Project NEPTUNE: An Interactive, Regional Cabled Ocean Observatory in the Northeast Pacific

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***Abstract*- Next-generation studies of dynamic, interacting processes in the Earth-ocean-climate system require new interactive, *in situ* approaches to complement and fundamentally extend the more traditional ship-based expeditionary science that has dominated oceanographic research for more than 100 years. Key to these studies are regional cabled ocean observatories. A US/Canadian consortium is building NEPTUNE, a regional observatory in the northeast Pacific that will be spatially associated with the Juan de Fuca tectonic plate.**

I. THE EMERGENCE OF REGIONAL CABLED OBSERVATORIES

For more than a century, oceanographers have used ship-based expeditionary studies as their primary tool for mapping, observing, and sampling the oceans. This approach has led to discovering the importance of a wide range of physical, chemical, biological, and geological processes. One of the results has been that our modern societies now recognize their increasing dependence on the oceans and the value of understanding natural processes at a variety of temporal and spatial scales. In parallel, dramatic technological advancements have occurred in sensor technologies, robotic systems, high-speed communication, nanotechnology, and rapidly escalating capabilities to computationally simulate reality. The societal recognition, combined with technological advances, has compelled oceanographers to move beyond traditional expeditionary modes toward a new paradigm: sustained, *in situ* observations of the oceans, the seafloor, and the subseafloor. Indeed, the Earth, ocean, planetary, and biological sciences are now in a transformational period. A revolution is under way in the exploration, discovery, and understanding of complex, interacting natural processes.

Regional cabled ocean observatories (RCOs) offer an example of this new paradigm, and interest in RCOs has grown substantially within the past five years. These next-generation facilities will use networks of fiber-optic cables to deliver high-bandwidth capabilities and considerable electrical power to hundreds of instruments and many autonomous vehicles distributed over hundreds of square kilometers of seafloor and within the overlying volume of ocean. The regional-scale observatory concept is based on the premises that many globally significant planetary phenomena operate at or below the regional scale; and that thorough 4-D examination of at least one tectonic plate/mesoscale system will generate major new insights into all such systems.

The ultimate vision of an RCO is to enable routine, real-time interaction between an extensive community of land-based researchers and a set of diverse *in situ* instrumental sensor arrays. These arrays will be comprised of remotely operated, user-generated experiments that will detect and quantify variability over a wide range of spatial and temporal scales for a broad range of ocean and Earth processes. Implementing the first of the regional-scale facilities will require a sizable and costly development effort.

II. THE OCEAN OBSERVATORIES INITIATIVE

In recent years and with support from several community-based reports [1,2,3], momentum has built toward a focused investment in operating routinely and remotely in the ocean space. The US National Science Foundation (NSF) received approval from the National

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Science Board to include the Ocean Observatories Initiative (OOI) as a project within the Major Research Equipment and Facilities Construction account. The OOI will implement the following program elements: 1) expand existing research capabilities in coastal zone research activities, 2) develop a global observational capability using durable and re-locatable mooring facilities designed to work in high latitudes and/or both the seafloor and the water column, and, 3) develop the regional cabled ocean observatory concept [4,5]. As of February 2003, the OOI was formally listed as a priority new start for FY06 at a level of ~$208 million (over 5 years) within the FY04 President's budget request to Congress.

The regional observatory has an important role to play in integrating the components of the OOI by seamlessly spanning the coastal to global components with a large and adaptable footprint. To achieve this integration, regional observatories must accomplish the following:

1) Span coastal to global systems, thereby linking all processes;
2) Document variability over many scales of space and time;
3) Expand surface (satellite) and point (mooring) coverage to an entire volume;
4) Archive data so as to enable modeling and data assimilation;
5) Maximize the scientific return from the investment in a regional facility; and,
6) Maintain optimal flexibility and expandability to operate for many decades.

An effectively operated RCO will also employ data archiving strategies that enhance modeling and data assimilation in real-time. Crucial data and metadata will be archived and accessible to enable later generations of ocean scientists to examine unprecedented comprehensive time-series information at nearly basin-scale levels of inquiry.

An important criterion in selecting the location of an RCO is the requirement of maximizing the scientific return on the initial investment by placing it where the best and most diverse scientific investigations can be conducted. Producing the first RCO is a substantial challenge for oceanographers in part because there is no pre-existing blueprint and relatively little existing expertise in our community. The complexity and novelty of RCO implementation poses different planning, engineering, and management challenges than continued use of the more familiar open-ocean moored buoys, coastal installations, or traditional ship-based expeditionary approaches. Regardless of the specific locality chosen for the first RCO, fostering the capability to implement a well-designed and tested RCO is critical to the health of the US oceanographic community.

III. NEPTUNE: AN INTERACTIVE RCO IN THE NORTHEAST PACIFIC

Several other countries are interested in pursuing regional cabled observatory construction efforts including Japan, the European Union, Korea, and Canada. Geographical areas of interest to be covered by an RCO should be guided by science objectives and not be limited by national borders.

Within the US, the NEPTUNE group formed a co-operative US/Canada planning team in 2000 to build an RCO in the northeast Pacific (*www.neptune.washington.edu)*. The partnership is working to create a 3,000-km network of fiber-optic/power cables that will host 30-50 subsea observatories at nodes along the cable (Fig. 1). To be spatially associated with the 200,000 sq. km Juan de Fuca tectonic plate, the NEPTUNE infrastructure will have an expected lifetime of 30 years. The infrastructure will be designed to maintain technical and spatial flexibility and expandability for many decades. Installation is planned for late 2007, with shore stations in Oregon and British Columbia.

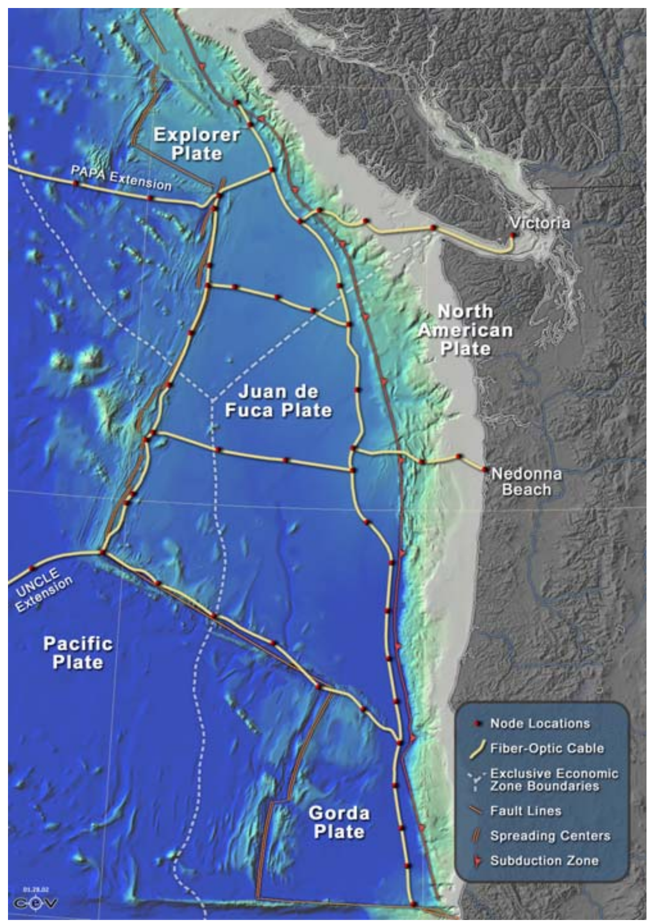

Fig. 1: NEPTUNE's 3,000-km network of fiber-optic/power cables will encircle and cross the Juan de Fuca tectonic plate. Between 30 and 50 experimental sites will be established at nodes along the cable. Node locations shown here are hypothetical.

Institutions that form the NEPTUNE construction partnership are the University of Washington, the University of Victoria, the Woods Hole Oceanographic Institution, Canada's Institute for Pacific Ocean Science and Technology, Caltech's Jet Propulsion Laboratory, and the Monterey Bay Aquarium Research Institute. This consortium will design, test, build, and operate the network on behalf of a wide community of scientists and educators. Indeed, NEPTUNE will serve as a community resource, much like a research vessel is an observational platform open to a wide range of users.

A. Why the NE Pacific?

The Juan de Fuca plate in the northeast Pacific Ocean was chosen for the NEPTUNE study site to attract the broadest possible user base to this full-service oceanographic research platform and to minimize cost. The footprint encompasses a broad spectrum of plate-tectonic processes including many important water-column, sedimentary, and biological phenomena that occur throughout the global ocean. The area is small enough to be instrumented, is adjacent to a continental margin, and is close to politically stable countries committed to supporting the ocean observatory effort. The well-developed ports and other infrastructure within the US and Canada will facilitate initial cable laying, reliable shore landings, and operations maintenance.

B. Feasibility

Discussions of NEPTUNE-type concepts date back to the 1980s. Momentum for the present effort began to build in 1997 at the International Workshop on Scientific Use of Submarine Cables held in Okinawa, Japan, and when the Dynamics of Earth and Ocean Systems (*www.COREocean.org/)* effort was formalized.

NEPTUNE feasibility studies [6,7], completed in 2000 by both the US and Canada, concluded that the Project is scientifically desirable, technically feasible, and financially reasonable. Representatives from many institutions have participated in NEPTUNE-related workshops, particularly science working groups formed as part of the feasibility studies in both the US and Canada and follow-on science workshops.

Each NEPTUNE experimental site, and cabled extensions, will host and power many scientific instruments on the surrounding seafloor, in seafloor boreholes, and buoyed through the water column. Remotely operated and autonomous vehicles will reside at depth, recharge at observatories, and respond to distant labs. Continuous near-real-time multidisciplinary measurement series will extend over decades.

Free from the limitations of battery life, ship schedules/accommodations, bad weather and delayed access to data, oceanopgraphers will monitor remotely their deep-sea experiments in real time on the Internet, and routinely command instruments to respond to storms, plankton blooms, earthquakes, eruptions, slope slides and other events. Scientists will be able to pose entirely new sets of questions and experiments to understand complex, interacting Earth-system processes such as the structure and seismic behavior of the ocean crust; dynamics of hot and cold fluids and gas hydrates in the upper ocean crust and overlying sediments; ocean climate change and its effect on the ocean biota at all depths; and the barely known deep-sea ecosystem dynamics and biodiversity.

C. Estimated Cost

The network and first arrays of experiments are estimated to cost approximately $250 million to design, build, and operate for the first five years. Operating costs are estimated at $10-15 million/year. By comparison, an ice-capable research vessel such as the *USCGC Healy*, which was commissioned in 1999, cost approximately $380 million to design, build, and outfit. Operating, maintenance, and support costs for the *Healy* are approximately $17 million/year.

As of mid 2003, several components of NEPTUNE have been funded, including development of the communications and power systems, program office, system engineering, and two test beds. The University of Victoria is close to finalizing the terms of a significant joint award from the Canada Foundation for Innovation and the British Columbia Knowledge Development Fund that would go toward constructing the portion of the network that lies in Canadian waters.

D. Test Beds

Two test beds are funded and soon will be under construction as a key component of NEPTUNE, specifically, and RCO development, in general: the Monterey Bay Accelerated Research System (MARS) and Canada's Victoria Experimental Network Under the Sea (VENUS). The main goals of these test beds relevant to an RCO are twofold: 1) mitigate engineering risk by early and realistic testing of key infrastructure components prior to deployment of the full RCO, and 2) provide facilities for early validation of science experiments and associated sensors so that the RCO will be used effectively for cutting-edge science once it is operational.

Major additional benefits of optimizing the test-bed scenario include the opportunity to explore five elements of importance to the community: 1) interactions between facility construction personnel and the scientific user community; 2) development of prototype outreach education components; 3) refinement of the organizational and managerial functions required to produce a final major product in the form of an RCO; 4) estimation of actual costs associated with operation of a cabled observatory; and 5) accessible test-beds for new instrumentation intended for observatory development.

The VENUS system will consist of 70 km of powered, fiber optic cable deployed in three separate corridors in coastal southern British Columbia waters: Saanich Inlet (in 2004), Strait of Georgia and Strait of Juan de Fuca (both in 2005). The system will be capable of future expansion at two levels: researchers or instrument developers will be able to attach new or complementary equipment; and the data distribution and archive will allow links or integration with existing and planned ocean databases.

The MBARI MARS test bed is an advanced, deep-water cabled observatory to be installed in Monterey Bay in 2005. MARS will include an expandable science node on 62 km of submarine fiber-optic cable. The system will make use of the tools, techniques, and products developed over the last several decades for high-reliability submarine telecommunication and military systems to ensure that this system can operate over a 30-year lifetime with minimum life-cycle cost.

E. NEPTUNE Science Planning

A key finding within a report of the National Academy of Sciences, entitled *Enabling Ocean Research in the 21st Century: Implementation of a Network of Ocean Observatories* [8] was that "Scientific planning to define the location, experiments, and instrument requirements of specific observatories varies significantly among the three OOI components, and additional planning is needed before the design of these systems can be finalized."

Recognizing the fundamental nature of good science planning, NEPTUNE embarked upon the process in 1999 with the convening of several *ad hoc* science working groups for the feasibility studies [9]. Canada too convened working groups within this same time frame. White papers and reports from these groups are posted at *www.neptune.washington.edu/pub/documents/documents.html*.

There have been several follow-on workshops related to science planning for the VENUS and MARS test beds. The NEPTUNE characteristics presented in Table 1 grew out of these early workshops. Further details on NEPTUNE's infrastructure subsystems are presented on the NEPTUNE web site (*www.neptune.washington.edu*) and in published papers [10,11].

A series of workshops is focusing on topics related to science planning for cabled ocean observatories. These workshops are crucial to the development of the experimental, or use, scenarios necessary to finalize the NEPTUNE system architecture. Scientists who wish to be involved may submit their contact information to the NEPTUNE mailing list via *www.neptune.washington.edu* and check the NEPTUNE web site for current information on how to participate in meetings and for reports produced by past workshops.

As science planning has proceeded, questions have often arisen regarding sources of funding for instrument development and science experiments on a regional cabled observatory. The National Academy report recommends the following to NSF on this topic:

- A core suite of instruments should be installed on every observatory node, and funded as part of the basic observatory infrastructure, not only to test system functionality but also to provide the essential scientific context for the observatory's effective use in basic research.
- A separate, well-funded observatory instrumentation program at NSF, and contributions from other agencies with an interest in ocean research, will be required to obtain the full suite of sensors and instruments needed to fully exploit the scientific potential of the ocean observatory infrastructure.
- The NSF should augment its programs in instrumentation development, support and calibration for observatory-capable sensors, including increasing grant duration to ensure that instrumentation groups have the capability to support the needs of the OOI.

IV. SUMMARY

Next-generation studies of dynamic, correlating processes in the Earth-ocean-climate system require new interactive, *in situ* approaches to complement and fundamentally extend the more traditional ship-based expeditionary science that has dominated oceanographic research for more than 100 years. Systematic, long-term access to episodic oceanic processes is crucial to continued growth in our understanding and predictive modeling of complex natural phenomena that are highly variable and span many scales of space and time. This access will be facilitated by innovative ocean facilities providing unprecedented levels of power and communication to access and manipulate real-time sensor networks deployed within many different environments within the ocean basins. These facilities, their real time or near-real time information flow, and the archives associated with them, will empower entirely new approaches to science and science policy. In addition, these approaches will enable educational-outreach capabilities that will dramatically impact general understanding of, and public attitudes toward, the ocean sciences and science in general.

TABLE 1
NEPTUNE Characteristics

These characteristics are current design parameters. They are subject to modification from science input.

Length: thousands of km of cable in a mesh topology, all nodes have multiple paths to shore
Infrastructure lifetime: 30 years with upgradeable infrastructure
Number of nodes: 30 to 50
Node spacing: ~100-km intervals
Secondary cables (extension cords): allow instrument placement tens of km from node
System is expandable
Scientific instruments connection: standard “plug and work” interface
Total power: more than 100 kW with average of 5 kW per node
Communications: up to 1 Gb/s data rate available at any single node
- ~10 Gb/s maximum aggregate data transmission rate

Reliability: major design driver
- each instrument to have >90% probability of shore connection each year
- entire network availability of >95%

Backbone failure:
- cable breakage temporarily shuts down system
- system will locate, isolate and restart, isolating failed section.

Data management and archiving system:
- store data and metadata
- enable multidisciplinary data mining

Time signals: distributed to nodes, accurate to 1 microsecond
Instrument deployment, recovery, and maintenance: use of academic assets

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