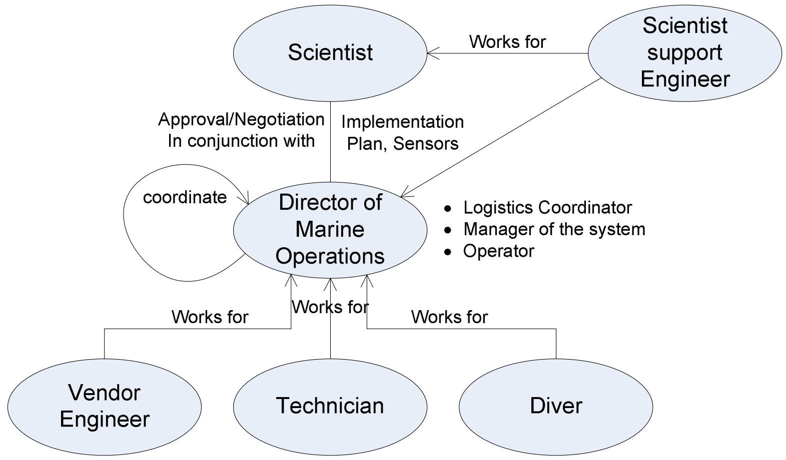

Figure 5: Roles and responsibilities for LEO-15 operations

RSN with structures based on Venus operations (see Figure 6):

- Principal Investigator
  - oversight of the entire project
- Operations Manager
  - Oversight of operations
  - not a scientist
- Project scientists
  - 2 water column scientists
  - Seafloor scientist (even though these two areas function together, the community has not developed experts in the interaction of the two spaces)
  - Watchdog and push proposals, make sure people have what they need, interface with CI, active scientists who can speak the language of people involved with Venus, they can be conflicted with scientists coming to table to use the system, so finding the right people is very tricky and important- it is a tough job.
- Chief Engineer
  - supervise engineering activities
- System Engineer
  - On the construction side. The goal is to link system people with operations people for knowledge exchange and innovation.
  - CI interface
  - CG interface
- Project engineers
- Public Outreach, Education
  - Education, public engagement (EPE)
  - Community development

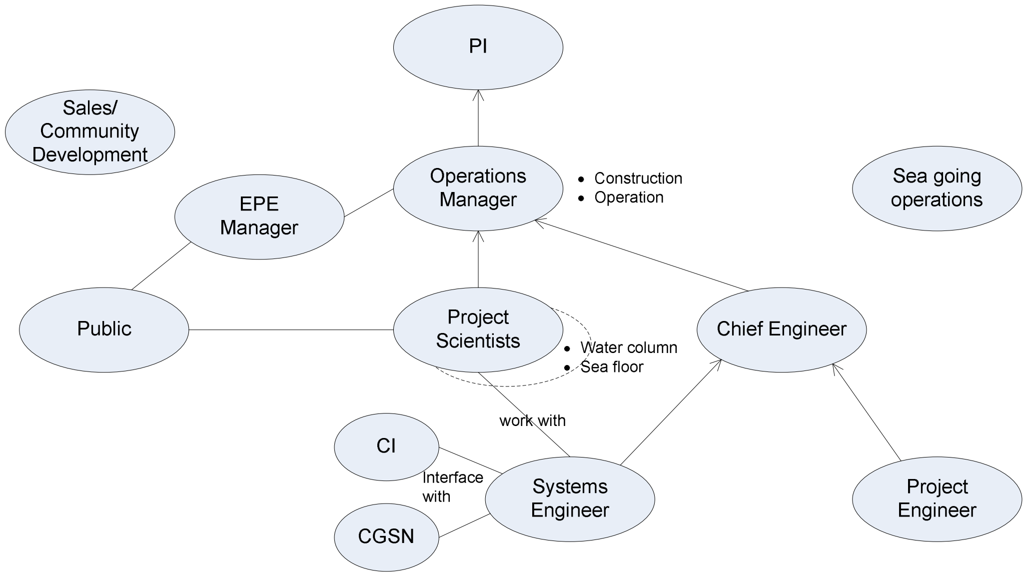

Figure 6: Roles and Responsibilities for RSN based on Venus

4.4 CI Use Case Scenarios

In all of the use case scenario sessions, the charge for the workshop participants was brainstorming and discussing various scenarios from the ocean observing domain. Scenarios covered both current day and future ocean observing applications, assuming the presence of the OOI integrated observatory providing IT services. The following sections document these sessions.

4.4.1 Scenario 1: Longitudinal Observations

Charge to the participants: Develop a scenario for a longitudinal observation assuming that a transformative integrated observatory is in place 5 years from now in the year 2013. It provides instrumentation, computation, storage and other infrastructure capabilities.

User of the system is most likely a scientist who is a receiver of funds from an NSF proposal. Some of the scientists will be deeply involved in the implementation plan, while others are not. In all cases, the science proposals need to justify their experiment, their tools and all plans.

Focus: The study looks at climate variability and ecosystems. How do climate signals lead the changes in water column structure and associated chemical and biological properties? The experiment is cross-cutting in terms of coastal/global measurements.

Study Process (iterative):

1. Develop a Science Plan:
   - Perform literature review.
   - Assemble a team of experts in biology, chemistry and physics to understand scientific requirements.
   - Determine up to a dozen environmental processes that could be observed: some are suitable for observation and some are not within the time and equipment constraints.
   - Decide on the most critical environmental processes for the study.
   - Define key properties of the selected environmental processes.
   - Create the science plan (can be part of the project proposal).

2. Develop an Implementation Plan:
- Select instruments
- Determine instrument configuration (such as sample rate)
    - need to resolve variability
- Create the Implementation Plan (can be part of the project proposal)

3. Develop a model of the observing system
- Fleshes out the Implementation Plan with engineering details
- Describe instrument platform: physical infrastructure, power, sample rates, memory capacity
- Perform a feasibility study
    - Inventory of resources – does it satisfy observing the selected environmental processes?
    - Budgets
    - Constraints
- Involve system engineers from marine observatories
- Document the model
    - Physical infrastructure
        - Can entail an infrastructure simulation
        - E.g. WHOI mooring, battery power
    - Environmental conditions
        - Bounds, worst case conditions, survivability
        - Develop a numerical model of physical system
        - E.g. extreme weather conditions, wave height
    - Scientific processes
        - Describe the intended sampling strategy imposed on the observing system
        - E.g. the temporal scale of eddies
- Document as an Observational Plan
    - Assigns responsibilities to parts of the infrastructure
    - Addresses logistics, documents constraints
    - Specific plan for each sensor and each part of infrastructure

4. Observation process
- Perform recurring (e.g. annual) reviews of plans
    - Science plan, implementation plan, and observation plan
    - Determine how to maximize or optimize system utility
- Issue change requests for observing infrastructure
    - Based on existing operational infrastructure
    - Record deficiencies and gaps in the existing infrastructure and issue change request to the infrastructure provider
    - Request modifications to the infrastructure
- Analyze and vet infrastructure use/change/extension requests
    - Manual process, but can involve decision support systems
- Refine knowledge of infrastructure and future use cycles
- Foresee and plan diagnostics in case of events
    - Interactive or automated

5. Create mission files
- One mission file per instrument, typically in native instrument language
- Collaboration of scientists and technicians
- Short-term updates are possible

- Includes parameterizations of sensors and adaptive behaviors

4.4.2 Scenario 2: Objective driven observations with gliders

Charge to the participants: Develop a scenario for an objective-driven observation program using glider assuming a transformative integrated observatory is in place 5 years from now in the year 2013. It provides instrumentation, computation, storage and other infrastructure capabilities.

<u>Scientific question:</u> What are the relative roles of storms and mesoscale eddies (~10s of km diameter) on the primary production (plankton growth) in the open ocean and mid ocean?

<u>Multiple hypothesis:</u> Water column above a volcanic system induces activity in the water column, which in turn increases plankton growth, which then inspires other activity including nutrient release that fosters bioplankton growth. Other causes for water activity include strong storms, eddies and circulation.

<u>Users:</u> Scientists studying the ocean.

<u>Assumptions:</u>

- There are operating global moorings with gliders in place as movable assets to provide a spatial footprint.
- Basic missions are already in place for gliders
- Current glider missions already provide low-resolution background data
    - E.g. a triangular region around a mooring covering 0-1000m depth
    - The location is in the middle of the ocean; spatial extent of 50 x 50 km
- Augmentation of assets with additional sensors (nutrient sensors, oxygen) is required

<u>Observation definition and operation process:</u>

1. Preliminary steps (see previous scenario)

- Develop science plan
    - Assemble base of knowledge
    - Inventory existing assets
- Develop implementation plan
- Put forward best conceptual models

2. Define a mission for mobile assets:

- Input for observation plan design:
    - Sensors already on board gliders
    - Potential additional payload capabilities, etc.
- Observation extent
    - Look below mixed layer but above thermocline
        - Local maxima and minima
        - Gradient in field
- Observation strategy
    - Task instruments to create optimal map of regions of interest
    - Use higher sampling rate and measure often enough to get the necessary observations
        - Sufficient horizontal/vertical resolution
    - Nest higher resolution observations in the mixed layer with lower resolution background samples
        - Limit vertical range of sampling to focus on the area of interest and not get extraneous information
        - Can be adaptive range based on what is currently being measured

- Develop models and an understanding for
    - Context of experiment
        - E.g., the radial current structure of the eddy
    - Capabilities of assets
        - Endurance
        - Speed, range, depth etc.
    - Cost of operation
    - Physical model of system
        - Some measure of physical structure
        - Proxies of properties, light, nutrients
        - What is an acceptable error rate so that spacing of survey tracks and number of vehicles can be specified (traded off with cos)
    - Simulation of experiment
        - In order to optimize and task assets
- Identify external sources of information beyond physical infrastructure
    - E.g. satellite remote sensing, ocean color, altimetry
    - Specify interpretation steps (event detection)
    - Tasking of assets
- Develop sampling plan (observation plan)
    - Map 2D projection of vehicle trajectories
    - Annotate/estimate vertical behavior (typically out of control of mission planners)

3. Develop detailed mission plan and asset tasking for

- Vertical navigation
    - Relative to environment
    - Define guide envelopes
    - Surfacing needs
- Horizontal navigation
    - (x,y) waypoints
- How to operate payload sensors
- Mobile asset tasking (vehicle dependent)
    - Identify applicable predefined behavior patterns and parameters
    - Detail out behaviors as programs
    - Add new behaviors if necessary
    - Depends on vehicle:
        - Gliders have to stay in vertical and horizontal motion, cannot hover
        - AUVs have a variety of behaviors
- Create missions as composites of behaviors, yielding collaborative adaptive behavior
    - At the behavior level
        - For one vehicle
        - As collaborative behavior
- Mobile asset tasking depends on the capabilities of the control interfaces made public by vehicle operators
    - E.g. take away vertical controllability

4. Observation monitoring

- Track mobile assets
    - Geographical position (x, y)
    - Depth (z)
    - Current position

    - Surface instantaneous position
- Flight performance
- Expendable asset parameters
    - E.g., energy levels
- Track air/water intrusion in vehicle (on a single screen)
- Track vehicle movement
    - Below the surface through models (depends on the accuracy of models)
    - By measuring GPS on surface
    - Through tracking assets
        - Surface vehicles
        - Fixed assets

5. Real-time mission control

- Aborting the mission through operator intervention
    - For vehicles that do come to surface
    - Safe mode is to stay at surface- (surface drifter)
    - If nothing is broken, then just start new mission- restart
    - Abort and come home- go to a way point
- Underwater vehicle recovery
    - For vehicles that don't come to surface
- Fallback scenario support: new behaviors enabled in trouble situations
    - E.g., keep vehicle off the surface if possible
- Change tasking to another mission
- Proactive user notification
    - Information about status sent to users as text, email, etc.
- Controllability depends on type of vehicle
    - Capabilities
    - Response times
- Have suitable user interfaces
    - Imaging and situational awareness are very important

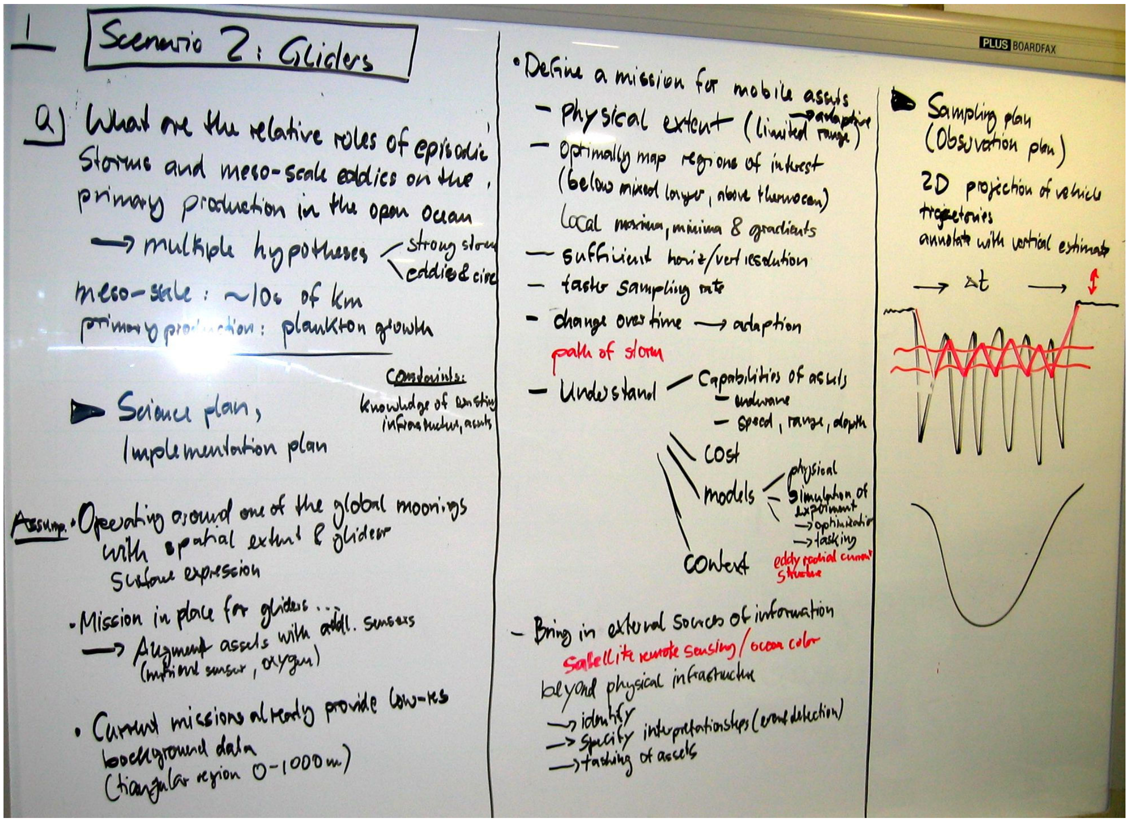

Figure 7: Glider scenario development on the whiteboard

4.4.3 Scenario 3: Objective Driven Observations using AUVs

Charge to the participants: Develop a scenario for an objective-driven observation using AUVs similar to the glider scenario above. Identify similarities and differences

Key properties of AUVs:

- Parameter space is different than with gliders
  - Speed
  - Navigational precision: AUVs can acquire specific locations in real time
  - Duration, endurance (for AUVs only in the ~10s of hours)
- Vehicle capabilities
  - Vary depending on make of AUVs; typically toward higher end compared to gliders, e.g. in terms of computation, imaging
  - Payload (e.g. sensor suites) is replaceable for missions within constraints
- Battery recharge is necessary for missions of more than 3 days
  - Requires recharge capabilities
  - Currently not done autonomously
- There exists a somewhat standardized payload and navigational control across makes of AUVs.
  - A standard for navigation control is ASTM F41, from the committee F41 on Unmanned Maritime Vehicle Systems (UMVS)

Typical AUV observation process:

- Characterize environment and find areas of interest

    - At a low resolution e.g. in the range of several km
    - Example: developing a base map that includes a vertical profile through the suspected area with scans for backscatter and optical anomalies
    - Can be the output of a ship side scan for the buoyant layer
- Develop analyses by different scientists (geologists, chemists, physicists, etc.)
    - Determine where to run the vehicles and what observations to make
    - Challenge: detection on the boundary of knowledge, sensor resolution, event detection algorithms
    - Currently, processing collected data takes about the same time as it takes to recharge the vehicle (analysis time = service time)
        - Analysis done by experts with their own (simple) tools
        - Currently data sets are small enough to fit into an ASCII file
- Vehicle operation cycle (typically one day)
    - Program camera runs
    - Drop AUV in water
    - Vehicle runs along defined track to gather data
    - Bring vehicle back
    - Analyze observations and determine deployment track for next cycle

<u>Phases of an example AUV observation process:</u>

- Phase 0: Perform multidisciplinary survey
    - Initial characterization of environment without knowledge of the specific seafloor
    - Multibeam observations, including side scan
    - Performed with non-AUV assets
- Following phase 0:
    - Install and survey acoustic beacons used by AUVs to navigate underwater
- Phase 1: Low resolution AUV observation
    - Systematic coverage of broad areas at high elevation above seafloor
    - Hydrothermal vent prospecting phase
    - Find neutral buoyancy level
    - Find warm spot
    - Get continuous data
- Phase 2: Medium resolution AUV observation of areas of interest
    - Systematic coverage of specific areas at medium elevation from seafloor
    - Track lines that are 30 meters apart
    - Water column and 30 meter intervals at same time
- Phase 3: High resolution AUV observation of specific selected locales
    - Tracking a specific hydrothermal event
- In case something goes wrong or errors are detected and corrected, deviations from the phased observation process occur as needed.

<u>Further findings:</u>

- The phased observation pattern is applicable to different environmental processes, constrained by available AUV assets
- More computational power and decision making intelligence on board the vehicles would lead to a higher degree of autonomy for the vehicles
- The availability of real time communication capabilities with the vehicle could lead to significantly different observation strategies and results
- The observation process needs to be disciplined and systematic. Emotional decisions will lead to distraction and incomplete observations; the discovery project can fail. The success lies in sys-

tematically scanning large areas, detecting and identifying potentially interesting spots, then subsequently ranking the findings and scheduling further observations to scan such areas.

- Challenges include
  - Opportunity cost, meaning the detrimental effect on time series caused by interruptions of long term systematic observation plans because of changing short-term objectives
  - Lock-step mode between analysis and observation
  - Social context: when there is time pressure, how do decisions get made, how can electronic communications help in this situation?

4.4.4 Future Scenarios

In this session, the participants were asked to brainstorm about future developments and visions – in their fields but also for the OOI and the cyberinfrastructure part of it.

Ideas and open questions for the use of the OOI:

- Deploy a fleet of gliders, for instance along the Pioneer array. In case anomalies and events are detected, use REMUS gliders for high resolution observations
  - Nest observational assets and use the asset most suitable for observing the incident
  - Tailor to platform characteristics, e.g. Pioneer Array
- Provide the physical infrastructure for long-term observations using mobile assets
  - OOI-supported AUV recovery and deployment
  - Enable longer deployments of AUVs
  - How will operation using the CI look?
  - Gliders can be used as a data transport mechanism
- How do fixed and mobile assets interact?
  - Simulation of mobile and fixed assts
  - Need to understand the entire system
  - Provide a flexible, dynamic planning tool
- Availability of high-bandwidth communication to track vehicles underwater in real-time
- Challenge: Building an adaptive, responsive, automated system
  - Current situation: Large scale networks, for instance IRIS seismic array, with limited amount of adaptive sampling
  - How to plan and manage the first day of such a system
  - Availability of testing and design tools and simulation environments
  - Resource limitation and allocation such as limited power on RSN
  - A major event will create a big impact on many resources. How can this be managed without system failure? Can this be simulated?
    - What are the limitations?
    - Can the system help distribute the resources? Will the users ever see the competition for resources? Who and how will conflicts be decided?
  - How can safeguards be established to ensure that mechanical, electrical, network, decision level and other requests never hit the physical infrastructure without vetting?
- Mission planning ideas
  - How can we study the entire world that is below sea level?
  - How can we employ the tools of this new world that we have at our disposal?
- Develop and support hybrid resources that are mobile and fixed
  - Mobile asset that becomes fixed, such as gliders that approach a certain position on the seafloor and then become stationary observatories for a period of time
  - Fixed assets that change position, e.g. coastal mooring arrays
  - Possibility to multiply limited fixed assets (e.g. seismometer on AUV)
  - How can they work together or act autonomously?

  - Multiple hybrids that spawn multiple packages, collect data, and then bring them home
- The CI organization and component should act as the "brain" of the integrated observatory and capture transformative ideas
- The OOI observatory infrastructure could provide sub-surface navigation infrastructure
- Self-organizing systems
- Develop gradient measuring assets through collaboration of mobile assets
- Capability to take physical samples
- Develop and be able to control and apply high capacity, high end sensors (e.g. mass spectrometer)
  - That cannot be used routinely
  - That need resource planning and execution, either built in or with human in the loop
    - Can intelligence be built in to do this?
- Support in situ laboratories
  - Take samples and collect data where they live
  - Calibration facility for instruments
- Gain collective experience with CI tools after FDR in an experiment
  - Use simulators but no real hardware; this makes it much more efficient
  - Using real hardware will increase practical understanding in CI team
  - Include experience with failures, cascading failure; don't tell testers that they are there

5 Science User Requirements

5.1 Requirements Elicitation Process

The requirements listed in the next section represent the current collection of science user requirements for the OOI CI. Some of the requirements were identified in prior requirements workshops and partially validated by the participants. Further requirements originate from the analysis of related cyber-infrastructure efforts. The remaining requirements were identified through a thorough post-workshop analysis process. Requirements were either directly stated by the participants during the workshop discussions, called out in the participant questionnaires or inferred through a requirements analysis process by the CI architecture and design team. Requirements are grouped into categories and formatted according to a template as described below.

In order to uniquely identify the elicited requirements, each requirement in this report follows a standard template. Each requirement contains a unique identifier issued by the DOORS requirements management system. Furthermore, each requirement contains a label and an explanation. Requirement labels are constructed in a schematic way. The listed requirements strive to be atomic (i.e., they express one idea only and do not contain sub-requirements). However, requirements might be related and one requirement might be influenced by another requirement. Further, the explanation might contain additional details about the requirement.

5.2 OOI Cyber User Requirements

This section contains a list of science user requirements as exported from the OOI cyber user requirements DOORS module on 7/31/08. It shows the identifiers and requirements labels and omits explanations and further attributes, such as priority. Please refer to [OOI-CU-REQ] for a full generated view containing all attributes. Requirements are grouped into categories, as indicated by the bold labels in the table. The numbering reflects the structure of the DOORS module. The requirements list contains all CI user requirements to date. Requirements that are traceable to the Ocean Observing Programs requirements workshop are marked in italics.

ID	Requirement / Category Heading
	4.1 Resource Management
L2-CU-RQ-50	The CI shall support distributed resources, applications and actors
L2-CU-RQ-51	The CI shall provide the capability for a given resource to initiate change in another resource
L2-CU-RQ-52	All resources under CI governance shall be identifiable
L2-CU-RQ-53	All resources under CI governance shall be authenticatable
L2-CU-RQ-54	All resources under CI governance shall be authorizable
L2-CU-RQ-55	All resources under CI governance shall be auditable
L2-CU-RQ-56	The CI shall incorporate a policy-based decision system for the management of CI-governed resources
L2-CU-RQ-57	The CI shall ensure that resource utilization is governed by the rights and allocations of the initiating actor
L2-CU-RQ-58	*The CI shall enable non-persistent connection of resources, users and applications*
L2-CU-RQ-59	The CI shall act as the facilitator and broker for resource usage
L2-CU-RQ-60	*The CI shall schedule resource usage based on capacity, capability and availability*
L2-CU-RQ-61	*The CI shall support the evolution of resources under CI governance*
L2-CU-RQ-62	The CI shall support the resource life cycle, providing notification to resource providers and consumers when manual intervention is required

ID	Requirement / Category Heading
L2-CU-RQ-63	The CI shall provide a catalog listing all resources under CI governance
L2-CU-RQ-64	The CI catalog shall provide status information for all resources under CI governance
L2-CU-RQ-65	All resources under CI governance shall be discoverable, either directly, by content or through their associated metadata
L2-CU-RQ-66	Multiple actors shall be able to simultaneously discover the same resource
L2-CU-RQ-67	The CI shall integrate resource discovery with resource access subject to policy
L2-CU-RQ-68	The resource catalog shall link entries to the associated metadata
L2-CU-RQ-69	The resource catalog shall incorporate information about physical samples
L2-CU-RQ-70	The CI shall cross-reference CI-governed resource catalogs and external resource catalogs
L2-CU-RQ-71	The CI shall enable discovery of all information resources that are derived from a given original information resource
L2-CU-RQ-72	The CI shall provide resource subscribers automatic and manual fallback options with similar characteristics in case the original resource becomes unavailable
L2-CU-RQ-73	The CI shall provide services to group resources
L2-CU-RQ-74	The CI shall provide registration services for resource notification
L2-CU-RQ-75	The CI shall automatically register resources for notification to the observatory operator
L2-CU-RQ-76	*The CI shall provide notification of resource state change to all resource subscribers*
L2-CU-RQ-77	The CI shall bind metadata to all resources under CI governance throughout the resource life cycle
L2-CU-RQ-78	The CI shall support standard OOI-standard metadata content that includes, but is not limited to, a complete description of resource behavior, content, syntax, semantics, provenance, quality, context, citation, correspondence and lineage
L2-CU-RQ-79	The CI shall specify and utilize a standard vocabulary
L2-CU-RQ-80	The CI shall maintain the relationship between OOI standard metadata and the vocabulary
L2-CU-RQ-81	The CI shall allow resource discovery utilizing the standard vocabulary
L2-CU-RQ-82	The standard vocabulary shall accommodate information on physical samples
L2-CU-RQ-83	The CI shall provide data generating resources using proprietary metadata formats with a means to transform them to OOI standard metadata
L2-CU-RQ-84	The CI shall support the provisioning of OOI standard metadata
L2-CU-RQ-85	The CI shall verify compliance of metadata with the OOI standard
L2-CU-RQ-86	The CI shall update resource metadata within 5 seconds of resource reconfiguration
L2-CU-RQ-87	*The CI shall provide services for control and monitoring of observatory infrastructure resources*
L2-CU-RQ-88	*The CI shall provide services for pervasive resource monitoring and control*
	4.2 Data Management
L2-CU-RQ-90	The CI shall be capable of archiving all data and data products associated with an OOI observatory
L2-CU-RQ-91	*The CI shall act as a broker for CI-managed data products*
L2-CU-RQ-92	*The CI shall ingest data with variable delivery order*
L2-CU-RQ-93	The CI shall support the delayed distribution of temporarily sequestered data
L2-CU-RQ-94	The CI shall ensure the integrity and completeness of all archived data products throughout the OOI life cycle
L2-CU-RQ-95	The CI shall ensure that all archived data products can be restored to their most recent state
L2-CU-RQ-96	The CI shall provide a topic-based (publish/subscribe) data distribution infrastructure
L2-CU-RQ-97	The CI shall provide registration services for data subscriptions
L2-CU-RQ-98	The CI shall publish unprocessed raw sensor data

ID	Requirement / Category Heading
L2-CU-RQ-99	The CI shall archive unprocessed raw sensor data
L2-CU-RQ-100	*The CI shall support the publication, distribution and archiving of different versions of the same data product or stream*
L2-CU-RQ-101	The CI shall support real-time data delivery
L2-CU-RQ-102	The CI shall support guaranteed data delivery
L2-CU-RQ-103	The CI shall support store until requested (pull mode) data delivery
L2-CU-RQ-104	*The CI shall support streaming data delivery*
L2-CU-RQ-105	*The CI shall integrate multiple data streams or data sets into a single stream or set, eliminating redundant entries*
L2-CU-RQ-106	*The CI shall support peer-to-peer communication between discoverable resources*
L2-CU-RQ-107	The CI shall support secure data delivery
L2-CU-RQ-108	The CI shall adapt data delivery in the presence of limited available bandwidth according to policy
L2-CU-RQ-109	The CI shall notify registered resource users when data delivery cannot be achieved due to low available bandwidth
L2-CU-RQ-110	The CI shall adapt data delivery in the presence of high channel latency according to policy
L2-CU-RQ-111	The CI shall notify registered resource users when data delivery cannot be achieved due to high channel latency
L2-CU-RQ-112	The CI shall publish data from external data sources, data bases, and data distribution networks from related scientific domains.
L2-CU-RQ-113	The CI shall provide support for large volumes of data
L2-CU-RQ-114	The CI shall archive and catalog text, images, pdf, .doc files and spreadsheets
L2-CU-RQ-115	*The CI shall flag and notify data stream and data set state change*
L2-CU-RQ-116	The CI shall flag and notify redundant data and metadata
L2-CU-RQ-117	The CI shall acknowledge requests for data with an estimate of delivery latency
L2-CU-RQ-118	The CI shall credit data publishers when data products are accessed
L2-CU-RQ-119	The CI shall provide services and interfaces for the acquisition of bulk data
L2-CU-RQ-120	The CI shall associate bulk data with their metadata and related data products
	4.2.1 Data Transformation
L2-CU-RQ-122	The CI shall support the moderation and auditing of published data
L2-CU-RQ-123	*The CI shall provide services for interactive and automated data quality control (QC)*
L2-CU-RQ-124	*The CI shall perform automated quality control of observational data products in near real-time*
L2-CU-RQ-125	The CI shall provide standard and user-defined methods to assess the quality of data
L2-CU-RQ-126	The CI shall specify data models for resources based on characterization of structure (syntax)
L2-CU-RQ-127	The CI shall translate between standard syntactic data models without loss of information
L2-CU-RQ-128	The CI shall support translation between user-specified syntactic data models
L2-CU-RQ-129	The CI shall specify data models for resources based on characterization of meaning (semantics)
L2-CU-RQ-130	The CI shall support mapping between senders and receivers using the standard vocabulary without loss of information
L2-CU-RQ-131	The CI shall provide capabilities to define event detectors
L2-CU-RQ-132	The CI shall provide event detection services
L2-CU-RQ-133	The CI shall provide registration services for event notification
L2-CU-RQ-134	The CI shall provide notification of detected events

ID	Requirement / Category Heading
L2-CU-RQ-135	The CI shall provide versioning for detected events
L2-CU-RQ-136	The CI shall update data sets as sensor calibrations become available
L2-CU-RQ-137	The CI shall be able to accumulate knowledge about the scientific interpretation of observational data from manual mapping and linking of variables between different data sets
L2-CU-RQ-138	The CI shall be capable of co-registering data from different instruments in space and time
	4.3 Research and Analysis
L2-CU-RQ-140	The CI shall suggest suitable data products, observation resources, analysis tools, visualization tools and other OOI resources based on user-specified research questions using the standard vocabulary
L2-CU-RQ-141	The CI shall support interactive data analysis and visualization through tools and user interfaces
L2-CU-RQ-142	The CI shall provide a standard, extensible set of data processing elements that provide data assimilation, alignment, consolidation, aggregation, transformation, filtering, subsetting, averaging and scaling
L2-CU-RQ-143	*The CI shall provide capabilities for analysis and presentation of environmental data at specified sites*
L2-CU-RQ-144	The CI shall support the integration of external analysis tools
L2-CU-RQ-145	The CI shall provide capabilities to transform between coordinate systems
L2-CU-RQ-146	The CI shall provide capabilities to transform between map projections
	4.4 Ocean Modeling
L2-CU-RQ-148	The CI shall enable the efficient configuration, execution, and debugging of numerical ocean models
L2-CU-RQ-149	The CI shall support the interaction of model developers and non-expert model users
L2-CU-RQ-150	The CI shall provide capabilities to tune numerical models
L2-CU-RQ-151	The CI shall provide a virtual model environment and simulator to determine optimal model inputs, parameterizations and outcome qualities
L2-CU-RQ-152	The CI shall enable the sharing of ocean modeling, data assimilation and visualization components, including the extension of models with new model components
L2-CU-RQ-153	The CI shall provide a repository and sharing capabilities for numerical model algorithms, model configurations, data processing tools and documentation
L2-CU-RQ-154	The CI shall archive numerical model workflows under configuration control
L2-CU-RQ-155	The CI shall recompute model data products using archived workflows
L2-CU-RQ-156	The CI shall enable the modification of archived workflows
L2-CU-RQ-157	The CI shall provide an environment for the development of community numerical models under community process support
L2-CU-RQ-158	The CI shall provide a non-restricted environment for the development of independent numerical models
L2-CU-RQ-159	The CI shall support the nesting of ocean models at different geographical scales
L2-CU-RQ-160	The CI shall provide a framework for the adaptation of model resolution to the available resources
L2-CU-RQ-161	The CI shall support model ensemble definition, execution and analysis
L2-CU-RQ-162	The CI shall publish both elements of and aggregated ensemble data products from ocean models
L2-CU-RQ-163	The CI shall support flexible high performance model execution
	4.5 Visualization
L2-CU-RQ-165	The CI shall provide interactive 2D, 3D and 4D visualization tools
L2-CU-RQ-166	The CI shall provide 3D visualization of sensor locations and their environment

ID	Requirement / Category Heading
L2-CU-RQ-167	The CI shall support the integration of external visualization tools
L2-CU-RQ-168	The CI shall provide extensible, configurable visualization capabilities for data streams
L2-CU-RQ-169	The CI shall provide a zooming interface for all visualizations with at least three levels of detail
L2-CU-RQ-170	The CI shall provide a user interface system that includes at least two different views of the data
	4.6 Computation and Process Execution
L2-CU-RQ-172	The CI shall support the execution of large scale numerical ocean models across different locations on the network
L2-CU-RQ-173	The CI shall support workflows for automated numerical model execution, including just-in-time input data preparation, model computation, output post-processing, and publication of results
L2-CU-RQ-174	The CI shall enable the one-time and recurring execution of numerical models on any net-worked computational resource with quality-of-service guarantees based on contracts and policy.
L2-CU-RQ-175	The CI shall provide interfaces to compose workflows
L2-CU-RQ-176	The CI shall provide services to execute workflows on computational resources with varying characteristics
L2-CU-RQ-177	The CI shall provide services to chain a plurality of workflows
L2-CU-RQ-178	The CI shall provide services to monitor and control instantiated processes
L2-CU-RQ-179	The CI shall provide actors with estimated performance/turnaround for instantiated proc-esses
L2-CU-RQ-180	The CI shall provide event-triggered workflow execution services
L2-CU-RQ-181	*The CI shall provide real-time access to high performance computation resources*
L2-CU-RQ-182	*The CI shall provide process support for the planning and operation of observational pro-grams*
L2-CU-RQ-183	*The CI shall provide process support for the coordination of instrument recovery, mainte-nance and replacement*
L2-CU-RQ-184	*The CI shall support, automate and combine workflows of shipboard observers*
	4.7 Sensors and Instrument Interfaces
L2-CU-RQ-186	*The CI shall provide a real-time communication interface for remote resources*
L2-CU-RQ-187	*The CI shall support robust instrument development, operation and maintenance processes*
L2-CU-RQ-188	The CI shall support discovery of the characteristics of sensors deployed on an instrument platform
L2-CU-RQ-189	*The CI shall support adaptive observation resource control*
L2-CU-RQ-190	The CI time standard shall be NIST traceable
L2-CU-RQ-191	The CI shall provide a synoptic time service with an accuracy of 1 microsecond to all re-sources connected to the OOI observatories
L2-CU-RQ-192	The CI shall serve synoptic time throughout the observatory using Network Time Protocol
L2-CU-RQ-193	The CI shall provide services to correct remote clocks to a synoptic standard
L2-CU-RQ-194	The CI shall provide services to synchronize remote clocks relative to each other with an accuracy of 1 microsecond
L2-CU-RQ-195	Upon receipt, the CI shall synoptically timestamp message headers with an accuracy of 1 millisecond
L2-CU-RQ-196	*The CI shall provide robust instrument access protocols*
L2-CU-RQ-197	*The CI shall provide direct bidirectional communications to resources that preserves their native functionality*

ID	Requirement / Category Heading
L2-CU-RQ-198	*The CI shall provide remote desktop access to resources that preserves their native functionality*
L2-CU-RQ-199	The CI shall automatically close down inactive direct access sessions
L2-CU-RQ-200	*The CI shall provide interactive web-based configuration of instrument platforms, instruments and sensors*
L2-CU-RQ-201	*The CI shall provide capabilities and interfaces for monitoring of resource-specific operational and environmental parameters*
L2-CU-RQ-202	*The CI shall provide services for positioning of mobile assets with a precision commensurate with the location technology*
L2-CU-RQ-203	*The CI shall support automated docking of mobile resources, including power management and high speed data down and up load*
L2-CU-RQ-204	The CI shall be capable of triggering instrument measurements
	4.8 Mission Planning and Control
L2-CU-RQ-206	*The CI shall support swarm-based deployment patterns for mobile instruments*
L2-CU-RQ-207	*The CI shall provide a repository for instrument behaviors*
L2-CU-RQ-208	*The CI shall provide a repository for observation plans*
L2-CU-RQ-209	*The CI shall provide shore-side and on-vehicle control capabilities for autonomous observational resources*
L2-CU-RQ-210	*The CI shall support observational resource control at different user-selected levels*
L2-CU-RQ-211	*The CI shall integrate environment and vehicle behavior models for event detection, coordinated control and adaptive sampling*
L2-CU-RQ-212	*The CI shall provide capabilities and interfaces for planning longitudinal observations*
L2-CU-RQ-213	*The CI shall provide capabilities and interfaces for planning objective-driven observations*
L2-CU-RQ-214	*The CI shall provide capabilities and interfaces for ad-hoc interactive and automated modification of ongoing observations*
L2-CU-RQ-215	*The CI shall provide capabilities and interfaces for simulating and verifying observation plans*
L2-CU-RQ-216	*The CI shall provide resource provisioning calculations from observation plans*
L2-CU-RQ-217	*The CI shall support observation planning and scheduling decisions based on the opportunity cost of observations and resource provisioning*
L2-CU-RQ-218	*The CI shall provide graphical user interfaces for planning observations and missions with spatial and temporal visualization of observation parameters*
L2-CU-RQ-219	*The CI shall provide spatial visualization of observation data overlaid with observation plans*
L2-CU-RQ-220	*The CI shall support tasking, deployment, mission control and retrieval of mobile and fixed instruments*
L2-CU-RQ-221	*The CI shall provide capabilities and interfaces for the simulation of observational infrastructure*
	4.9 Application Integration and External Interfaces
L2-CU-RQ-223	The CI shall provide documented resource-data connectors for all services
L2-CU-RQ-224	*Conditional on OOI policy, the CI shall not impose specific processes, tools and formats on resource providers for the operation and control of their OOI-connected resources*
L2-CU-RQ-225	*The CI shall interface with external resource monitoring, operation and control systems*
L2-CU-RQ-226	The CI shall provide a Web 2.0 environment
L2-CU-RQ-227	The CI shall support interfacing with web service-accessible resources
L2-CU-RQ-228	The CI shall interface to live video feeds during instrument operation and maintenance
L2-CU-RQ-229	The CI shall provide interface support for Java-based tools and scripting languages

ID	Requirement / Category Heading
L2-CU-RQ-230	The CI shall provide standalone installations that may have no or intermittent connection to the OOI network
	4.10 Presentation and User Interfaces
L2-CU-RQ-232	The CI shall provide annotation, commenting, ranking and rating services for CI-managed resources
L2-CU-RQ-233	The CI shall provide user and group workspace capabilities
L2-CU-RQ-234	The CI shall provide capabilities to personalize user and group workspaces
L2-CU-RQ-235	The CI shall provide social networking capabilities
L2-CU-RQ-236	The CI shall provide an intuitive interface to access the functionality of all CI services and resources
L2-CU-RQ-237	The CI shall present the full CI functionality at a single access point with a single dashboard
L2-CU-RQ-238	The CI shall provide services to make OOI-standard metadata human readable
L2-CU-RQ-239	*The CI shall provide a resource monitoring and control interface*
L2-CU-RQ-240	*The CI shall provide an adaptive, simple-to-use interface for data access*
L2-CU-RQ-241	The CI shall provide transparent access to heterogeneous, large-scale computational resources
L2-CU-RQ-242	The CI shall provide transparent access to heterogeneous, large-scale storage resources
L2-CU-RQ-243	The CI shall provide a single user interface that supports observatory operators, science and engineering users, the education community and the general public
L2-CU-RQ-244	The CI shall provide dialog box interaction for operations requiring the input of more than two parameters
L2-CU-RQ-245	The CI shall provide input screens that include tabs for any process that requires users to input more than five parameters
L2-CU-RQ-246	The CI shall provide a common font set for all screens
L2-CU-RQ-247	The CI shall employ a common look and feel based on a standard screen design
L2-CU-RQ-248	The CI shall employ a standard set of colors for use in all user interface presentation screens
L2-CU-RQ-249	The CI shall employ a standard workflow for all user interface screens
L2-CU-RQ-250	The CI shall employ a common navigation scheme that is consistent from application to application
L2-CU-RQ-251	The CI shall provide visualization and metadata browsing of the processing pipeline
L2-CU-RQ-252	The CI shall provide checklists for standard instrument operations
L2-CU-RQ-253	The CI shall provide capabilities and interfaces to capture structured input, feedback and results from analysis processes on data
	4.11 Security, Safety and Privacy Properties
L2-CU-RQ-255	The CI shall authenticate and authorize all resources connected to an OOI observatory
L2-CU-RQ-256	The CI shall authenticate all observatory actors
L2-CU-RQ-257	The CI shall provide different levels of access to actors with different levels of authorization
L2-CU-RQ-258	The CI shall enforce user privacy policies
L2-CU-RQ-259	The CI shall be capable of auditing all services and resources under CI governance
L2-CU-RQ-260	The CI shall trace resource utilization to the initiating actor
L2-CU-RQ-261	The CI shall support different levels of access for resources and their metadata
L2-CU-RQ-262	*The CI shall protect physical resources from damage and misuse by enforcing resource use policies*
L2-CU-RQ-263	The CI shall provide interfaces to define security and policy for information managers at participating institutions
L2-CU-RQ-264	The CI shall support the diversion, filtering and sequestering of raw data streams at the ac-

ID	Requirement / Category Heading
	quisition point
	4.12 Quality Properties
L2-CU-RQ-266	The CI infrastructure shall deliver messages with reliability that is comparable to that of the Internet
L2-CU-RQ-267	*The CI shall provide robust, reliable remotely deployed components*
L2-CU-RQ-268	The CI shall provide services with reliability and accuracy that is comparable to those of distributed Internet applications
	4.13 Education and Outreach
L2-CU-RQ-270	The CI shall provide numerical ocean models with a limited set of modifiable parameters for educational purposes
L2-CU-RQ-271	The CI access point shall provide educators with instructions about data usage
L2-CU-RQ-272	The CI access point shall provide the educator with a list of projects and their attributes
L2-CU-RQ-273	The CI access point shall provide the educator with a means for social networking.
L2-CU-RQ-274	The CI shall provide a discoverable repository for educator-provided tools
L2-CU-RQ-275	The CI shall provide versioning and citation for educator assets
	4.14 Documentation
L2-CU-RQ-277	The CI IO shall make all source code for the OOI Cyberinfrastructure implementation and drivers publicly available, subject to applicable licenses
L2-CU-RQ-278	The CI IO shall document all external interfaces
L2-CU-RQ-279	The CI IO shall document all device drivers
L2-CU-RQ-280	The CI shall provide discoverable web-based documentation for all services
L2-CU-RQ-281	The CI shall utilize a naming scheme that is compliant with OOI naming conventions
L2-CU-RQ-282	**4.15 Development Process**
L2-CU-RQ-283	The CI IO shall seek to influence the direction of CI standards to effectively meet the needs of OOI users
L2-CU-RQ-284	The CI shall utilize open standards and open source software to the maximum possible extent
L2-CU-RQ-285	The CI IO shall accommodate local innovation that can be scaled to the community level
L2-CU-RQ-286	*The CI IO shall support the verification of hardware and software components that will be deployed on OOI infrastructure*
L2-CU-RQ-287	*The CI shall support modular components*
L2-CU-RQ-288	The CI implementation shall be platform-independent
L2-CU-RQ-289	CI service interfaces and capabilities shall maintain backward compatibility as the services evolve
L2-CU-RQ-290	The CI architecture shall be scalable to accommodate an increasing range of actors, resources, and services
L2-CU-RQ-291	The CI shall be extensible to allow the addition of new resources, services and applications to the OOI infrastructure
	4.15.1 Other
L2-CU-RQ-293	*The CI shall provide process support for "dry" observational infrastructure development, verification and simulation*
L2-CU-RQ-294	The CI IO shall provide technically-qualified user care support and assistance through a human actor
L2-CU-RQ-295	The CI shall provide capabilities to maintain contact between users and user care
L2-CU-RQ-296	The CI shall provide capabilities to initiate and track trouble tickets
L2-CU-RQ-297	The CI shall provide tools for observatory operators to communicate with users

6 Workshop Conclusions

6.1 Feedback from the Participants

The following list contains feedback statements from the workshop participants that were provided during and at the end of the workshop in the feedback sessions. The statements are listed anonymously and in no given order. Statements might be redundant, overlapping and contradictory due to the fact that they originate from different individuals.

- Most participants thought the workshop was helpful; it gave them a better understanding of where the CI is going and its scope and complexity.
- The workshop was an eye opener to understand certain concepts.
- It was not fully clear how the work during the workshop sessions inform the requirements elicitation and prioritization process
- The goals of the meeting were not get fully clear. Was the goal developing requirements or use case scenarios? This could have been explained more extensively at the beginning, together with the process and its drivers and goals.
- The scenario exercises could have emphasized more situations where the system was stressed and considered simulation further.
- There could have been more interplay between scientists and engineers to describe the scenarios. The role playing could have been improved. The critical mass for such an exercise was not there. The group was too heterogeneous for real scientist/engineer interplay.
- Reservations in the community exist against a premature formalization of observing concepts by the CI.
- How will sensor data get off the water, e.g. in the case of the CGSN sensors, and how will the interface with the CI look?
- Would like to hear more from JPL.
- The context information and CI overview presentation should be more extensive. It was addressed too quickly at the beginning; slow down to provide the participants more opportunity for questions. Show the big picture up front.
- Saw many different perspectives on the OOI from the different groups. It is positive to have different types of professionals come together such as in this workshop; this leads to converging vocabularies.
- The word “interactive” should have been used more. It needs to pervade the discussion to push visionary ideas. Ocean scientists have traveled though the ocean, but have not yet fully embraced the time domain. Studying observations in time and space provides further information, and helps to make connections that are currently overlooked. If a well run CI can be created where many people can have access to many data streams, it would provide a successful system.
- Liked the intellectual stimulation. Liked the structure of the workshop.
- Strongly recommends that everyone involved in the OOI attend one of the workshops
- Calling the workshops “community workshops” is misleading. They are by invitation at this point in time. Reserve the word “community” for public engagement of the related communities.
- Make sure that people who are not fully informed about what is happening in this project be included. Perhaps we need better communication. We need to reach out to the community.
- The CI organization should make information about the workshops and the OOI development process accessible to those who want to look at it. This enables people to use their own perspectives and ensure the developments are positive. Start with a letter to anyone interested with statements of the process and intermediate results. This creates transparency which is strongly needed.
- Problems will occur when the OOI and CI usage becomes a closed loop. A challenge will be allocating various types of resources for an efficient observing performance. The job to build the OOI

and CI is huge – therefore keep things simple and in touch with reality. Address the basic functionality first.
- Face to face interaction helps a lot in understanding the different concepts and technologies involved. It's hard to grasp this information from the material available on the web.
- A simulator will increase the understanding even more.
- The structured use case scenario development exercises were very successful. On the program level, the overall structure is one of the challenging items. More use cases are helpful.
- Overall the workshop was worthwhile

6.2 Next Steps and Action Items

Next steps include:
- Consolidate requirements from all user requirements workshops into a consistent list of CI user requirements.
- Prioritize and rank all user requirements, leading to a selection of baseline requirements for the construction of the OOI, to be reviewed during FDR.
- The user community will be asked to validate the requirements as well as their prioritization and selection during various phases before and after FDR.
- The requirements validation and community involvement process will continue past FDR throughout the entire OOI design and construction program.

6.3 Conclusions from the Organizers

The third OOI CyberInfrastructure Requirements Workshop, hosted by the Woods Hole Oceanographic Institution in Woods Hole, MA, provided broad but detailed and valuable insight into current day ocean observing programs; it also led to the elicitation of user requirements for an OOI cyber-infrastructure that will provide transformative support for the entire ocean observing community and beyond. During this workshop, invited domain scientists, analysts and system engineers from the CI architecture and design team, project scientists and system engineers from the two marine observatory implementing organizations and members of the OOI program office discussed and collaborated on creating this outcome and a vision for the future of the overall OOI integrated observatory.

This workshop was very successful in advancing the CI requirements definition and validation efforts, for refining and complementing the CI architecture and design, and in further fostering the mutual understanding of prospective CI user communities and the CI design team. Direct outcomes include a list of identified and validated requirements, jointly developed domain analyses and several extensive current day and future use scenarios. Each will contribute to complementing and refining the OOI requirements and design efforts in preparation of the upcoming Final Design Review in November and the time afterwards.

All presentation materials can be found on the workshop website [CI-OOP-WEB]. The CI workshop overview page [CI-WS-WEB] provides a more general context for all the CI requirements and design workshops to be scheduled and completed before FDR, with detailed background and accompanying material.

Appendices

A Workshop Participant Questionnaire

The CI ADT refined the OOI CI requirements questionnaire from the previous workshop (see [CI-RWS2]) with specific adaptations for the ocean observing topics. The invited scientists were asked to provide answers to these questions prior to the workshop.

Intent of this template

- This slide set is a template for participants at the OOI CI requirements workshop
  - For presentations during the workshop
  - To capture relevant information in a structured way
- Goals of this exercise are
  - To capture as many CI-relevant details as possible before the workshop
  - To capture structured, relevant information for use during and after the workshop
  - To enable quick information access for domain modeling during the workshop
  - To provide you some ideas about the expected outcome and materials covered during the workshop from the perspective of the CI design team
- We ask you to please fill it out to the degree possible/applicable. Please try to provide answers to as many (relevant) questions as you can
- You can use this template as you like. You can modify it, take only parts of it, add your own slides, copy/paste from it, use it to structure your own text/spreadsheed/slideset documents …

General Goals for the Requirements Analysis

- Analyze the current situation
  - Definition of basic terms: instrument, platform, data, etc.
  - Tools, technologies, processes, data used and/or available
  - Organizational details (e.g. responsibilities, roles in team, workflows, policies)
  - Current shortcomings for whatever reason
- Determine short-term improvements
  - What would make every-day observation tasks easier and more effective?
  - What shortcomings should be eliminated most urgently?
- Identify CI transformative vision and requirements
  - Assuming there is a transformative community CI in place, what are the expectations for an "ideal CI"?
  - Capabilities, interfaces, necessary guarantees, resources provided, etc.
- Scope
  - As relevant to the OOI CyberInfrastructure
  - From the viewpoint of your community

Current situation and Expected changes

- What capabilities and properties do you require from a cyber-infrastructure that supports your current work? Please rank.
- What capabilities and properties do you expect from a transformative cyber-infrastructure in the oceanographic domain that would benefit you and the community in the next decade? Please rank.

- What works particularly well in your domain? Exemplary standards, tools, platforms, portals, technologies, etc?
- Please list the biggest impediments that currently exist for your work and/or the community. Please rank and explain.

Instruments and Instrument Platforms

- What instruments/platforms do you currently use and/or develop? Please explain some important specifics of these and any related tools.
- Please describe a typical every-day scenario developing and/or using your instruments/platforms. Example pictures, configurations, documentation etc. are always helpful. Please attach, if available.
- What would make your observational work more effective?

Mission Tasking

- How do you plan observational programs?
- Do you modify observational programs while they are executing? Please describe how this is done.
- How do you find results from prior observation programs? Pls describe how data and metadata from them are accessed.
- How do you store/quality control/visualize the results from observational programs?

Interfaces

- What application interfaces, user interfaces and visualization support do you envision and/or require of an effective and easy to use community cyber-infrastructure?
- What instrument interfaces (both sensor and actuator) do you envision and/or require of an effective and easy to use community cyber-infrastructure?

Privacy, Security, Policy

- Please explain the relevant security and policy guarantees that you and/or your organization require. This includes authentication mechanisms, authorization (access control) and resource access policy strategies, privacy needs, intellectual property issues, etc.

Operations and Maintenance

- How do operation and maintenance requirements affect the design of your instruments/platforms and your daily work?
- What importance does this topic have in your overall work?
- How do you manage changes to instruments/platforms, data sources, technology platforms, standards etc.?

Education and Outreach

- How do education and outreach concerns affect your observation programs and the presentation of the results?
- How do you make observation program results available for education and outreach purposes?

- What would make these tasks easier?

Comments, Expectations, Suggestions

- What do you expect from the upcoming OOI CI requirements workshop?
- What topics do you think are relevant and should not be missed by the organizers?

Additional reading materials, References

- Are there any similar projects/communities that you like and/or that are technology-wise exemplary?
- Are there standards, other national or international efforts that the OOI design team should consider/evaluate?
- Anything you think is relevant that you want to add to this questionnaire?
- Further reading materials
- References

B List of Previous User Requirements

The following table provides the list of CI science user requirements as of May 2008, resulting from the first two requirements workshop. For detailed explanations with each requirement, please refer to [CI-RWS2].

Cat.	Req-ID	Requirement
Resource Management		
	RWS2-R1	The CI shall notify registered users and applications when new resources are added to the system.
	RWS1-R3	The CI shall be extensible to allow the addition of new resources and applications to the OOI infrastructure.
	RWS1-R9	The CI shall provide a catalog listing all resources under CI governance.
	RWS1-R9A	The CI shall enable users to discover observatory resources together with their meta-data based on resource characteristics and user-defined search criteria.
	RWS1-R11	The CI shall catalog physical samples in the CI resource catalog.
	RWS1-R12	The CI shall support cross-referencing from CI governed resources to external resource catalogs and metadata.
	RWS1-R16	The CI shall bind metadata to all resources under CI governance throughout the resource life cycle.
	RWS1-R18	The CI shall provide standard OOI metadata descriptions that include, but are not limited to, a complete description of resource behavior, content, syntax, semantics, provenance, quality, context and lineage.
	RWS1-R19	The CI shall allow the discovery of all information resources that are based on a given original information resource.
	RWS1-R20	The CI shall provide information resource subscribers automatic and manual fallback options with similar characteristics in case the original resource becomes unavailable.
	RWS1-R26	The CI shall provide notification of resource state change to all resource subscribers.
	RWS1-R33	The CI shall collect and provide resource access statistics.
Data Management		
	RWS1-R21	The CI shall be capable of archiving all data and data products associated with an OOI observatory or other CI-governed information resource.
	RWS1-R22	The CI shall support the publication, distribution and archiving of different versions of the same data product.
	RWS1-R23	The CI shall ensure the integrity and completeness of all data products throughout the OOI life cycle.
	RWS1-R24	The CI shall ensure that all archived data products can be restored in their complete and most recent state.
	RWS1-R30	The CI shall publish new data products resulting from processing of existing data products.
	RWS1-R31	The CI shall enable users and applications to subscribe to information resources in the form of data streams.
	RWS1-R47	The CI shall provide a topic-based (publish-subscribe) data distribution infrastructure that supports real-time and near real-time delivery, guaranteed delivery, buffering and data streaming subject to resource availability.
Science Data Management		
	RWS2-R2	The CI shall interface with, ingest and distribute data from external data sources, databases, and data distribution networks of related scientific domains.
	RWS2-R3	The CI shall provide interactive and automated data quality control (QC) tools.

Cat.	Req-ID	Requirement
	RWS2-R4	The CI shall provide standard and user-defined methods to assess the quality of data.
	RWS2-R5	The CI shall facilitate the moderation and auditing of published data.
	RWS2-R6	The CI shall act as a broker for CI-managed data products.
	RWS2-R7	The CI shall provide access to CI-manage data products in standard formats and subsets.
	RWS2-R8	The CI shall act as a broker between information and processing resources.
	RWS2-R9	The CI shall make unprocessed raw sensor data available on request.
	RWS2-R10	The CI shall track data provenance and correspondence.
	RWS2-R11	The CI shall credit data publishers when data products are accessed.
	RWS2-R12	The CI shall create and distribute related data products from a given source data product that have different characteristics, such as resolution, level of detail, real-time, form and quality.
	RWS2-R13	The CI shall flag data stream state change.
	RWS2-R14	The CI shall support the provision of complete metadata by users.
	RWS1-R4	The CI shall support a standard set of data exchange formats.
	RWS1-R4a	The CI shall translate between the standard data exchange formats without loss of information.
	RWS1-R5	The CI shall allow the addition of user-defined data exchange formats and translators.
Research and Analysis		
	RWS2-R15	The CI shall provide capabilities and user/application interfaces for researching scientific materials and OOI-governed resources across disciplines.
	RWS2-R16	The CI shall suggest suitable data products, data transformations, observation resources, analysis tools, visualization tools and other OOI resources based on user-specified research questions in domain language.
	RWS2-R17	The CI shall support interactive and iterative analysis and visualization through infrastructure, tools and user interfaces.
	RWS2-R18	The CI shall provide tools, user interfaces and visualization for the analysis, combination and comparison of disparate, heterogeneous data sets..
	RWS1-R25	The CI shall provide a standard, extensible set of data product processing elements that provide data assimilation, alignment, consolidation, aggregation, transformation, filtering and quality control tasks.
Ocean Modeling		
	RWS2-R19	The CI shall enable the efficient configuration, execution, debugging and tuning of numerical ocean models.
	RWS2-R20	The CI shall support the interaction of model developers and non-expert model users.
	RWS2-R21	The CI shall provide facilities to develop and tune numerical models and their parameters.
	RWS2-R22	The CI shall provide a virtual model environment and simulator to determine optimal model inputs, parameterizations and outcome qualities.
	RWS2-R23	The CI shall enable the sharing of ocean modeling, data assimilation and visualization components, including the extension of models with new model components.
	RWS2-R24	The CI shall provide a repository and sharing capabilities for numerical model algorithms, model configurations, data processing tools and documentation.
	RWS2-R25	The CI shall archive numerical models under configuration control.
	RWS2-R26	The CI shall recompute model data products using archived models and workflows.
	RWS2-R27	The CI shall enable the modification of archived numerical models and and workflows.

Cat.	Req-ID	Requirement
	RWS2-R28	The CI shall provide an environment for the development of community numerical models under community process support.
	RWS2-R29	The CI shall provide a non-restricted environment for the development of independent numerical models.
	RWS2-R30	The CI shall support nesting of ocean models at different geographical scales.
	RWS2-R31	The CI shall provide a framework for the adaptation of model resolution to the available resources.
	RWS2-R32	The CI shall support model ensemble definition, execution and analysis.
	RWS2-R33	The CI shall publish both elements and aggregated ensemble data products.
	RWS2-R34	The CI shall support flexible high performance model execution.
Visualization		
	RWS2-R35	The CI shall provide a uniform and consistent for numerical model output visualization and analysis in 2D, 3D and 4D.
	RWS2-R36	The CI shall provide interactive visualization of the 3D and 4D ocean.
	RWS2-R37	The CI shall support the integration of external visualization and analysis tools.
Computation and Process Execution		
	RWS2-R38	The CI shall support the execution of large scale numerical ocean models across different locations on the network.
	RWS2-R39	The CI shall support workflows for automated numerical model execution, including just-in-time input data preparation, model computation, output post-processing, and publication of results.
	RWS2-R40	The CI shall enable the one-time and recurring execution of numerical models on any networked computational resource with quality-of-service guarantees based on contracts and policy.
	RWS1-R27	The CI shall provide uniform and easy-to-use interfaces to computational resources with varying characteristics to define executable processes.
Sensors and Instrument Interfaces		
	RWS2-R41	The CI shall provide flexible and reliable access to remote resources.
	RWS2-R42	The CI shall provide real-time monitoring of remote sensors.
	RWS2-R43	The CI shall provide continuous collection of scientific data during extreme weather events.
	RWS2-R44	The CI shall provide discovery for the number and characteristics of sensors deployed on an instrument platform.
	RWS2-R45	The CI shall support adaptive observation.
Mission Planning and Control		
	RWS2-R46	The CI shall provide capabilities and user/application interfaces for mission planning and control.
Application Integration and External Interfaces		
	RWS1-R1	The CI shall provision an integrated network comprised of distributed resources, applications and users.
	RWS1-R2	The CI shall enable non-persistent connection of resources, users and applications.
	RWS1-R6	The CI shall provide application program interfaces (APIs) to all CI services.
	RWS1-R7	The CI shall provide a synoptic time service with an accuracy of TBD to all resources connected to the OOI observatories.
Presentation and User Interfaces		
	RWS2-R47	The CI shall provide "one stop shopping" interfaces that provide and collocate relevant information regarding scientific research using OOI resources.

Cat.	Req-ID	Requirement
	RWS2-R48	The CI shall provide annotation, commenting, ranking and rating services for resources.
	RWS2-R49	The CI shall provide project and user workspace capabilities and user interfaces.
	RWS2-R50	The CI shall provide long-term and ad hoc social networking and collaboration capabilities.
	RWS1-R34	The CI shall provide homogeneous, intuitive, easy-to-use web-based interfaces to all CI services and resources.
	RWS1-R35	The CI shall provide the capability to make OOI-standard metadata human readable.
	RWS1-R38	The CI shall provide extensible configurable visualization capabilities for selected types of data streams.
	RWS1-R49	The CI shall provide real-time analysis and visualization for data resources.
Security, Safety and Privacy Properties		
	RWS2-R51	The CI shall provide interfaces to define security and policy for information managers at participating institutions.
	RWS2-R52	The CI shall provide secure operations.
	RWS2-R53	The CI shall only permit authenticated and authorized users to access OOI resources.
	RWS1-R43	The CI shall provide mechanisms to enforce user privacy policies.
	RWS1-R44	The CI shall enable any authenticated party to share their resources.
	RWS1-R44A	The CI shall grant or restrict resource access subject to use policy.
Quality Properties		
	RWS1-R46	The CI infrastructure shall provide services and deliver messages with reliability and accuracy that is comparable to that of distributed Internet applications.
Education and Outreach		
	RWS2-R54	The CI shall facilitate the creation of publicly available idealized numerical ocean models with a limited choice of modifiable parameters for educational purposes.
Documentation		
	RWS1-R41	The CI IO shall make all source code for the OOI CyberInfrastructure implementation and drivers publicly available, subject to applicable licenses.
	RWS1-R42	The CI shall provide documentation for all components of the CI, including all application program interfaces (APIs) to CI services.
	RWS1-R39	The CI IO shall provide all documentation in web-based formats.
Development Process		
	RWS2-R55	The CI IO shall circulate CI requirements and designs within and outside the OOI community so that comparable infrastructures can adopt them.
	RWS1-R8	The CI shall utilize open standards and open source software to the maximum possible extent.
	RWS1-R40	The CI IO shall provide a process for submitting and incorporating user-suggested changes to the CI.
	RWS1-R48	The CI shall provide for the flexible and transparent extension of CI services and interfaces to incorporate user-provided processes, user and application interfaces, applications and resources.

C Workshop Agenda

Day 1, May 13, 2008 (Tuesday)

Time	Presenter(s)	Topics
09:30 AM	Alan Chave	Welcome from the organizers; OOI program overview and current status; Workshop goals and science background
09:50 AM	Alan Chave	CI user requirements elicitation process
10:10 AM	Matthew Arrott	Proposed CI infrastructure for the OOI
10:45 AM	Dave Frantantoni	Project and research overview
11:00 AM	Dana Yoerger	Project and research overview
11:30 AM	Mike Benjamin	Background: MOOS-IvP, ROADNet
11:50 AM	John Delaney	Background: OOI science motivations and overview
12:15 PM	Al Plueddemann	Background: WHOI Upper Ocean Group
01:30 PM	CI ADT	Validation and review existing user requirements
02:40 PM	CI ADT	Analysis and discussion session: Present day longitudinal programs
03:50 PM	Arjuna Balasuriya	Background: Objective-driven observations
04:45 PM	CI ADT	Analysis and discussion session: Present day objective-driven observational programs
05:45 PM	Alan Chave	Day 1 wrap-up and feedback

Day 2, May 14, 2008 (Wednesday)

Time	Presenter(s)	Topics
08:15 AM	CI ADT	Domain Analysis: Observation parameters and variables
09:00 AM	CI ADT	Use case scenario session: Transformative CI longitudinal programs
10:20 AM	CI ADT	Use case scenario session: Transformative CI objective-driven observational programs
11:00 AM	Steve Chien	Background: Mission Planning Component of the OOI CI
11:25 AM	CI ADT	Use case scenario session: Transformative CI objective-driven observational programs: Gliders
01:00 PM	CI ADT	Use case scenario session: Transformative CI objective-driven observational programs: AUVs
02:45 PM	CI ADT	Domain Analysis: Roles and Responsibilities
03:30 PM	CI ADT	Future scenario session and open ideas
04:30 PM	Alan Chave	Feedback session
05:00 PM		Workshop Adjourns

D List of Participants

Name	Organization	Project Role
Arrott, Matthew	UCSD/Calit2	CI Project Manager
Balasuriya, Arjuna	MIT	
Benjamin, Mike	MIT	
Brasseur, Lorraine	Ocean Leadership	
Chave, Alan	WHOI	CI System Engineer
Delaney, John	UW	RSN PI
Farr, Norm	WHOI	CGSN Engineer
Fratantoni, Dave	WHOI	
Harrington, Mike	UW APL	RSN System Engineer
von de Height, Keith	WHOI	CGSN Engineer
Klacansky, Igor	UCSD/Calit2	CI System Modeler
Lerner, Steve	WHOI	CGSN Engineer
Meisinger, Michael	UCSD/Calit2	CI Requirements Analyst
Petrecoa, Rose	Rutgers	
Plueddemann, Al	WHOI	CGSN Project Scientist
Rosenzweig, Elizabeth	Bubble Mountain Consulting	CI Information Architect, Consultant
Talalayevsky, Alex	Ocean Leadership	
Yoerger, Dana	WHOI	

E Abbreviations

Abbreviation	Meaning
ACOMM	Acoustic Communication
ADCP	Acoustic Doppler Current Profiler
AUV	Autonomous Underwater Vehicle
CCL	Compact Control Language (by WHOI)
CGSN	OOI Coastal/Global Scale Node
CI	OOI CyberInfrastructure
CI ADT	OOI CyberInfrastructure Architecture and Design Team
CI IO	OOI CyberInfrastructure Implementing Organization
EOS	Earth Observing System (NASA)
FDR	Final Design Review
IOOS	Integrated Ocean Observing System
NODC	National Oceanographic Data Center
OOI	Ocean Observatories Initiative
PDR	Preliminary Design Review
RSN	OOI Regional Scale Node
SCCOOS	Southern California Coastal Ocean Observing System

F References

Reference	Citation
[CI-CARCH]	CI conceptual architecture and initial requirements, available at http://www.orionprogram.org/organization/committees/ciarch
[CI-DPG-WEB]	OOI CI Requirements Elicitation Workshop, Data Product Generation. Website available at: http://www.ooici.ucsd.edu/spaces/display/WS/RWS-DPG
[CI-IOM-WEB]	OOI CI Requirements Elicitation Workshop, Integrated Observatory Management. Website available at: http://www.ooici.ucsd.edu/spaces/display/WS/RWS-IOM
[CI-OOP-WEB]	OOI CI Requirements Elicitation Workshop, Ocean Observing Programs. Website available at: http://www.ooici.ucsd.edu/spaces/display/WS/RWS-OOP
[CI-PAD]	OOI CI Architecture Document, PDR Final version, 16-Nov-2007
[CI-PROPOSAL]	Network for Ocean Research, Interaction and Application (NORIA) Proposal, 22-Dec-2006
[CI-RWS1]	OOI CI First Science User Requirements Elicitation Workshop Report, OOI CI, Final version 1.0, 08-Nov-2007, available at: http://www.ooici.ucsd.edu/spaces/download/attachments/10453181/OOI-CI-ReqWS1-Report-FINAL.pdf?version=1
[CI-RWS2]	OOI CI Second Science User Requirements Elicitation Workshop Report, OOI CI, Final version 1.0, 09-May-2008, available at: http://www.ooici.ucsd.edu/spaces/download/attachments/10453181/OOI-

	CI-ReqWS2-Report.pdf?version=2
[CI-WEBSITE]	OOI CI Website, available at http://www.ooici.uscd.edu
[CI-WS-WEB]	OOI CI requirements and design workshops overview page. Website available at: http://www.ooici.ucsd.edu/spaces/display/WS
[OOI-CU-REQ]	OOI Cyber User Requirements, exported from OOI DOORS requirements database. Version of 7/31/08. Available at: http://www.ooici.ucsd.edu/spaces/display/WS
[SCIPROSP]	OOI Science Prospectus, Dec 2007, available at: http://www.oceanleadership.org/files/Science_Prospectus_2007-10-10_lowres_0.pdf