Report of the D&I Workshop
27-30 March 2006

by
Kendra Daly, Chair
Richard Jahnke, Co-Chair
Mark Moline, Co-Chair
Robert Detrick
Doug Luther
George Matsumoto
Larry Mayer
Keith Raybould

18 May 2006
1.0. Executive Summary

I find the great thing in this world is not so much where we stand, as in what direction we are moving: To reach the port of heaven, we must sail sometimes with the wind and sometimes against it, - but we must sail, and not drift, nor lie at anchor.

- Oliver Wendell Holmes
  The Autocrat of the Breakfast Table

The ocean is a dynamic system with processes and phenomena that interact in complex ways that are not well understood. Since the days of the Challenger expedition, research vessels have become high-tech floating laboratories and computer centers, but still they exist as opportunistic single points in time and space. Research vessels forge into the polar ice and plumb the trenches, but only on schedules determined long in advance, so that being in the right place at the right time becomes more fortuitous than deliberate. To capture the intricate interactions of ocean processes, we must open new windows through which ocean phenomena can be observed.

Emerging remote sensor, power and communications technologies provide an opportunity to establish a continuous, high-resolution observational presence in the ocean to meet this challenge. Integrating these systems with fixed and mobile deployment platforms enables a new intellectual approach in which researchers can interact remotely with sensor systems to probe and adaptively sample ocean phenomena. This interactive and adaptive “observatory” science will allow the investigation of complex atmospheric, ocean, and earth system processes and the linkages among them over a large range of time and space scales.

The NSF’s Division of Ocean Sciences has established the Ocean Research Interactive Observatory Networks (ORION) Program to guide the planning for an integrated observatory network, the Ocean Observatories Initiative (OOI), that will be constructed with funds from the NSF Major Research Equipment and Facilities Construction (MREFC) account. The OOI will provide the oceanographic research and education communities with transformative access to the ocean, bringing ocean research live to classrooms and desktops worldwide. The OOI has three components accessing complementary scales of variability, and linked by overlapping infrastructure and information management: fixed and relocatable coastal observing arrays; a cabled network on the Juan de Fuca geologic plate in the northeast Pacific; and globally distributed deep-sea buoys in remote environments such as the Southern Ocean.

The ORION Design & Implementation Workshop:

- Engaged the ocean research community in the draft Conceptual Network Design (CND) that had been developed by ORION advisory committees based on responses received through the Request for Assistance solicitation, an unconflicted review panel assessment of the responses and previous planning documents.
- Solicited comments and recommendations about the design.
- Provided opportunities, in the context of these intense infrastructure discussions, for the formation of collaborative groups focused on developing future, observatory-based, integrated research projects.

Nearly 300 members of the ocean research community participated in the workshop. In many cases this was the first opportunity for researchers from disparate disciplines to discuss observatory research opportunities with a wide cross-section of ocean researchers and disciplines. Within cross-scale science themes, participants identified exciting new research strategies enabled by OOI infrastructure. Within each OOI component, integrated and integrating plans emerged that will transform ocean research.

The following report documents the workshop deliberations. It does not provide a revised OOI CND. The ORION Project Office, working with the ORION Advisory committees is responsible for generating the next version of the CND based on the input received at the workshop and on engineering and fiscal considerations.
# 2.0. Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0. Executive Summary</td>
<td>1</td>
</tr>
<tr>
<td>2.0. Table of Contents</td>
<td>2</td>
</tr>
<tr>
<td>3.0. Introduction and Background</td>
<td>3</td>
</tr>
<tr>
<td>4.0. Workshop Organization</td>
<td>5</td>
</tr>
<tr>
<td>5.0. Science Theme Discussions</td>
<td>7</td>
</tr>
<tr>
<td>5.1. Physical Processes/Climate Variability</td>
<td></td>
</tr>
<tr>
<td>5.2. Biogeochemical Cycles and Marine Ecosystems</td>
<td></td>
</tr>
<tr>
<td>5.3. Earth Structure and Geodynamics</td>
<td></td>
</tr>
<tr>
<td>5.4. Fluid-Rock Interactions and Sub-Seaﬂoor Biosphere</td>
<td></td>
</tr>
<tr>
<td>5.5. Ocean-Atmosphere Fluxes and Marine Meteorology</td>
<td></td>
</tr>
<tr>
<td>5.6. Ocean Hazards</td>
<td></td>
</tr>
<tr>
<td>6.0. Coastal Draft Conceptual Network Design</td>
<td>20</td>
</tr>
<tr>
<td>6.1. Overview Description</td>
<td></td>
</tr>
<tr>
<td>6.2. Major Discussion Points, Comments, Strengths and Criticisms</td>
<td></td>
</tr>
<tr>
<td>6.3. Recommendations</td>
<td></td>
</tr>
<tr>
<td>7.0. Regional Draft Conceptual Network Design</td>
<td>26</td>
</tr>
<tr>
<td>7.1. Overview Description</td>
<td></td>
</tr>
<tr>
<td>7.2. Major Discussion Points, Comments, Strengths and Criticisms</td>
<td></td>
</tr>
<tr>
<td>7.3. Recommendations</td>
<td></td>
</tr>
<tr>
<td>8.0. Global Draft Conceptual Network Design</td>
<td>32</td>
</tr>
<tr>
<td>8.1. Overview Description</td>
<td></td>
</tr>
<tr>
<td>8.2. Major Discussion Points, Comments, Strengths and Criticisms</td>
<td></td>
</tr>
<tr>
<td>8.3. Recommendations</td>
<td></td>
</tr>
<tr>
<td>9.0. Acknowledgements</td>
<td>36</td>
</tr>
<tr>
<td>10.0. Appendix</td>
<td>separate documents posted</td>
</tr>
<tr>
<td>10.1. Agenda</td>
<td></td>
</tr>
<tr>
<td>10.2. Attendees</td>
<td></td>
</tr>
<tr>
<td>10.3. Overview Draft CND</td>
<td></td>
</tr>
<tr>
<td>10.4. Coastal Draft CND</td>
<td></td>
</tr>
<tr>
<td>10.5. Regional Draft CND</td>
<td></td>
</tr>
<tr>
<td>10.6. Global Draft CND</td>
<td></td>
</tr>
<tr>
<td>11.0. Comments Received</td>
<td></td>
</tr>
</tbody>
</table>
3.0. Introduction

The ocean is a highly dynamic environment, with processes, phenomena and systems that interact and feed back in complex ways that are not well understood. These interactions and feedbacks occur over a range of scales, intensities and frequencies that are difficult to capture with traditional discrete expeditionary sampling. Expeditionary sampling is also an ineffective way of recording aperiodic events that are a critical component of ocean dynamics. To characterize the range of temporal processes occurring in the ocean, new types of infrastructure are needed that are capable of providing in situ, long-term, high-resolution observations of critical environmental parameters. Emerging technological capabilities are making it possible to investigate complex atmospheric, ocean, and earth system processes and the linkages among them through a new intellectual approach: interactive and adaptive “observatory” science. This approach will allow the study of multiple inter-related properties, variables, and processes over a large range of time and space scales.

The NSF’s Division of Ocean Sciences has established the Ocean Research Interactive Observatory Networks (ORION) Program to guide the planning for an integrated observatory network, the Ocean Observatories Initiative (OOI), which will be constructed with funds from the NSF Major Research Equipment and Facilities Construction (MREFC) account. Construction of the OOI infrastructure will be distributed over 6 years beginning in FY07. The OOI will provide the oceanographic research and education communities with a new mode of access to the ocean, one that will provide real-time, continuous data streams, high bandwidth communications, and ample power for oceanographic discovery, and will facilitate cutting-edge oceanographic investigations. The OOI has three components accessing complementary scales of variability, which will be integrated through common elements of infrastructure and information management:

1. new construction, or enhancements to existing facilities, leading to an expanded network of U.S. coastal observatories;
2. a regional cabled network in the northeast Pacific Ocean on the Juan de Fuca plate, consisting of interconnected sites on the seafloor spanning several geological and oceanographic features and processes; and
3. deep-sea buoys to investigate global-scale processes, which, especially, could be deployed in harsh environments such as the Southern Ocean.

The scientific problems driving the need for OOI infrastructure are broad in scope and encompass nearly every ocean science discipline. The ORION Science Plan and its many antecedents (see the partial reference list below) provide profound evidence for two facts: (1) the ocean observatory concept would enable exceptionally novel and groundbreaking research, and (2) a very large segment of the oceanographic community, encompassing nearly all ocean disciplines, is eager to expand knowledge of the oceans and earth beneath through utilization of ocean observatories. Once established, the observatories constructed as part of this initiative will provide earth, ocean, and atmospheric scientists with unique opportunities to study multiple, inter-related processes over time scales ranging from seconds to decades; to conduct comparative studies of regional processes and spatial characteristics; and to map whole-earth and basin scale structures.

The infrastructure for all three components of the OOI includes both moorings capable of two-way communications with a shore station and dedicated seafloor fiber-optic cables (to shore or to moorings). Seafloor junction boxes connected to this primary backbone will support individual instruments or instrument clusters at varying distances from cables and moorings. These junction boxes include undersea connectors that provide not only the power, time stamping, and two-way communications needed to support rapid-sampling seafloor instrumentation and adaptable sampling strategies, but also the capability to exchange instrumentation in situ when necessary for conducting new experiments or for repairing existing instruments. In order to expand the spatial “footprint” around junction boxes, acoustic modem or extension cable links up to 100 km will be employed. Mobile assets (e.g., ROVs, AUVs, gliders) and supporting navigation and communications networks are essential elements of the OOI infrastructure that further extend and resolve the spatial
coverage of the observatories and link components together.

Conceptual designs for OOI infrastructure have been described in numerous community reports (see the partial reference list below). However, more detailed engineering specifications based on specific science user requirements are needed to further define the needed infrastructure so that the next level of engineering, cost projections and project review can proceed. To initiate this, the ORION Project Office, in cooperation with NSF’s Division of Ocean Sciences, issued a Request for Assistance in January, 2005, in order to acquire detailed conceptual proposals for experiments from interested investigators that would define the nature and cost of the principal OOI infrastructure needed to support the highest priority science of the ocean research community. The submission of 48 RFA proposals, representing the thoughts and ideas of more than 550 investigators and direct participants, and the involvement of over 130 separate research and educational institutions attests to the exceptional level of interest and enthusiasm on the part of the U.S. oceanographic community for ocean observatory based science. A review panel comprising scientists with no connection to any RFA proposal was convened in September, 2005, to evaluate the RFA proposals and provide a prioritization based on the importance and uniqueness of the proposed research, the adequacy of the experimental plans, the readiness of the experimental designs and proposed technologies, and the innovative use of the OOI concept.

As a step toward establishment of the detailed engineering specifications for the OOI, the ORION Project Office tasked its advisory committees; the Science and Technical Advisory Committee (STAC), the Engineering Committee, and the Sensors-Technology Committee; to produce draft Conceptual Network Designs (CNDs) for the three components of the OOI (coastal, regional and global). STAC sub-committees led these efforts. The draft CNDs provide a description of the required infrastructure for specific but numerous science initiatives, with sufficiently realistic cost estimates to enable the oceanographic community to weigh the pros and cons of the infrastructure.

The STAC sub-committees were directed to begin their development of the draft CNDs based on the prioritizations of the RFAs provided by the RFA review panel, but they were also enjoined to provide designs that would enable as much of the science in all the RFAs as possible, while maintaining flexibility to incorporate unanticipated future initiatives. The required reductive synthesis is an extraordinarily difficult task, considering the excellence of the proposed science across the spectrum of oceanographic and marine geophysics disciplines, and considering that the infrastructure required to enable all the RFA science would claim several times the resources currently available for construction of the OOI. That is, after consideration of anticipated costs for management, cyberinfrastructure, education and outreach, surveying, permitting, and contingency reserves, etc., the STAC sub-committees were directed to plan for $40M, $90M, and $30M funding levels for the coastal, regional and global components, respectively, of the OOI (including installation costs). In order to provide options and choices for debate by the oceanographic community, the draft CNDs provided at the ORION Design and Implementation Workshop describe infrastructure with total costs well exceeding the guidelines above.

There were three overarching goals for the D&I Workshop.
1. **Present the draft conceptual network designs to the research community.**
2. **Obtain comments and recommendations about those designs.**
3. **Provide opportunities, in the context of these intense infrastructure discussions, for the formation of collaborative groups focused on developing future, observatory-based, integrated research projects.**

The following report documents the deliberations that occurred at the ORION Design and Implementation Workshop. This report does not provide a revised Conceptual Network Design for the OOI. The ORION Project Office, working with the ORION Advisory committees is responsible for generating the next version of the CND based on the input received at the workshop and on engineering and fiscal considerations.
4.0 Workshop Organization

If you want to build a ship, don’t drum up people together to collect wood or assign them tasks and work, but rather teach them to long for the endless immensity of the sea.
- Antoine de Saint Exupery

The D&I workshop was populated by an open invitation to the ocean research community that was distributed through multiple advertisements in EOS, newsletters, and websites in addition to two direct mailings of postcard announcements. The workshop provided to the community the draft conceptual design of the global, regional, and coastal ocean research observatory network to be implemented under the ORION Program. The draft conceptual design was developed based on an extensive effort by ORION’s Program Office and scientific, technical and engineering advisory committees, using the ideas submitted in the Request for Assistance Responses, previous workshop reports, and other planning and advisory documents.

Workshop participants were expected to engage in intensive component/scale (global, regional, and coastal) and cross-scale thematic breakout group discussions to evaluate the conceptual design and its implementation. Members of the STAC and Engineering Advisory Committees served as co-chairs for the component breakouts, and appropriate advisory committee members and others from the broader community served as co-chairs for the thematic breakouts. To facilitate this effort, participants indicated during the online registration process a component/scale interest, disciplinary expertise and areas of research so that they could be grouped for the component/scale breakout groups with equitable distribution of expertise and research interest among the component breakouts. Breakout groups were intended to be small enough to facilitate discussion, so multiple groups deliberating in parallel were planned for each component.

All registrants were notified of the posting of the draft CNDs approximately two weeks prior to the workshop, and at that time were also given a list of cross-cutting thematic breakout topics and asked to be prepared to select a thematic breakout upon arrival at the workshop. All registrants were provided with a series of questions developed by the workshop organizing committee, which were used as the basis for discussions in the breakout groups.

**Component Breakout Group Questions:**

1. Are there changes (e.g., in location or capabilities) to the CND that would enable additional science objectives to be supported by the network for this component, while not significantly increasing costs?

2. Given the constraints of the budget, does the balance between investments in instrumentation and infrastructure in the CND meet the scientific requirements? What further tradeoffs can be suggested?

3. How should the individual elements of the CND be prioritized to meet the target budget for this component? Provide advice on tradeoffs in terms of capabilities or choice of type of infrastructure; and capital versus life cycle costs.

4. What experiments or observations are likely to yield early success for the ORION Program based on the OOI implementation timetable? How can ORION facilitate that success?

5. Are there any broad science needs that are not served by the draft Conceptual Network Design (CND)? What longer-term (20-30 yrs) science requirements need to be considered?

**Cross-Cutting Science Theme Breakout Group Questions:**

1. How can the CND be enhanced to better address this science theme?

2. What other approaches could be combined with the observatory elements to better address the science questions across the range of spatial/temporal scales?

3. What experiments, observations, or activities are likely to yield early success for the ORION program? How can ORION facilitate that success?

The workshop was organized around an alternating series of informational plenaries and breakout sessions. The first morning and early afternoon was devoted to inspirational and informational presenta-
tions by NSF representatives and overviews of the ORION Program and planning and development efforts already undertaken by the ORION Program Office and subcommittees, so that the participants would have a clear grasp of the current depth and extent of the OOI effort when they began component breakout discussions late on the first day.

The initial plan of parallel component breakouts (3 coastal, 2 regional, 2 global) was revisited soon into the process. Regional and global groups elected not to divide further, while the coastal group elected to break out into three disparate functional groups evaluating cabled endurance lines, uncabled endurance lines and pioneer arrays, respectively. Following plenary updates on component deliberations, participants joined their thematic breakout group for evaluation of the thematic questions. Plenary presentations of the thematic deliberations were followed by a reconstitution of component breakouts to finalize their recommendations for presentation at the workshop finale.

Evening sessions were also organized to facilitate information exchange on specific topics of critical importance to the OOI/ORION effort. These sessions were:

Event Response, AUVs and Sensors/Sampling Forum: The objective of this session was to better define science user requirements for event response for sensors, AUVs and docking, or other infrastructure needs.

ORION Cyberinfrastructure Forum: The focus of this session was to hear, question and comment on what cyberinfrastructure entails, how it has been applied in other observatory efforts, and what it means to oceanographic research on ORION.

Modeling Forum: The focus of this session was to define specific ORION modeling research challenges, examine the status of and recommendations for coastal, regional, basin-scale and global models, and discuss the concept of 'modeling centers.'
5.0. Science Theme Discussions

We need a theme? then let that be our theme:
that we, poor grovellers between faith and doubt,
the sun and north star lost, and compass out,
the heart’s weak engine all but stopped, the time
timeless in this chaos of our wills --
that we must ask a theme, something to think,
something to say, between dawn and dark,
something to hold to --

- Conrad Aiken,
  *Time in the Rock*
  *or Preludes to Definition*

The following section reports the major comments and recommendations from the thematic breakout groups.

5.1. Physical Processes/Climate Variability

Group Leaders for the breakout were Charlie Erikson, Roger Samelson, David Farmer and Roger Lukas. Rapporteur was Katrina Hoffman.

This group focused their discussions on two major science themes. These were:

*Examine the connections in climate signals between the open (deep) and coastal ocean.*

*Examine variability of vertical and horizontal mixing in the ocean*

**East Coast Continental Margin**

The East Coast shelf and slope systems have strong links to climate. The northeast US shelf receives colder and fresher waters from higher latitudes via the Labrador Current. Variations in the magnitude of this input impact the northeastern shelf ecosystem coupling it to larger scale climate signals. In the southeast, the Gulf Stream flows poleward along the continental margin, providing nutrients to the adjacent shelf and slope sea further north and dominating North Atlantic basin meridional heat transport. Variability of the Gulf Stream flows, such as growth and decay of meanders, influences these systems, and variation in transport may drive larger global signals. Both sites are nicely coupled to the global and larger regional scales for both of those reasons. Exchange processes across the shelf and slope are influenced by variations in forcing from both the northern and southern regions and control to a large extent the characteristics of the MAB shelf ecosystem.

The need to better examine forcing from the Labrador Sea was raised. An observatory in the Labrador Sea, and in particular within the Labrador Current, would be very useful for the east coast array. We should encourage our Canadian colleagues to explore this possibility. This would directly determine whether freshwater input is increasing in response global climatic changes.

Local effects will add complexity to other signals at the short, near-shore cabled array currently proposed in the Gulf of Maine, making it difficult to observe the salinity and temperature variations that are driven by large scale climate forcing. Similarly, nutrients in the GME can be traced to the Gulf Stream since it supplies nutrients to the slope waters. To capture variability associated with larger scale variability, measurements in the Northeast channel are needed rather than along the upper slope and shelf.

We’re trying to look at global and coastal connectivity and the influence of advection and propagation down the Labrador shelf. A station W at 40°N and 70°W near the continental slope was identified as a site of high interest from the PO community in RFA responses. That site was not pursued because it wasn’t considered to be ‘global’ enough. It might be worth considering as an observatory location to establish a connection between large-scale and coastal systems. The site currently has a mooring with support from WHOI.

It is not understood how variability in forcing affects slope waters. In addition, cross shelf and slope exchange occurs on very small horizontal scales. Gliders crossing the slope waters should be considered to examine how the character of this water evolves in response to other signals. Glider lines could be established between Cape Sable and the Gulf Stream and near Cape Hatteras.

From point of view of NE climate forcing, there was a consensus that the concept of sustained observa-
tions from an endurance array is important. These arrays should not be confused with planned IOOS moorings however. We need to make clear how OOI observatories differ from and complement IOOS so both communities understand their relevant roles.

**West Coast Continental Margin**

On the West Coast, intrusions of sub-arctic water coming from Gulf of Alaska alongshelf to the Washington and Oregon margin are observed. Lines of moorings across the shelf/slope and glider lines will examine flow variability in relation to PDO and ENSO. We also want to measure the split of the West Wind drift and why transport into the CA current system varies.

Major interannual and interdecadal climate signals, including an invasion of subarctic water that doubled the primary productivity of CA current waters during an el Niño, has been observed in this region. The proximity to the mooring at OWS PAPA and the moorings planned for the RCO permit integration across scales.

**Coastal Pioneer Array**

The Pioneer Array (proposed for MAB) has the power of multi-scale, 3D, process study operation for deployment periods of up to 5 years. In expeditionary science, we can make flux measurements but for a short period of time. In a full annual cycle, stratification varies significantly, which dramatically influences water-column dynamics. The relative mix of controlling processes (which would also be true of river plumes) will be captured by the Pioneer Array.

**Mixing**

Mixing and basin-scale tomography were identified as compelling physical oceanographic issues. Mixing was the topic of many conversations, and we need to go beyond short, ship-based time series and look at a variety of different physical configurations and open-ocean topography and mesoscale areas. The idea of a global pioneer array came up and was compared to an unmanned, deep-sea drilling program: an itinerant pioneer array that could go around the world and do mixing studies as large as 10 km to 1 km to 100 m horizontal scales, with associated mobile platforms (gliders and eventually AUVs). This is a capability we don’t have now that would be transformative.

**Global Pioneer Array**

The issue of how to cover the globe with very limited resources was discussed. Deep-sea drilling has been doing it by virtue of their longevity. One could imagine a process-oriented, multidisciplinary ‘ship’ that could run for years, be on station like a drilling ship, chase gliders, do a pioneer array at one site, and then move to another site with another PI, and have its own gliders and AUVs. It could be a sort of “traveling road show” observatory.

In terms of numbers of elements, if the focus is on mixing, it wouldn’t have to be a very big aperture but a horizontal extent that covers different scales, like 1km and 10km, with AUVs and gliders. The ability to move/relocate builds community support. Correlation scales vary for process, and the array scale could be optimized for each deployment.

This global Pioneer Array was strongly endorsed by this thematic breakout group as a worthwhile idea to be carried forward to component breakout and the STAC committee. Long time series for climate means millennia; but for mixing it could be a few months. It would be transformative for each of us to have access to this resource a couple of times a decade. The data have to be public.

**Calibration for climate and consistent data processing**

It was recognized by the participants that there is a need to promote system-wide calibration and consistency in data processing. The goal is to have a data set that will be a long-term resource for retrospective climate studies.
5.2 Biogeochemistry and Ecosystems

Group Leaders were Jim Yoder, Wade McGillis, Dan Costa and Scott Gallager. Rapporteurs were Esat Atikkan and Barbara Kirkpatrick.

To stimulate initial discussion, session leaders posed the science question: How does forcing by the Northern Hemisphere climate system impact the North American coastal ocean? Hypotheses related to this question were stated as: 1) The West Coast is affected by ENSO, and the effects propagate from S to N, and by changes in the strength and location of the Aleutian Low (related to PDO), and the effects propagate from N to S.  2) The East Coast is affected by freshwater discharge from Hudson Bay and mixing in the Labrador Sea (related to conditions indexed by the NAO), and the effects propagate N to S to the Scotian Shelf, Gulf of Maine, MAB shelf and slope area; maybe some effects extend to the SAB.

This theme was considered appropriate for ORION in that it involves linking climate and ecosystems over a broad range of scales that require all of the observatory elements and can not be done with any technology today. With these hypotheses, the primary focus would be comparison of the PNW and GME and it was suggested that both be enhanced by eliminating the SAB coastal endurance line.

Other key research themes that relate to this overarching question include:

- carbon transport (land, ocean and air)
- organization and persistence of food webs and how they change in response to climate variability
- population dynamics of top predators (e.g., marine mammals, seabirds), including movement over large areas (Fig. 5.1)
- land - ocean connections (e.g., freshwater input)
- boundary current - shelf interactions (e.g., Gulf Stream - shelf interactions in SAB)

In the context of the above questions, OOI observatories would be critical for measuring and providing samples for assessing numerous ecosystem structuring factors including:

- physical factors, such as light, temperature, mixing, turbulence, currents, transport

![Figure 5.1. Migratory tracks exemplifying the interconnections of oceanic coastal and global systems.](image-url)
• chemistry, including macronutrients, concentration and availability of selected trace elements, $O_2$, $CO_2$
• biology - primary and secondary production, grazing, predation, and respiration

Other considerations noted by the participants included:
• Recognition that coastal systems are not included in global maps of CO2 exchange. ORION could be instrumental in supplying this needed information.
• Because observatories provide a continuous observational presence, complex interactions and exchanges with other local habitats, such as, mangroves, corals, salt marshes, ground waters, rivers, etc., can be assessed.
• This topic provides excellent education and outreach opportunities – thinking big (blue whale) but also life cycles of other organisms (rockfish, mammals, birds).
• Many large animals travel over basin-scale distances so we need integration of OOI observation scales to follow activities
• Chemosynthetic activity and the role of chemosynthesis in biogeochemical cycles is also important. This includes reactions at deep sea vents, cold seeps, hydrates and reducing coastal and shelf sediments.
• Human activities also impact biogeochemistry and ecology, especially of coastal ecosystems, and provide a focus for observing activities.
• Sediment type needs to be considered in siting observatories; the majority of shelf sediments are coarse-grained, relict sediments. Recent studies suggest that because of elevated permeabilities, these types of sediments support very high remineralization and denitrification rates and may play major roles in biogeochemical cycles.
• There is a need to strongly tie coastal observations with exchanges with the land. This suggests expanding our coordination with NEON to facilitate nearshore and estuarine - ocean exchange studies.

In the context of the proposed overarching question, sensitivity of the coastal ecosystem to climate change was considered the primary criterion for selecting observatory locations. With this emphasis, the potential coastal observatory sites were prioritized as PNW, GME and SAB.

In discussing this prioritization, a variety of other criteria were discussed that were not included in the above ranking. They include:
• extent of light penetration
• extent and mechanisms of benthic-pelagic coupling
• role of the coastal system in biogeochemical cycles
• denitrification in permeable sands - an open issue
• types and species composition of fish and anticipated population changes
• GME is a good macrocosm - but may not be a good idea to concentrate efforts in a 'small basket'
5.3 Earth Structure and Geodynamics

Group leaders were Doug Toomey and Barbara Romanowicz. Rapporteurs were Alison LaBonte and John DeLaughter.

Discussion-group participants were charged with discussing three questions.

Question 1. How can the CND be enhanced to better address research related to earth structure and geodynamics?

To examine this science theme, the group first agreed that the overarching science questions focused generally on two basic themes:

1. What are the scales, shapes and natures of heterogeneities in the Earth’s mantle and core and how do they relate to key processes such as plate tectonics, the generation of the earth’s magnetic field, or variations in earth’s rotation?

2. What are the linkages between tectonic and volcanic processes in the ocean crust, from its formation to its destruction, and ocean ecology and biogeochemistry, both above and below the seafloor?

Within this context the group agreed on a variety of recommendations for each of the OOI observatory scales.

Recommendations for the RCO

• Make the node near the CLEFT site fully operable.

• Redesign the RCO CND to include the southeastern corner of the Juan de Fuca Plate. This will allow better coverage of the Juan de Fuca Plate and the Blanco Fracture Zone and will facilitate possible future expansion of the observatory toward the seismically active Gorda Plate.

• Assess the cost/benefit of the redundancy of N5; if insufficient, delete N5 from the system and re-allocate funds to other needed components

Science recommendations that impact both Global/RCO

RIDGE community needs to prioritize MOMAR and EPR. Discussion and ranking of these sites may also include a discussion of the Cleft site. Issues to be addressed in evaluating the Cleft site relative to the other potential sites include:

• How does Cleft play off against MOMAR and EPR?

• Cleft is more typical of EPR, not of MOMAR. So if Cleft is occupied, is EPR needed?

• How do subduction zone sites also trade off against Margin sites?

• Defense of EPR vs. Cleft: EPR has a long history of having an event and then another event.

• Technical considerations include that the RIDGE site has 500W and high bandwidth.

• Cleft was the ‘original’ ridge site chosen. EPR has vents and activity; 9N erupts and its vents change rapidly.

Global Scale Observatory Science Priorities

• Occupy existing boreholes drilled for global seismology. Top choice is near EPR (OSN2) unless RIDGE chooses EPR site, then H2O or 396B are preferred sites.

• Other priority global sites include sites in Southern Ocean and western Pacific (55°S 150°W)

Coastal-Scale Observatory Science Priorities

It was noted that there were no geophysics research questions posed in the context of the coastal observatories but that these observatories nonetheless provide excellent opportunities to study the structure of continental margins, generation of hazards through slumping and other processes.

Furthermore, coastal observatories provide opportunities to connect continental and marine geophysical studies and can serve as the starting point for more extended arrays.
Coastal observatories could clearly provide an important linkage between the ORION and Earthscope Programs.

**Scale-independent recommendations:**

- The Ocean Mantle Dynamics Initiative should be revived and given some urgency, as it provides a mechanism for linking observatories. It also provides a means of linking observatories and bridges a gap in scales between local, regional and global studies. This would require and promote coordination of EarthScope ORION, Webfoot, and other transportable array deployments.

- Study of the Earth’s “hum” should be advanced by generating better global wave measurements and utilizing the RCO to provide a full suite of data.

**Question 2.** What other approaches could be combined with the observatory elements to better address the science questions across the range of spatial/temporal scales?

- Design compatible interfaces that allow instrumentation to be moved among different components of the ORION observatory (global, RCO, coastal).

- Make a suite of measurements at all sites (e.g., seismic, pressure gauge, wave heights) in order to understand coupling between the solid earth, oceans and atmosphere.

- Encourage NSF/ORION to work with other global programs, such as ADOP and NOAA buoys, to provide additional sensors and even slow data rate reporting locations.

- Work to increase satellite bandwidth available via Iridium.

**Question 3.** What experiments, observations, or activities are likely to yield early success for the ORION program? How can ORION facilitate that success?

- Deploy a high-bandwidth SPAR buoy at a dynamic environment to allow for interactivity and response to events, return of data from webcam (educational component). High bandwidth is most useful for interacting with instruments. The most likely locations will be ridge-crest or margins sites. Data return/interactivity with sites would be high profile and exciting.

- Using FLIP as the first SPAR buoy on EPR/MOMAR, could yield high band-width results. It could be deployed at an instrumented RIDGE site to show recovery of data from buoy. This can be done rapidly.
5.4 Fluid/Rock Interactions and Sub-seafloor Biosphere

Group Leaders were Susan Humphris and Peter Girguis. Rapporteurs were Leslie Sautter and Deborah Glickson.

To initiate discussions, this group reviewed the key science questions posed in the OOI Science Plan.

- What is the extent, abundance, distribution, and diversity of the subseafloor biosphere?
- How do submarine hydrothermal systems and their associated biological communities vary over time?
- What processes control the formation and destabilization of gas hydrates? What role do gas hydrates play in catastrophic slope failure?

One overarching question was identified that could serve to focus research for the next 20 years:

How do subseafloor processes impact life on our planet?

It is recognized that the deep biosphere may host more biomass than any other ecosystem and yet it is virtually unknown. One strategy to examine this issue is to characterize the mass and energy exchange among the lithosphere, the subsurface ecosystem, and the ocean, and how it influences our planet (Fig. 5.2).

Issues concerning the global and RCO draft CNDs:

- While global sites currently identified provide a diversity of abyssal sites, none look at geologically dynamic areas (subduction, vents, etc.) although one may be at MOR in phase II and there may be a subduction zone in phase III.
- Global sites mostly address water column and physical questions.
- No sites in phase I are looking at subseafloor.

Figure 5.2. Sub-seafloor fluid flow systems in geological, biological and hydrographic communities. Many seafloor and all sub-seafloor ecosystems are inextricably linked to, and perhaps an inevitable consequence of, the flow of energy and material between the earth’s crust and the deepest portions of the overlying ocean. The direct linkages between life and planetary processes operating along deep-sea spreading centers, subduction zones, and transform faults, as well as mid-plate circulation, can only be understood through tightly integrated studies across a broad range of disciplines in geophysics, geology, chemistry, biology, and oceanography. From the ORION Science Plan and references therein.
• OOI could bring or provide power, instruments etc to CORK world. Greater emphasis in current planning needs to be placed on placing global buoys near the CORK sites.

Within the context of these discussions, the highest priority global sites were considered to be:
- MOR site (beyond the RCO sites)
- Subduction zone site
- Near-ridge CORKed site

In addition, high priority was given to the Barkley Canyon and Hydrate Ridge sites for study of gas hydrates.

**Issues concerning coastal CND:**
- Many fluid/rock interactions occur in continental margin and shelf environments also (e.g. groundwaters, freshwater aquifers and recirculated seawater flows). CSO planning should also consider research requirements for these types of studies.
- There is little discussion of subseafloor biology in coastal groups at present
- There is no geophysics in East Coast coastal discussions

Within the context of these discussions, high priority was also given to establishing a:
- coastal sedimented site
- coastal sites in areas of gas hydrates and/or freshwater aquifers

**Recommendations:**
- Encourage coastal group to explore groundwater seeps, methane-rich areas (suggestion to extend line to hydrates!)
- For the RCO, studies are need both near and away from plate boundaries. We need to work with a design team to ensure a proper balance.
- Sensor development is needed; fouling is a huge issue.

• Use piston coring initially as part of global site surveys to begin to examine the subsurface biosphere.
- The ORION Program Office should investigate the possibility of sponsoring a workshop that brings together IODP, ORION, NOAA (DART) Buoys and maybe DOE interests for discussion and joint planning.
- The ORION Program Office should promote the coordination of the global array with existing and planned IODP efforts.
- ORION should investigate the use of FLIP as a spar buoy to incorporate spar technology and capabilities into the ORION Program as early as possible.
- Powered sites are a priority.
- The PNW coastal Endurance Line should have power from the RCO
- There is a need to develop infrastructure capable of performing in situ perturbation experiments in the future.
5.5. Ocean Atmosphere Fluxes and Marine Meteorology

Group Leaders were Bob Weller and Jim Edson. Rapporteurs were Chris Petrone and Barbara Simon-Waters.

The community has a tremendous opportunity to advance the development of regional atmospheric models. A major driver for this is to directly observe and quantify ocean atmospheric interactions and exchange over the full spectrum of conditions encountered in the natural environment (sea breeze to cyclone; Fig. 5.3.). Especially important is to obtain information in high-wind regimes where previous measurements are nearly non-existent. Study of these conditions is of critical importance to advancing understanding of such phenomena as hurricanes.

The discussion amongst the participants began by noting the unique opportunities provided by the planned OOI observatories. Opportunities highlighted and suggestions that would enhance atmospheric research capabilities of the OOI for each component were:

- **coastal** -
  - The PNW coastal array provides excellent opportunities to study ocean-atmosphere interactions over a broad spectrum of conditions because of the frequency of major storms passing through this region. The surface expression of the buoys must be designed to optimize the use of meteorological sensors for flux measurements. An issue is that it does not extend far enough to the south.
  - By leveraging with existing tower observatories, the SAB offers many unique opportunities. They include studies ranging from gas exchange studies, studies of sea breezes and high wind speed - ocean interactions associated with hurricanes. It was also noted that the new cruise track of the Explorer of the Seas will pass through this region and provide supporting information and opportunities for public outreach.
  - Absence of Gulf of Mexico OOI Observatories. This could be a location for a Pioneer Array deployment in the future.

![Figure 5.3. Ratio of the heat to momentum exchange coefficients (y-axis) versus wind speed (x-axis). Points show where measurements have been made; line represents extrapolations made for models. Note how few data exist for extreme storm events. Image courtesy Jim Edson.](image-url)
Pioneer Arrays have the advantage of good spatial coverage and spatial optimization for specific phenomena. However, they are currently not designed to support atmospheric flux measurements. Can this capability be supported on the Pioneer Array?

If the Pioneer Array can support flux measurements, it examine heat and moisture fluxes in Nor’easters.

**regional -**
- Take advantage of the spatial coverage and capabilities provided by the RCO/PNW Coastal array to establish a mesoscale air-sea array for coupled-model research and validation.
- Ensure the capability on the RCO to support a passive acoustic array for direct measurement of ocean rain.

**global -**
- Spar buoys in high latitudes (both but especially southern ocean) offer significant opportunities.
- We need to make sure that spar buoys are designed to support turbulent flux and atmospheric boundary layer studies.
- We should add flux systems at existing sites; e.g., PAPA should have flux measurements.
- We should add high-quality met measurements and aerosol measurements at all global locations.

Numerous experiments and activities were noted in response to the question: What other approaches could be combined with the observatory elements to better address the science questions across the range of spatial/temporal scales? Examples include:
- Develop nested, coupled air-sea interaction models from Coastal to Global (i.e., seabreeze to cyclone to climate; Pioneer to RCO to Global).
- Combine observatory elements (Coastal and Pioneer) to close the oceanic heat budget for a particular set of atmospheric flux conditions (can also do CO$_2$ by the same strategy).
- Use observatories to obtain integrated studies of breaking waves, bubbles, surfactants, and gas concentrations as controls for gas transfer.

- Advance air quality measurements (e.g., ozone, CO$_2$, sulfur, NOx).
- Utilize distributed measurements of aerosols, DMS, and sea salts to contribute to the production of CCN and global albedo.

**Recommendations**
- SAB is the first-priority coastal location. Research drivers include the carbon cycle, mesoscale variability, hurricane activity, strong sea breeze, boundary-layer interaction and the Gulf Stream impacts.
- PNW is the second-priority coastal location. Research drivers include examination of mesoscale variability and extreme wind conditions.
- Top priority at global scale is a high-latitude location (preferably in the Southern Ocean) equipped with spar buoy technology that provides power and reasonable bandwidth.
- Second priority for a global location would be in the equatorial Atlantic. Research drivers would include studies of hurricane formation and aerosol deposition.
- All surface moorings (GSO, RCO, and CSO) must be capable of supporting high-quality meteorological measurements, surface currents and directional wave spectra.
- At selected locations, infrastructure should also support sensors to measure turbulent fluxes.
- At coastal sites, we should ensure that the infrastructure can support visibility and liquid water content measurements to study coastal fog.
- We should ensure that the infrastructure supports atmospheric boundary layer measurements (e.g. rawinsondes, profiles, ceilimeters, aerosols) at selected sites to entrain the atmospheric science research community.
5.6. Ocean Hazards

Group leaders were Oscar Schofield and John Or-cutt. Rapporteur was Jim Brey.

All aspects of hazards understanding and potential for mediation have both an IOOS and OOI component, and these problems should provide a great partnership for all the observing communities. ORION will need to be proactive in building the linkages among communities. ORION’s OOI is the NSF contribution to IOOS and will contribute to the seven stated societal goals of IOOS. As well, many of the issues directly impact the national economy and security. Here ORION and IOOS can work together to educate the public, and succeeding at this will take an effort by both entities to span the gray area between research and operations. Education and Outreach can especially benefit from the hazards focus by galvanizing community participation to make a difference. Hazards are the science driver that may convince the public that we are trying to do might actually matter (Fig. 5.4.).

Climate change, sea level change, salinity changes

For the coastal and global efforts this is a central overarching research theme (for example how will continental shelf ecosystems be impacted). Time series are necessary to look at secular versus cycli-cal processes. We should have good sea-level measurements given that the rates of sea-level rise are a hot topic of discussion in all ORION components (for example in the open ocean, in situ measurements will be helpful). This is a great opportunity for partnership both nationally and internationally. Understanding ice dynamics and changes in ocean salinities will be a central research need. Will major current systems change?

---

Figure 5.4. Billion-dollar US climate and weather disasters 1980-2004 (right), and RB image of Hurricane Katrina approaching landfall in the Gulf of Mexico, August 29, 2005 (below). Damage from Hurricanes Katrina and Rita are already estimated in excess of $100 Billion. Images courtesy of NOAA.
Instruments: Seismic and geodetic, bottom pressure, acoustic arrays, hydrography, flow meters, biogeochemical sensors

Ocean acidification, global carbon cycle
Acidification affects the ability of the ocean to act as a future sink for short- and long-term carbon removal by shifting the ocean chemical equilibrium and solubility of CO$_2$ and by reducing and perhaps eliminating many carbonate test-bearing plankton species that alter the long-term removal of carbon from the ocean. The depletion of carbonate bearing plankton species and corals also removes one of the main food sources for larger forms of life in the ocean, thus impacting the ocean ecosystem. This is a global issue requiring improvement in understanding in many aspects, including air-sea fluxes and budgets. The OOI infrastructure will enable study of the potential hazards of these global-scale changes. How much carbon can be assimilated by the ocean? This is a tremendously important question.

Instruments: pH, dissolved gas sensors, gas exchange, optics and biogeochemical sensors, acoustics (absorption of sound as a function of pH)

Hurricanes, storms
There is an absolute need to measure surface gravity waves, wind, and the air-sea exchange of heat and momentum. Locations proposed might be optimized specifically to this purpose but current proposed sites will be impacted and therefore useful. The ability to study intensification is not covered if we do not have the Gulf of Mexico (Fig. 5.4.). The ability to study thermal resources, high-wind physics, storm surge, and the impact of the event will be necessary. Improved wind-wave physics will be key to understanding geomorphology-altering processes. An unexamined biological/chemical forcing function should be considered. Pioneer arrays may provide a unique tool in this regard.

Instruments: Directional wave buoy, pressure sensors, flow meters, anemometers, bathymetric surveys to shore, hydrography, sea floor optics and acoustic imaging, seismic sensors, and meteorological sensors.

Harmful algal blooms, spills, coastal water quality, disease vectors (plague) affecting human health, hypoxia, rip currents, beach erosion, pollution (including unexploded ordnance)
All are significant issues for the community. For example, rip tides are the no. 2 coastal killer among them. Economic impact of the damage is considerable. Nearshore processes will impact human populations. Spatial issues here are very important, and the pioneer arrays and mobile assets will be a critical tool. This will require specific regulatory outreach also. An Endurance Line is necessary, with assets moving onshore spatially as needed, which will also require a responsive shore capability. Surface gravity waves are also fundamental to these processes. Wave initialization information is needed for nearshore processes. Shelf observatories will be key to providing the boundaries.

Instruments: Biogeochemical sensors, bio-optical, genomic and immuno-sensors, flow meters, wave buoys, side scan sonar, geophysical seismic measurements, bathymetric surveys to the shore

Tsunami, earthquake, strong ground motion (including volcanic)
We need to provide a research footprint for understanding processes that might provide earlier warnings and determine if a seismic event has generated a tsunami. Data should be freely available. Dart buoys would be augmented by the RCO, for example. The design of the network could be optimized for this, and the presence of the RCO would increase public awareness. The ability to add nodes or expand branching units will be key and should be pursued. This would provide the platform for instrumentation to conduct the basic research for a framework of offshore warning networks. The ability to monitor small earthquakes would help to understand processes that might allow improved predictions (what-when-where).

Instruments: Seismic and geodetic, bottom pressure, acoustic arrays, bathymetric surveys
**Underwater slope failures**
What generates submarine slope failures? Why do they occur: storm surges, earthquakes, methane hydrates, volcanoes, shallow overpressure conditions, or other causes? Also, methane hydrates are a hazard in and of themselves; they will require a spatial perspective over time. Small-scale events are also crucial issues to be measured. Progress here should leverage all assets (seismology and geodesy) in addition to the OOI. For example, the range of the coastal observatories might allow comparing and contrasting studies.

**Instruments:** Seismic and geodetic, bottom pressure, acoustic arrays, bathymetric surveys, gas sensors and measurements, sub-seafloor pore pressure

**Over-fishing, invasive species, sound in the ocean**
Monitoring stocks, migration, behavior, and larval transport via acoustics (active and passive) should be a high priority. An adaptive sampling capability here will be key, and mobile assets and Pioneer Arrays could fuel great studies. Long-term ambient noise time series would be extremely interesting at all sites. Here well calibrated sensors will be necessary to document changes. New biosensors will be important for invasive species. Long time series for fishing issues will hopefully allow us to understand secular versus cyclical long-term changes, or “degraded” local ecosystems. We will need to improve our “Easy Pass” for fish.

**Instruments:** Active and passive acoustic arrays, chlorophyll, hydrography, genomic sensors

**Hazards to navigation, undersea volcanism, ice (scouring, bergs, etc.), surface gravity waves (wave climates):**
These represent challenges, and we contribute to mapping these hazards. Although this is not a primary goal, we will make contributions (maybe help in ship routing).

**Instruments:** bathymetric surveys to shore, directional wave buoys, hydrography, seismic arrays, sea floor acoustic and optical imaging

**Aeolian dust, volcanic (dust), air quality, atmospheric brown clouds (acbs), atmospheric pollution**
What is the impact on reefs? We understand very little, and ORION will help understand these processes in the atmospheric boundary layer. The entire network should be used and complement other efforts (NASA). How much dust is coming from Asia? What is the difference in urban vs pristine locations?

**Instruments:** above-water dust sensors, sediment traps, optics and biogeochemical sensors
6.0. Coastal Draft Conceptual Network Design

Always use the word impossible with the greatest caution.

- Werner Von Braun

6.1 Overview Description

Coastal systems define the boundary between the terrestrial and marine realms and the interface at which most human-ocean interactions occur. A critical need exists to advance understanding of these regions of intense interaction. More than 50% of the human population resides along the coasts which are also susceptible to hazards such as inundation due to hurricanes or tsunamis. Greater than 90% of the world’s fish catch is harvested from coastal waters. These regions also support major recreation and maritime industries. Transport across the coastal ocean exerts a dominant control on major global chemical cycles determining, for example, material exchange between the terrestrial and oceanic realms. Thus, coastal systems play disproportionately important roles in the ecology and biogeochemistry of the global oceans.

The Ocean Observatories Initiative Science Plan and previous workshop planning documents identify and discuss numerous coastal science drivers. In general they can be organized into a relatively few research themes. Example questions within these themes include:

What processes determine the transport of carbon, nutrients, planktonic organisms, and other materials within the coastal ecosystem?

What conditions trigger the occurrence of harmful algal blooms and regime changes in the species composition of coastal ecosystems?

How will climate change and human activities alter coastal ecosystems, habitats and living marine resources?

There will not be a single answer for any of these questions. The mix of controlling processes within coastal systems vary with the relative magnitudes of local forces and with bottom morphology. Important factors to consider include wind forcing, buoyancy inputs, tidal energy, and oceanic boundary current interactions. In addition, local morphology and bottom sediment characteristics impact process interactions by influencing bottom friction, directing bottom currents, providing habitat and substrate for organisms and mediating a variety of biogeochemical processes. Interactions between the fluid water column and the sediments that are transported primarily by energetic, short-term events offer one example of the challenging temporal variability of coastal systems.

Prior to the workshop, the Coastal STAC subcommittee, working with the 22 RFA coastal responses, previous planning documents and the results of the RFA review panel, reduced to recommended sites and elements for coastal observatories to six options. They include two Pioneer arrays (initial proposed deployments in the MAB and PNW), and four Endurance Observatories located on at Oahu, Hawaii, PNW, Gulf of Maine, and the South Atlantic Bight. This ‘menu’ of options served as the starting basis for discussions at the workshop. The complete draft coastal CND is provided as Appendix 10.4.

6.2 Major Discussion Points, Comments, Strengths and Criticisms

Group leaders were John Trowbridge, Collin Roesler, Mark Moline, Bill Kirkwood, Andy Barnard and Gene Massion. Rapporteurs included Tim Short, Jim Brey, Chris Petrone, Leslie Sautter, Rick Baker, Barbara Kirkpatrick, Barbara Simon-Waters and Esat Atikkan.

Because of the diversity of coastal environments and the mix of controlling processes they represent, identifying a small number of specific locations as initial deployments for a long-term detailed focus effort for future coastal research is extremely difficult. The strategy adopted by the STAC Coastal subcommittee, therefore, was to provide a menu of potential OOI study sites, gleaned from possibilities provided in the RFA responses, and solicit discussion from the D&I Workshop participants. The funding available will require that only approximately half of the infrastructure elements identified in the preceding section can be implemented. The need
to fully vet and discuss the potential sites dominated much of the discussion at the expense of the questions proposed by the workshop organizers. The following account, therefore, follows these discussions rather than the suggested questions.

The group accepted the situation that to fit within the prescribed budget, significant cuts from the draft CND ‘menu’ had to be made. Early in the group’s deliberations, it was decided to focus discussions around three general areas: an uncabled Endurance Array on the West Coast, a Pioneer Array, and cabled arrays. The latter concentrated the discussion around RFA proposed sites in the South Atlantic Bight, Gulf of Maine and Oahu, Hawaii.

Criticisms of this focus centered on two main points. First, the Gulf of Mexico is not represented within the current plan. Many attendees recognized the importance of the Gulf of Mexico, in general, and the continental margin of the northern Gulf in particular as deserving of study. The water, sediment and nutrient inputs of the Mississippi River are major drivers of shelf processes in the region. Further mechanistic studies of ocean - atmospheric interactions, as they relate to hurricane formation and in particular mechanisms of storm intensification, were also discussed as important research priorities. It was noted that Pioneer Arrays are designed to be relocatable, and that this region would be an excellent location for a Pioneer Array experiment in the future.

A second overall criticism noted that the proposed infrastructure was generally focused on the mid to outer shelf areas with little focus in the nearshore region (water depth shallower than 10 m). While this environment is generally more accessible than deeper areas, through small boat operations and conventional SCUBA operations, observatory experiments that would advance understanding of this interface zone were envisioned and again, could be the focus of future Pioneer Array deployments. The results of the RFA response and binning process did not indicate an intensive OOI investment in depths less than 10 m.

The majority of the remaining discussions centered on trade-offs between concentrating observing assets at a very few locations versus distributing them more widely. The benefit of focusing observing capabilities at a few locations is that it permits specific science issues to be examined in greater detail and from a variety of observing perspectives. However, this also limits the breadth of research that can be conducted because the mix of important processes that control coastal ecosystems are also distributed, controlled by such factors as seafloor morphology, external inputs (e.g., sunlight, freshwater and nutrient input) and dynamic interactions at coastal boundaries (e.g., eastern and western boundary-current interactions). Of course, distributing observing sites too broadly will stretch the infrastructure resources more thinly and will limit the types of measurement activities that can be performed at each site. To assess the appropriate balance between distributing and concentrating infrastructure, each of the proposed locations for endurance arrays were discussed in detail.

Cabled Endurance Line Site Discussions

Oahu, Hawaii

This proposed system builds on the existing cabled Kilo Nalu observing system which extends out on a steep south Oahu slope to a depth of 30 m. This is a low-latitude, tropical reef/island coast, comprising carbonate sands exposed to the open ocean. Because of the steep morphology, the shelf is very narrow (“nanoshelf”) and deep-water environments are in close proximity.

Science questions that were highlighted for this system include:

- Tropical ecosystem response to climate change, including the study of shallow vs. deep, and hypereutrophic to oligotrophic systems.
- Offshore forcing effects on coastal tropical ecosystems, such as the impacts of meso-scale eddy forcing, baroclinic forcing, and changes in nutrient availability.
- Effects of physical forcing on benthic biogeochemical exchange through highly permeable sediments.
- Land-based nutrient and suspended sediment inputs, representative of island systems which differ from continental regimes.
Other potential opportunities here include acoustic tracking of marine mammals and fish.

Logistical advantages of this site include that water depths of 200 m can be reached within 1-2 km from shore and that, because of the tropical weather, the site is accessible by small boat and divers (shallower nodes) nearly all of the time. It might be a good place to test new technologies.

**Gulf of Maine**

The Gulf of Maine is a semi isolated basin, simplifying the task of modeling and measuring its outer boundary conditions and inputs. Fresh water from the Scotian shelf drives the overall circulation in the gulf, which comprises two separate, cyclonic eddies. Deep water is exchanged mostly through the NE Channel. Temperatures of the eastern gyre are controlled by the influx of deep water and are generally correlated with the North Atlantic Oscillation. In general, heating and mixing of colder waters coming down from the north, especially at the boundary between the two gyres, provide a strong thermal gradient that represents the northern limit of many temperate species and the southern limit of many arctic boreal species. Thus, the ecology and species composition of this region is expected to be sensitive to climate variations. In addition, this region displays extensive and repeated outbreaks of harmful algal blooms.

The revised plan presented at the meeting is to install a cable to 120 meters, which will be one of the few sites on the eastern seaboard where muddy, accumulating sediments can be reached within a modest distance from the coast. Glider lines and independent buoys are proposed to monitor water motions and properties in the far field from the cabled nodes.

Science in this section fell under the general question of “How does climate variability effect change in primary productivity and benthic-pelagic coupling in the Gulf of Maine (GME)?” Highlighted issues included:

- **Interannual variation in delivery of Labrador Slope Water versus Warm Slope Water.**
- **Phytoplankton response (type and abundance) to delivery versus local conditions as water is transported southwestward, eventually into the western gyre.**
- **Benthic processes (including non-invasively measured bioturbation) affected by phytoplankton inputs and boundary-layer flows.**
- **Benthic-pelagic coupling, especially by vertically migrating mysids sensitive to both benthic and planktonic conditions.**
- **Use of benthic sonar to provide a coordinate system (x,y,z,t) for benthic experiments and a measure of observatory artifacts (reef effects).**
- **Accelerated development of cabled, scanning sonar, PIV and holography.**

Emphasis was placed on assessing forcings that propagated to mid levels in the food web, requiring power and bandwidth that only a cabled system can provide. Proposed activities at the cable nodes include installing optical and flow cytometry sensor systems, holography and particle image velocimetry (+high definition video). Highlighted research uses of these instruments include examining behaviors of mid-trophic level organisms and non-invasive studies of bioturbation and benthic organism activities. These instruments require power and bandwidth that can only be provided by a cabled system.

**South Atlantic Bight**

The region consists of a broad continental shelf, adjacent low-lying coastal plain with relatively low sediment supply, characteristics representative of many passive continental margins (Eastern North America, Eastern South America, Africa, Europe, and Australia). It is bounded by the Gulf Stream, which like other western boundary currents (Agulhas, Kuroshio, Brazil, East Australia Currents), is a warm, deep, narrow, and fast flowing current moving poleward on the west side of ocean basins. Collectively, these currents account for much of the meridional oceanic heat transport and therefore influence climate. Because of its location and offshore warm waters, this location is also exposed routinely to hurricanes and other cyclones. Sandy, relict sediments, representative of most of the world’s shelves, characterize the seafloor and the ecosystem is at the temperate to subtropical transition.
This observatory location builds on mid to outer shelf military towers that permit unique air-sea and atmospheric studies. While initial plans outlined in the RFA response were very ambitious, the modified plan discussed at the workshop consisted of a single cable to the SABSOON towers and a line of CPIES extending across the Blake Plateau that would support most of the identified research activities. Science enabled highlighted for this area includes:

- Direct examination of Gulf Stream variability and interactions with basin-wide thermohaline variability
- Gulf Stream - shelf Interactions
- Buoyancy effects related to seasonal and interannual remote forcing (Rainfall in SE is correlated with ENSO variability)
- Shelf-slope circulation and exchange
- Vertical and horizontal mixing
- Response of plankton/nekton community structure
- Detection of episodic biological phenomena
- Wave propagation on shallow shelf (supported by extant WERA HF Radar)
- Sediment transport/mobilization
- Carbon cycle research of global relevance
- Endangered species such as sea turtles

It should also be noted that large and variable groundwater discharge has been reported in this region and could be the focus of interactive observatory experiments.

**Uncabled Endurance Lines in the California Current**

The participants recognized that the California Current system comprises four distinct bio-geographical regions that are interconnected and interact via the transport of materials within the Current system. While the principal focus of the West Coast Endurance Array effort remains in the Oregon/Washington continental margin area, it was pointed out that there were advantages to expanding the footprint of observations southward to capture important forcing associated with variability in such factors.

*Figure 6.1. West Coast plan recommended by coastal breakout groups.*
as sea level and the undercurrent. The strategies discussed by which this could be accomplished while not greatly increasing the budget included enhancing capabilities at MARS, adding a very few selected, long-term, multidisciplinary moorings at key southern locations, and adding glider lines to advance understanding of current dynamics from Southern California to Washington in the along-shore dimension. Where possible, these additional measurements will be provided by partnering with other ongoing observatory programs such as SC-COOS, MBARI, SB LTERs, RCO, NEPTUNE Canada, VENUS, SATURN, PISCO, and CORIE.

**Pioneer Array**

The Pioneer Array concept was recognized as a potentially revolutionary tool for future studies of coastal dynamics. As a relocatable array, it can provide detailed information about a wide range of processes controlling coastal ecosystems over a fixed period. At each deployment, the design of the array can be optimized for the location and processes being studied. In addition, two-way communications between both fixed and mobile platforms will permit adaptive sampling, ensuring that important features are resolved on the appropriate scale both vertically and horizontally. This technology has the potential to transform the way shelf dynamics are studied in the future.

It was also recognized that the Pioneer Array is generally applicable to processes and system responses that occur on time scales of less than 1-2 years. As such, this system has the potential for rapid return and for demonstrating early success with the OOI concept.

Furthermore, it was recognized that many of the individual components required for the Pioneer Array (basic moorings, coastal telemetry, power production from surface moorings, gliders) are ready or nearly...
ready for incorporation into an integrated system and deployment. One exception are AUVs and AUV docking stations. While the concept of Pioneer Arrays can go forward absent full incorporation of AUVs, it was agreed that their incorporation would greatly expand overall capabilities and that AUV and AUV docking development is a high priority.

6.3 Recommendations

A major research challenge is to unravel the impacts of climate variability on coastal ecosystems. This requires understanding process interactions across a wide range of space and time scales and developing an understanding of the functioning of coastal margin ecosystems and communities in different coastal regimes, such as eastern and western boundary currents. In addition, understanding the role of continental margins in global biogeochemical cycles and the impact of human activities on coastal systems must be advanced.

**Final recommendations presented in plenary were:**

Work to design one Pioneer Array. Because this system will be relocated periodically throughout the ORION Program, it can have an important research impact at a variety of locations. It is anticipated that a small level of modification and tuning will be required for each installation. For current planning purposes, the overall design provided in the Mid-Atlantic Bight shelf-edge exchange proposal will be used. It provides a visionary integration of fixed and mobile assets that has the potential to greatly expand research capabilities.

Work to design a West Coast California Current array (Fig 6.1.) to capture the dynamics of the California Current system, focusing most assets along two endurance lines on the Oregon and Washington continental margins where the majority of the detailed, process-oriented observations will be concentrated. In addition, two profiling moorings would installed in the Santa Barbara and Pt. Conception areas, and additional profiling capabilities would be installed at MARS. To capture the far field dynamics of this current system, glider lines are proposed as shown.

Work to design an integrated East Coast Endurance Array (Fig 6.2.) that captures the collision of the two water masses that control East Coast ecosystems. From the south, the Gulf Stream transports massive amounts of heat, nutrients and organisms while colder, fresher waters flow southward from the Scotian shelf. Given the magnitude and diversity of this environment and the broad and fundamental research needs, it is clear that OOI observatories will need to partner with other observatory efforts, such as IOOS, state and institutional efforts, to achieve the desired, system-wide context while opening windows for observations at previously unachievable temporal and spatial scales. It is important to recognize that the OOI observatory effort is distinct in its degree of sensor–scientist interactivity, scales of observations and use of cutting-edge sensor technologies and that the concentration of these capabilities at specific sites provides transformative research possibilities.

The recommended plan suggests that cabled observatories be installed in the southern (SAB) and northern (GME) regions. To provide observations of far-field variability and integration of the detailed observations at the cabled observatories, glider lines and information from other, non-OOI observatories will be incorporated. Existing observatories at MVCO and LEO-15, as well as glider lines in Virginia, New Jersey and at Martha’s Vineyard, are maintained through non-OOI support and would provide important observations in the MAB.

Further work on the East Coast Endurance Array will necessarily include cost estimates, which may motivate reconsideration of a single East Coast Endurance site because of funding constraints.

Examine the potential of enhancing the Kilo Nalu Observatory on Oahu, Hawaii. It is clear that observatory infrastructure is necessary in a wide range of coastal environments and the environments in this location are not represented by the other proposed observatories. Among the motivations for giving this site serious consideration are its unique position, within the OOI framework, as a tropical observing site, and its capability of providing infrastructure to enable studies of globally important problems of coral reefs.
7.0. Regional Draft Conceptual Network Design

7.1. Overview Description

The Regional Cabled Observatory (RCO) is an unprecedented plate scale experiment focused on integrated investigations spanning the subseafloor biosphere to the hydrosphere, the entire ocean water column, and the sea surface-atmosphere interface. Spatially associated with the Juan de Fuca tectonic plate, the RCO will enable in-depth study and decadal time-series observations of regional oceanography - including biogeochemical cycles, fisheries and climate forcing, tsunamis, ocean dynamics, life in extreme environments, and plate tectonic processes. Dense spatial and temporal sampling, coupled with interactive capabilities will allow the ocean science community for the first time to make fundamental measurements and exciting discoveries about processes that occur over centimeter to 100’s of kilometer distances, and at seconds to decade time scales. This thirty-year experiment, which includes ~2000 km of instrumented electro-optical cable on the seafloor and thousands of meters of instrumented moorings reaching from the seafloor to the oceans surface, will fundamentally change the way we view and study our planet and how we educate and interact with researchers, students and the public. Sensor networks, seafloor cameras, and interactive experiments will be easily accessible in real-time via the Internet to researchers, educators, students, policy makers, and the public around the globe.

The Northeast Pacific has been identified as the location of the first regional cabled observatory (www.orionprogram.org/documents.default.html). Working with the RFA responses, previous planning documents and cost estimates provided by the ORION engineering committee, the RCO STAC subcommittee developed two draft conceptual network designs for the RCO. The less expensive option is displayed in Figure 7. These two designs served as the starting point for discussions at the workshop. The complete draft CND for the RCO is provided as Appendix 10.5.

7.2. Major Discussion Points, Comments, Strengths and Criticisms

Group leaders were Deborah Kelley (UW), Keith Reybould (MBARI), William Wilcock (UW) and Alan Chave (WHOI); rapporteurs included Deborah Glickson (UW) and Alison Labonte (SIO).

The RCO participants were charged with addressing five main questions, similar to the other component groups of the OOI. The discussion below lists those questions and presents a summary of the dialogues surrounding them, conclusions, and action items for follow-on investigation. Although participants were given guidance from ORION that the priorities for infrastructure should be governed by science objectives, the infrastructure and associated costs to complete the science objectives for the RCO are linked. Therefore, significant discussion focused on the trade-offs between infrastructure, science, cost, and risk. The results of these discussions are included where appropriate.

1. Are there changes (e.g., in location or capabilities) to the CND that would enable additional science objectives to be supported by the network for this component, while not significantly increasing costs?

There was a general consensus that Scenario 2 for Stage 2 of the RCO (Fig. 7.1) was an appropriate design to meet many of the science objectives. This scenario includes 1750 km of backbone cable, six science nodes, five branching units, and nine water column moorings (two moorings to the north are non-cabled moored profiling buoys). It was recognized that the RCO is in a unique position to serve as an integrator of science at the global (Station PAPA), regional, and coastal (west coast endurance and pioneer arrays) scales. It is also well positioned for integration of geophysical measurements from the onshore observing systems offered by the MREFC program EarthScope (http://www.earthscope.org/).

There was interest from the geophysical and physical-biogeochemical community in adding 1) additional backbone cable to the southeast along the
Blanco Fracture Zone at the boundary between the Juan de Fuca plate and the Gorda plate, and making the Cleft branching unit a full-up primary node with appropriate secondary infrastructure (Fig. 7.1). In addition, there was significant interest in integrating the RCO with the coastal endurance arrays near Willapa Bay and the Newport Line (Fig. 7.2). The connection/integration between the RCO and endurance lines was considered important for optimization of science objectives and linkages between the program as a whole.

In addition to these modifications, there were questions regarding the junction between the mid-plate Node N8 on Stage 1 of the RCO and Node N5 on Stage 2. This issue is largely an engineering question that addresses optimization of redundancy for communications and power for both systems. In the preliminary CND for the RCO, this junction is costed out as a primary node, but this is largely a placeholder for funds should a connection be desirable. It was never intended to be a full capacity node. At this time it is unclear whether this would be the case.

Figure 7.1. Proposed infrastructure layout for Stage 2 of the RCO and overlapping science objectives for each node. Stage 1, NEPTUNE Canada will be on line in 2007-2008. As currently planned, some Station 2 infrastructure would augment this system.
be a full node. The final design will depend on what infrastructure is chosen for the RCO, and the risks and costs of such a connection.

**Action items associated with these recommendations included:**

- Cost out additional cable and primary-secondary infrastructure required to extend the backbone cable southeast to the Blanco Fracture Zone
- Invite comments from the RIDGE community on the benefits of having a primary node at Cleft, and possible trade-offs between this site and a proposed Global Buoy at 9°N on the East Pacific Rise (note this is now available at http://www.ridge2000.org/science/discussion/)
- Work closely with representatives from the Coastal Group to develop the science, infrastructure, and costing for integration of the RCO and focused endurance arrays.

![Figure 7.2. Modifications suggested to Scenario 2 resulting from the D&I RCO breakout discussions are indicated by the heavy red solid and dashed lines. Specifically, there were recommendations to 1) extend the backbone south to the boundary between the Gorda and Juan de Fuca plate to allow increased coverage for geophysical and water column biogeochemical studies (this would require getting rid of N1-N2-N3 connections and incorporation of a single extension cable from either N1 or N3), 2) change the branching unit at Cleft (1) to a full primary node, 3) evaluation of the connection between Stage 1 and Stage 2 nodes N4 and N8 (N5 is not a full primary node in these planning efforts); and 4) integration of the RCO with Coastal Endurance Lines to depths of 50 m. These modifications are currently being priced out and undergoing cost-risk analyses.](image-url)
• Task the Engineering component of the Science and Technical Advisory Committee (STAC) to investigate in more detail the junction between Stages 1 and 2 of the RCO.

• To complete the full plate-scale backbone design, it may be necessary to sacrifice some of the secondary infrastructure recognizing that this can be added later.

2. Given the constraints of the budget, does the balance between investments in instrumentation and infrastructure in the CND meet the scientific requirements? What further tradeoffs can be suggested?

Significant dialogue focused on the above two questions. There was a nearly unanimous consensus from the RCO breakout groups that the design meet the vision of a plate scale experiment, which addresses large scale geophysical, hydrogeological, biological, biogeochemical, and physical oceanographic questions. The plate scale nature of the infrastructure was considered to be of primary importance. There was also nearly unanimous agreement that this system be viewed as a 25-30 year experiment and that the design that is eventually implemented allow for future expansion. It was recognized that significant leveraging opportunities for funding outside of NSF likely exist from foundations and industry. Examples of leveraging now in place included the $80M CN for implementation of Stage 1 through Neptune Canada, $5M from the Keck Foundation for design, fabrication and deployment of a suite of sensors at the Endeavour Integrated Studies Site, and recent funding from Keck for a suite of seismometers for deployment at Blanco for Stage 2 of the RCO.

To guide the discussion, cost summaries were obtained for Scenario 2 as presented in the CND for the RCO. The summaries are listed below. It was recognized that the entire ~$25M in instrumentation and additional infrastructure would not be incurred during the initial first few years, but phased in over the lifetime of the system through competitive proposals and funding outside of NSF. Some investigators would need to obtain significant numbers of new instruments, while others had sensors that could be transferred onto the observatory with modification for power and communication at minimal cost.

<table>
<thead>
<tr>
<th>Scenario 2 costs from Table 3 in the CND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure</td>
</tr>
<tr>
<td>Backbone and Primary Nodes</td>
</tr>
<tr>
<td>Profiling Moorings</td>
</tr>
<tr>
<td>Secondary Infrastructure</td>
</tr>
<tr>
<td>TOTAL</td>
</tr>
<tr>
<td>Instrumentation (+ additional secondary infrastructure)</td>
</tr>
</tbody>
</table>

This philosophy of planning for a 25-30 year experiment guided follow-on discussion concerning possible mechanisms whereby the RCO science, instruments, and infrastructure could be best optimized and augmented. Suggestions to meet these goals included:

• Recognizing that the RCO will not be in the water for at least five years, it is important to begin raising funds for instrumentation through NSF, foundations, and industrial opportunities.

• Explore a scenario whereby some funds from the MREFC are held in reserve for core sensors in the event that funds cannot be raised elsewhere.

• Realize that there may be tradeoffs specific to particular communities with respect to infrastructure and core sensors. For example, a few of the water column profiling moorings could be implemented at a later date through other funding sources, allowing a suite of instruments to be incorporated into infrastructure costs associated with the moorings that remain.

• Identify groups of people from each discipline that agree to get funding for their “core” instruments through a diverse funding strategy that includes NSF, industry and foundations.

Action items associated with these recommendations included:

• Reconsider these options once a thorough costing of the system is completed.
A majority of the participants indicated that maximization of the infrastructure with MREFC funds should be the highest priority, but there was recognition that demonstration of a functioning system would be important early on, and that this demonstration may need to include some core instruments.

3. How should the individual elements of the CND be prioritized to meet the target budget for this component? Provide advice on tradeoffs in terms of capabilities or choice of type of infrastructure; and capital versus life cycle costs.

Question 3 and follow-on considerations addressing this topic were difficult to make significant progress on because the final engineering design has not yet been determined. Prioritization of nodes is difficult, but it has to be driven by the science. There was a general consensus that Scenario 2 was the basic design needed to meet the science objectives and that, if anything, it required some expansion.

4. What experiments or observations are likely to yield early success for the ORION Program based on the OOI implementation timetable? How can ORION facilitate that success?

There was consensus that the community early on needs to take advantage of the opportunities provided by Stage 1, Neptune Canada. Installation of this system in 2007/2008 will allow opportunities to develop and test instruments and it will likely facilitate significant science successes early on in the program. Examples include event responses to earthquake or eruption events along the ridges, early integration with information geophysical and observations coming from EarthScope, and incorporation of current CORK hydrogeological and biosphere observatories and those soon to be coming online with funding through the Integrated Ocean Drilling Program (IODP)(CORK = Circulation Obviation Retrofit Kit; http://www.earth.rochester.edu/issep/Advanced_CORK_report.html). It may be appropriate for the OOI steering committee and the EarthScope steering committee to have a formal meeting about links between EarthScope (which stops at the coastline) and the RCO, and the ability to share data, link concepts etc. This is also true for NEON although participants were less familiar with this MREFC program and a way to integrate it with the OOI.

There was recognition that intra-operability between Stage 1 and Stage 2 is highly desired such that instrument connectors, standard interfaces for instruments, metadata etc. are seamless between the two systems. There was some discussion regarding early funding by the US for augmentation of Stage 1. This would include secondary infrastructure such as secondary nodes, benthic nodes and connectors for future expansion when Stage 2 comes on line. Detailed, early bathymetric mapping of node sites is critical for early success of the RCO. These studies need to be completed within the next couple years so that optimal cable routes can be found, flat/benign areas for node placement determined, and detailed layouts of sensors and ancillary cables planned.

The group considered a few overarching questions that would link the different observational scales provided by the global, regional, and coastal observatories. These questions include:

- What is the relationship between transport of large water masses from the north, major anoxic events on the coast that result in major fish kills, and implications for carbon flux to the seafloor?
- What is the carbon cycle and net flux of carbon from the continent, across the shelf-slope and out across the plate? What is the flux of carbon from the seafloor and how does this compare productivity in the overlying oceans?
- What are the plate scale linkages between geophysical events and geochemistry?
- What are the linkages among tectonic, hydrogeological and biogeochemical processes at a plate scale?
Action items associated with these recommendations included:

- Obtain a cost-risk analyses of funding for early augmentation of Stage 1 at key sites outlined by the RFA’s (e.g. Middle Valley, 1027, Endeavour)

5. Are there any broad science needs that are not served by the draft Conceptual Network Design (CND)? What longer-term (20-30 yrs) science requirements need to be considered?

In the spirit of the MREFC, there needs to be strong links between the coastal and global programs. Although some of these science linkages were outlined in the draft CND for the RCO, they are not fully developed and the three components of the OOI are not well integrated in the coastal and global CND’s. Development of instrumentation that is not considered in the initial instrument suites is also important. These sensors include the addition of bioacoustic instruments that measure frequencies for investigation of large animals at shallow depths, geodetic instruments, and ecogenomic sensors that are now being developed. Although AUV’s with docking capabilities are mentioned in many of the RFA’s and within the CND’s this capability is not available yet and will need significant development and testing efforts. In addition to these instrumentation needs it will also be important for full water column surface moorings that allow investigation of sea-atmosphere exchange and weather research, prediction, and modeling development. It was noted that even an increase to five moorings off the coast could increase weather prediction accuracy by 20%, potentially providing large financial payoffs for agriculture and fishing industries.

7.3 Recommendations

A summary of recommendations for the ORION office to consider include:

- The ORION office should establish a mechanism for community interaction via the internet that includes updates, e-mail lists etc.
- It is critical to maintain the integrity of the full plate scale experiment, prioritize the budget to ensure that that the backbone is put in well and allows future expansion
- Early detailed mapping is critical for site characterization and route planning
- The STAC Engineering group needs to evaluate the cost/reliability trade-offs for connection of Stage 1 and 2 of the RCO
- Once costing of the infrastructure is better known (costing depends on the design of the infrastructure), prioritization of backbone cable, branching units, and primary and secondary infrastructure needs reevaluated
- There will be a need for real estate management (cables, acoustic interferences, cycling time of instruments etc)
- MARS and Stage 2 must be interoperable; goal for similar compatibility with Stage 1
- Investigate expansion of the backbone cable to the southeast toward the Gorda plate
- The RIDGE community needs to evaluate the Cleft site and phasing
- Consideration should be given to the trade-offs between a full scale mooring experiment, or fewer moorings with a suite of core instruments
- The RCO participants need to establish close coordination of experimental design and science objectives with the Coastal Group
- The STAC Engineering and CI groups need to define interfaces and dependences between CI and the RCO e.g. CI should be built from the individual sensor up
- Full water column moorings that breach the surface should be considered to allow characterization of sea-atmosphere exchange
8.0. Global Draft Conceptual Network Design

8.1. Overview Discussion

Long-term continuous open-ocean observations are required for quantifying and understanding interannual-to-decadal changes in ocean circulation, water properties, water mass formation, and ecosystems, for observing episodic events and their impact, for providing reference sites for atmospheric time series and quantifying air-sea fluxes, for determining the role of the oceans in the global carbon cycle, for improving our understanding of the Earth’s interior and geodynamics, and for measuring global plate motions and studying plate boundary processes. Mooring-based open-ocean observatories are well suited to address these needs, especially in remote ocean areas where cabled observatories are unavailable or prohibitively expensive to install. Moored observatories are an important complement to other components of a global ocean observing system, like satellite remote sensing, profiling floats, surface drifters, gliders and research vessels.

From previous planning documents and the RFA responses, global scale observatory elements are of significant interest to four different disciplines (physical oceanography, biogeochemistry, geophysics, air-sea processes). Working with these documents, the GSO STAC subcommittee developed the draft CND shown in Figure 8.1. This mix of sites attempts to maximize the value and impact of the future network to all disciplines and to include the largest possible diversity of sites (mid, equatorial, high-latitude, acoustic and EOM discuss, new and existing) as early as possible in the program. The complete draft Global Conceptual Network Design is provided as Appendix 0.6.

8.2. Major Discussion Points, Comments, Strengths and Criticisms

Group leaders were Uwe Send, John Collins, Dan Frye and Bruce Howe. Rapporteurs included Peter Worcester, John DeLaughter, Katrina Hoffman and Sarah Stoltz.

Global Breakout participants were charged with addressing the same five questions as the other groups. However, similar to the coastal array, the breadth and novelty of scientific research that can be performed with the global observatory array is dependent on the location of the observing components and much of the discussion, therefore, focused on the selection of specific observing sites. The group also refocused research drivers and questions to aid in the evaluation and comparison of specific sites.

Figure 8.1. Phased implementation of proposed global network. A = phase 1; B = phase 2; C = phase 3.
There were several concerns about the draft CND plan raised in the initial discussions. It was recognized that the proposed locations are nearly all in the western hemisphere and that the proposed sites do not comprise a global array. Given financial constraints, it is unlikely that the array can be expanded. In fact, it became clear that it will not be possible and is not the objective of the OOI to build a global array. Instead, it was emphasized that the proposed infrastructure will yield an observing capability that can address global scale science questions and that by partnering with other agencies and countries, a global network can be achieved.

Another initial concern was that only the spar buoy design may be well-suited for the study of air-sea fluxes. Because of cost, it is likely that only a few of these types of buoys will be deployed, greatly limiting the extent of air-sea flux measurements. Other issues raised included whether sites identified in the draft CND were well positioned for global seismology research and whether more emphasis should be placed on co-locating buoys at existing borehole sites.

To aid in the evaluation of the potential sites, it was decided to extract the overarching science questions and topics from previous documents and planning efforts, and to use these in making the case for high priority sites with maximum scientific payoff. The goal was to find one major question per discipline, and the status concerning these at the end of the meeting is listed below (Fig. 8.2).

1. How will changing physical forcing due to climate change perturb ocean ecosystems and flux of carbon to the deep sea and sea floor? This general question would also include the impact of changing CO$_2$ concentration on biogeochemical cycles.

2. How are different ecosystem regimes, community composition and biodiversity affected by changes in climate?

3. What are the interplays between tectonic and volcanic processes in the ocean crust, from its formation to its destruction, and ocean ecology and biogeochemistry?

4. What is the scale, shape and nature of heterogeneities in the Earth’s mantle and core and how do they relate to key processes such as plate tectonics, generation of the Earth’s magnetic field or variations in the Earth’s rotation?

---

Figure 8.2. White: questions 1&2 (biogeochem, ecology, biodiversity) Yellow: question 3 (ridge and subduction sites) Pink: question 4 (seismic studies of earth structure) Green: question 5 (air-sea flux). PO is covered by all the sites. Difficult to provide East Coast upstream boundary condition with GLOBAL system.
5. What is the impact of extreme and/or episodic events and of aerosols/dust on air-sea fluxes and aerosol/dust deposition?

6. What is the relationship between physical variability and human activity?

7. What is the sound budget of the ocean?

Specific physical oceanography issues are:
- What is the variability of the meridional heat flux of the oceans?
- What is the role of mesoscale eddy fluxes in the evolution of the physics, biology, and chemistry of the upper ocean?
- How do subtropical and subarctic gyres respond to wind and large-scale forcing?
- How does ocean interior heat content affect sea level rise?
- What is the space-time geography of energy input and energy dissipation in the ocean?

Individual sites could then be grouped according to their relevance to each question.
- Q1&Q2. BATS or HOT, S. Chile, off Peru, OWS PAPA, subtropical South Pacific gyre, and possibly a subpolar North Atlantic site
- Q3. EPR and MOMAR are excellent choices - RIDGE
- Q4. Instrument existing borehole - there are three existing holes (1 in the Atlantic; 2 in the Pacific)
- Q5. Southwest of Chile, subtropical central Atlantic
- Q6. Most of the proposed sites

OWS PAPA was highlighted in many sessions and topics, not only for the science issues and long historical record, but also for providing a deep-ocean connection to the RCO and West Coast coastal ORION system.

In addition, it was recognized that acoustic thermometry paths should be considered in the final siting of the global observatory buoys.

In addition, it was emphasized that the OOI moorings should be placed in the context of other global assets such as the Argo Float program. Also, the possibility of proposing a deep water Pioneer array was discussed for smaller scale process-oriented studies.

The specific questions provided by the organizing committee were also addressed by this group.

1. Are there changes (e.g. in the location or capabilities) to the CND that would enable additional science objectives to be supported by the network for this component, while not significantly increasing costs?

The group indicated a few changes on the accompanying map to more clearly reflect the central science questions. Participants also emphasized the need for standardization and interoperability to facilitate comparison of results amongst the sites. The fixity of sites must also be made clear if they are to host long-term acoustic thermometry studies. To provide a spatial context and examine far field influences, a lagrangian component at and between sites was also suggested. Finally, it was noted that a relocatable “Pioneer” array capable of deployment in the deep sea could provide important spatial resolution.

2. Given the constraints of the budget, does the balance between investments in instrumentation and infrastructure in the CND meet the scientific requirements? What further tradeoffs can be suggested?

The group felt that there really is no single answer to this question, but that it is important to have some sensors included when the infrastructure is deployed. The investment need not be equally distributed among all moorings but may be optimized for each location. In addition, mobile platforms should be included to ensure some far-field measurements. While there were differing views within the group, there was a sense that approximately 20% of the available support should be allocated for sensors and other (non-mooring) infrastructure.

3. How should the individual elements of the CND be prioritized to meet the target budget for this component? Provide advice on tradeoffs in terms of capabilities or choice of type of infrastructure; and capital versus life cycle costs.
A major criterion for establishing prioritization for specific aspects of the design should be life cycle costs. Especially critical is to evaluate sensor endurance, susceptibility to biofouling and servicing interval. Highest priority should be given to establishing the capability for powered, high latitude moorings. These are considered transformative systems. The highest priority sites were judged to be the site off Southern Chile and one of the RIDGE sites. The other sites were not prioritized.

4. What experiments of observations are likely to yield early success for the ORION Program based on the OOI implementation timetable? How can ORION facilitate that success?

If FLIP could be used as a spar buoy, spar technology could be implemented early in the OOI project. This could be used as the focus for the RIDGE site. Occupation of the Southern Chile site, even if initially with non-spar technology, is also likely to lead to new discoveries. In addition, sending high-quality realtime data from a borehole would be an important demonstration early in the project.

5. Are there any broad science needs that are not served by the draft CND? What longer-term (20 - 30 yr) science requirements need to be considered?

The group thought that better development of the Lagrangian component would serve longer-term science needs although no specific science questions or issues were posed. It is also important to note that while the OOI global assets will comprise a global scale observing array, it is too limited to be considered a global array. It is important to integrate the OOI observatories into other observing systems, such as Argo, Ocean SITES, DART and NDBC buoys, seismometer networks, etc. Although different in capabilities, information provided by these other systems can provide the context to achieve a more holistic global view. Finally, the concept of a Pioneer Array that comprising several relocatable moorings and gliders for use in the deep sea should be examined. This system could be deployed a selected global mooring sites for a limited period of time to examine horizontal spatial scale features not observable by the central mooring array itself. It was felt that, at the cost of sacrificing one global site, this could be achieved and would be worthwhile.

8.3. Recommendations

The overarching outcome and recommendations were to:

- Refocus on building a system that addresses global science issues in innovative, transformative ways, without complete and exhaustive coverage.
- Build new capabilities that can be used later in development of an IOOS/GOOS.

Recommendations for the ORION Program Office to consider include:

- Modify the draft CND in accordance to recommendations from the RIDGE and MARGINS programs. Clarify the fixity of the global sites to permit long-term planning of acoustic thermometry experiments.
- Investigate the possibility of implementing a lagrangian observing component at and between global sites.
- Develop overall planning assuming that approximately 20% of available funds will be used for sensors and other, non-mooring, infrastructure.
- The most transformative aspect of the global buoys is the capability of providing power and high bandwidth into the ocean, to occupy high latitude sites, and to enable simultaneous vertical, temporal and spatial sampling of many variables, under bi-directional control, addressing for the first time the interrelation of the processes. Development of these capabilities is a high priority.
- Highest priority deployment sites for the high power, high bandwidth spar are the site adjacent to Southern Chile and the RIDGE site.
- Life cycle costs, including sensor endurance, biofouling susceptibility, and servicing interval, should be a major criterion in establishing priorities.
- Investigate the use of FLIP as a spar buoy to enhance the probability of early ORION success.
- Cooperate and partner with other observing efforts to expand the OOI global mooring footprint.
9.0. Acknowledgements

The list of individuals who have risen above and beyond the call of duty with the goal of making ocean observatories a reality is too long to print here. Members and chairs of all standing ORION subcommittees (named in Section 10) have contributed substantial effort. Weekends, nights, holidays, vacations and precious research time were sacrificed. Manuscripts have undoubtedly been delayed, in the belief that the effort will have been worth it.

The Co-chairs of the STAC component subcommittees, John Trowbridge and Collin Roesler (coastal), Deborah Kelley and William Wilcock (regional), and Uwe Send and John Collins (global) put forward a tremendous effort in advance of the workshop, to develop the draft CND documents upon which the workshop discussions were based. Each one assured a successful workshop outcome by patiently guiding the often passionate and occasionally contentious exchanges to productive conclusions. In addition, Bill Kirkwood, Andy Barnard and Gene Massion served as co-chairs in Coastal session breakouts; Alan Chave served as Co-chair in Regional session breakouts, and Dan Frye and Bruce Howe served as Co-chairs in Global session breakouts.

The Co-chairs for the Science Theme breakouts led constructive and often illuminating discussions of their respective themes. The time available for thematic efforts was brief due to the weight of the infrastructure and component issues driving the workshop, but the Co-chairs kept the thematic efforts on topic, cross-scale, and productive. Thanks to Charlie Eriksen, Roger Samelson, David Farmer and Roger Lucas for the Physical Processes/Climate Variability session; to Jim Yoder, Wade McGillis, Dan Costa and Scott Gallager for the Biogeochemistry/Ecosystem session; Barbara Romanowicz and Doug Toomey for the Earth Structure/Geodynamics session; Susan Humphris and Peter Girguis for the Fluid-Rock Interaction/Subsurface Biosphere session; Bob Weller and Jim Edson for the Ocean-Atmosphere/Meteorology session; and Oscar Schofield and John Orcutt for the Hazards session.

The exceptional group of educators and graduate students who first competed for support to attend the workshop and then worked tirelessly to participate as rapporteurs for every breakout session deserve special recognition for their efforts. The role of rapporteur is both difficult and underappreciated for its importance. We thank Jim Brey, Alison Labonte, Sarah Stoltz, Barbara Simon-Waters, Leslie Sautter, Chris Petrone, Rick Baker, Barbara Kirkpatrick, Katrina Hoffman, Esat Atikkan, Deborah Glickson and John DeLaughter.

Julie Farver, from the Joint Oceanographic Institutions (JOI) Travel and Meeting Planning Office, provided a constant, calm and professional presence during planning and realization of the workshop. Julie handled the registration process, arranged travel and lodging for many participants, made all the catering and meeting room assignments, managed to keep the wireless internet engaged and smiled through all the sudden changes in meeting room requests when the best-laid plans of the organizing committee didn’t match rapidly evolving discussions, spontaneous work sessions and unpredictable group dynamics. She kept us fed and hydrated, caffeinated, connected, and compatible.

ORION office staff Emily Griffin and Peter Milne were instrumental in the planning and success of the workshop. Among her many contributions, Emily managed the website and mailing list and handled the production of the printed copies of the draft CNDs that were given out at registration. Although she printed more than the participant count, every single copy was claimed and scavenging of undefended copies began to occur midway through the event. Peter kept the gears moving at the office and during the workshop, stepping up to whatever task was at hand. Gratitude is also due to the entire JOI staff (thanks especially to Rob Wright and Amy Page) and to JOI President Steve Bohlen, for making a welcome place for ORION to exist.

The National Science Foundation provided support for the workshop, and NSF representatives contributed plenary and personal discussions, both inspirational and instructional, as needed. The opinions expressed herein do not necessarily reflect those of the National Science Foundation or its staff.