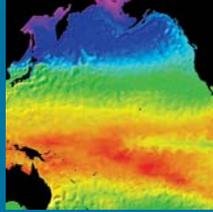
The cover features a background of blue and yellow horizontal bands. A large, light blue circular arrow graphic is positioned in the upper right, and a smaller, similar graphic is in the lower right. The text is centered and reads:

OCEAN OBSERVATORIES INITIATIVE

Science Plan Summary

Revealing the Secrets
of Our Ocean Planet



THE IMPORTANCE OF establishing an ocean-observing capability has long been recognized and was re-affirmed in late 2004 by the U.S. Commission on Ocean Policy (see www.oceancommission.gov). In the last decade, a number of national and international programs have been developed that are concerned with observing the oceans. Their missions are to conduct fundamental research into important ocean processes and to provide timely, useful, and practical information to a variety of users in areas such as fisheries management, maritime shipping and safety, public health, homeland security, tsunami warning, and weather and climate forecasting.

The Ocean Observatories Initiative (OOI) is the National Science Foundation's contribution to this broader effort to observe the oceans. It will deliver an interactive, globally distributed, integrated observatory network to enable next-generation studies of the complex, interlinked processes operating throughout the global ocean. The OOI will design, test, and install pioneering ocean-observatory technology for the research-driven Ocean Research Interactive Observatory Networks (ORION) Program, ensuring that the U.S. oceanographic community has the infrastructure required to meet the research challenges of the 21st century and retain its global leadership in Earth and ocean sciences.

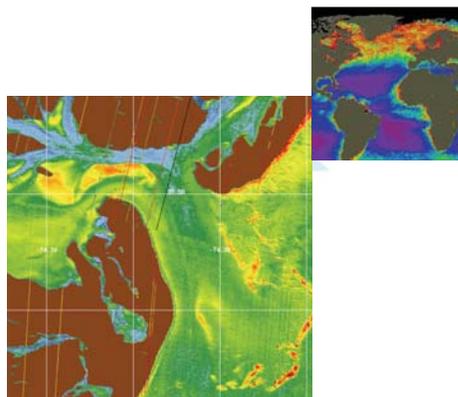
THE OCEAN OBSERVATORIES INITIATIVE

The quality of life on Earth is determined in large part by a set of partially understood and interacting environments and processes that operate in the world's oceans. This complicated system, covering two-thirds of the planet, modulates both short- and long-term variations in climate, harbors major energy and raw material resources, contains and supports the largest biosphere on Earth, significantly influences rainfall and temperature patterns on land, and occasionally devastates heavily populated coastal regions with storms or tsunamis. The Ocean Observatories Initiative (OOI) is designed to enable powerful new scientific approaches for exploring the complexities of Earth-ocean-atmosphere interactions to accelerate progress toward the ultimate goal of understanding, and eventually managing, our planetary environment.

As understanding of the oceans has advanced, it has become increasingly apparent that many critical processes occur at temporal and spatial scales that cannot be effectively sampled or studied using research ships or satellites. Ship-based studies, for example, are very limited in their ability to investigate episodic events or to study dynamic systems that change over time periods longer than a few months. Some critical processes occur only during certain times of the year or during events, such as storms, when measurements from shipboard platforms are simply not possible. Although satellite observations have provided oceanographers with a unique synoptic, global perspective on the ocean, they remain primarily limited to measuring properties at the air-sea interface and in the uppermost ocean. Consequently, even after many decades of study using ships and satellites, the global ocean is still poorly explored and its complex behavior is not well understood.

The urgent need to make measurements of the global ocean over long time periods and at spatial scales from microscopic to global requires new technology and a new paradigm for doing ocean research. This paradigm will exploit two classes of tools: (1) sensors that collect data at high sampling rates at fixed sites for years or decades, and that can be operated and manipulated in real-time, and (2) mobile ocean-observing systems that will provide broad spatial coverage, though with limited power and more restricted real-time data telemetry capabilities.

This new technology will not replace shipboard expeditionary research or satellites, but it will open a new window from which to observe ocean and seafloor systems. Together, these complementary research strategies will transform oceanography in the coming decade, changing in fundamental ways the manner in which marine science is conducted, and will provide exciting new avenues through which to convey the importance of the oceans to a wider audience.



MAJOR COMPONENTS

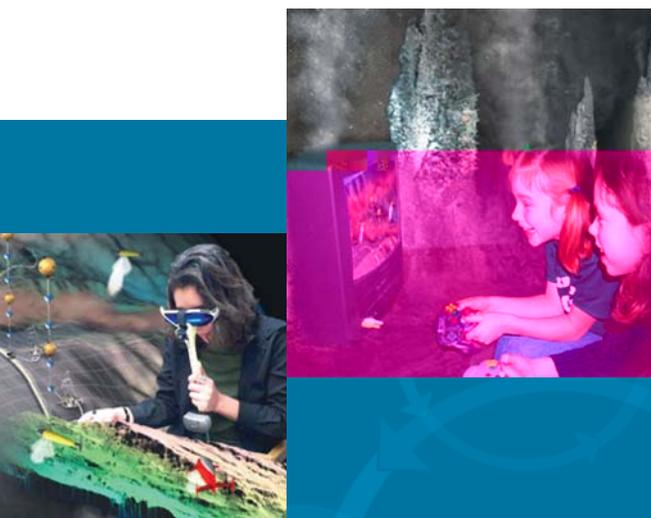
To provide the ocean sciences research community access to a broad range of long-term measurements in the oceans and the seafloor below, the OOI is comprised of three principal elements, which are linked by a common instrument, infrastructure, and information-management system:

- The **Global Ocean Observatory** comprises a set of highly capable interactive moored buoys sited around the world's ocean in places where surface-to-bottom ocean data needs are greatest. These observatories will consist of large, rugged, self-powered, telemetering buoys where scientific need dictates high data-return rates and power requirements, and simpler, but still very capable, designs for other settings.
- The **Regional Cabled Ocean Observatory**, in cooperation with ongoing Canadian efforts, will instrument an entire tectonic plate at key locations in the Northeast Pacific Ocean offshore northern California, Oregon, Washington, and Vancouver Island. A permanent electro-optical seafloor cable will connect multiple

seafloor nodes that will provide power (tens of kilowatts) and high bandwidth (data transfer rates of 10 to 100 gigabits per second) for the sensors, instruments, and underwater vehicles, allowing access to surrounding waters from the seafloor to the sea surface.

- The **Coastal Ocean Observatory** will provide sustained, but adaptable, access to dynamic and heterogeneous coastal systems. Fixed arrays of "Endurance" lines will provide continuous observations at widely distributed locations to document events and long-term changes, while relocatable "Pioneer" arrays will provide a flexible capability to focus on key processes in optimal configurations.

A system-wide **cyberinfrastructure** will allow users to remotely control their instruments, enabling adaptive strategies; perform *in situ* experiments; construct virtual observatories of suites of sensors specifically tailored to scientific needs; and access data in near-real time from almost anywhere in the world's oceans.

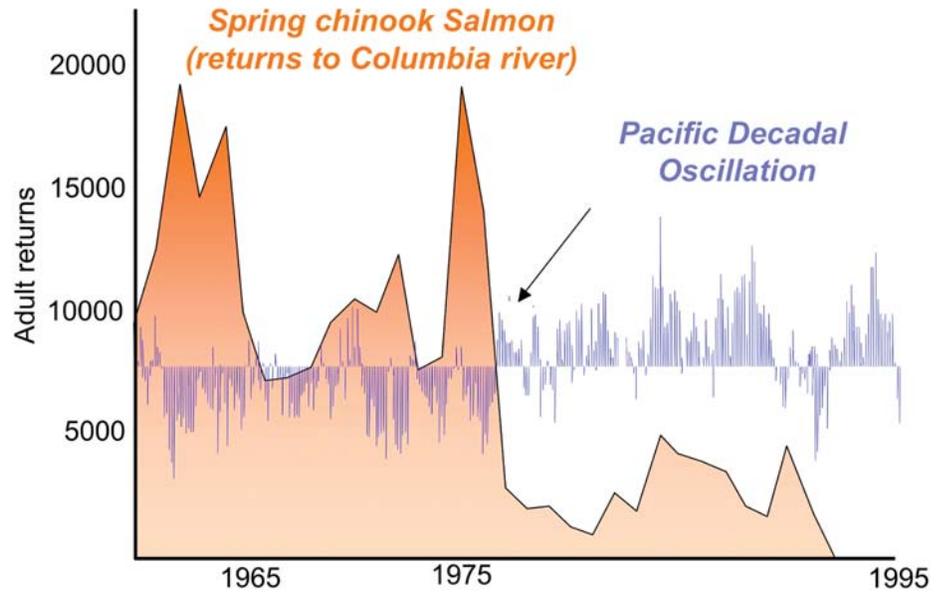


EDUCATIONAL AND PUBLIC OUTREACH OPPORTUNITIES. The real-time data and high-speed, interactive communication capabilities of ocean observatories will open entirely new avenues for diverse student and public audiences to interact with and understand the natural world. Citizens of all ages will be able to participate in the journey of scientific exploration and discovery through a rapidly expanding array of online, interactive learning experiences that use data products from observatories. To exploit these opportunities, ocean scientists and educators are working together to ensure that educational and public outreach needs are factored into observatory planning from the beginning. An important element of this strategy will be developing working partnerships with a number of existing education programs in the marine sciences.



THREE

Correlation between the presence of spring Chinook salmon in the Columbia River and the Pacific Decadal Oscillation, a climate variation that primarily affects weather patterns and sea surface temperatures in the Pacific Northwest and Alaska. Salmon returning to the Columbia River increased during negative, or cool, Pacific Decadal Oscillation phases, presumably due to the increased availability of zooplankton on which they feed. Figure courtesy of M. Barange and the International GLOBEC Office.



SCIENCE DRIVER

CLIMATE VARIABILITY, OCEAN FOOD WEBS, AND BIOGEOCHEMICAL CYCLES

The oceans affect climate and weather through the ocean's capacity to store and release heat and CO_2 . Marine communities contribute to carbon cycling through food-web interactions. Relatively rapid, dramatic changes in marine communities (i.e., regime shifts) that persist for years have been observed and likely result from complex, non-linear responses to decadal-scale atmosphere-ocean interactions. The OOI offers unprecedented opportunities to investigate the ocean-atmosphere-climate system to better understand sea-level rise, the effect of increasing ocean CO_2 concentrations (and resulting increase in acidity) on marine communities, and regime changes, and to assess the response of marine mammals to ocean variability. Long-term measurements of physical, chemical, and biological parameters will advance understanding of the mechanisms that lead to ecosystem change and the

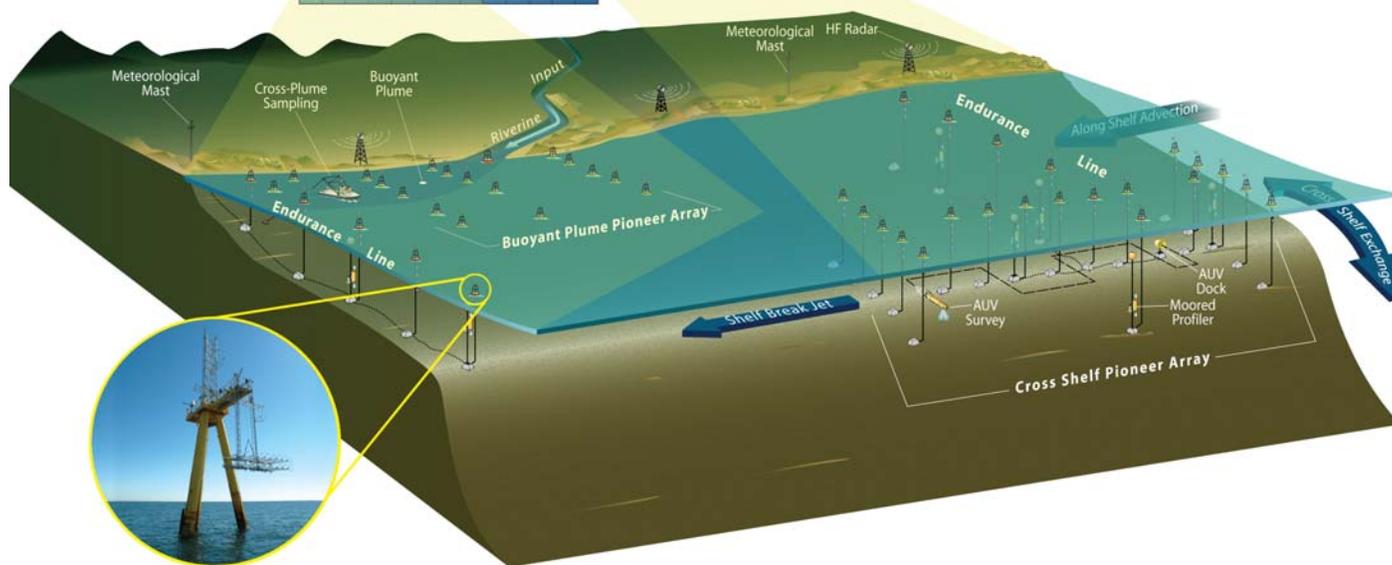
role of biological feedbacks. Near-real-time data telemetry will allow adaptive sampling of episodic events, which may control many dominant processes. The OOI sites will complement other components of a global climate observatory, including the Argo profiling float program and satellite missions.

KEY QUESTIONS

- What is the ocean's role in storing anthropogenic carbon?
- What are the magnitude and cause of recent sea-level rise?
- What is the importance of low-frequency climate cycles versus longer-term global change for ocean food webs?



Conceptual placement of coastal buoy and cable array assets for a coastal observatory. Standard time-series data collected would include temperature, salinity, currents, nutrients, inherent optical properties, and fish acoustics. Figure modified from Jahnke, R., et al. 2003. Coastal Observatory Research Arrays: A Framework for Implementing Planning. <http://www.skiio.peachnet.edu/research/coop/cora.php>. Inset photo is of an air-sea interaction tower, which can be used to measure momentum, heat, and mass exchange between the atmosphere and the ocean (<http://www.whoi.edu/mvco>).



SCIENCE DRIVER

COASTAL OCEAN DYNAMICS AND ECOSYSTEMS

Most human-ocean interactions, including fish harvesting, transportation, recreation, and marine-related threats to life and property, occur in the coastal zone. Advancing understanding of coastal processes to use and manage these resources better, mitigate risks, and explore for new phenomena is challenging; important controlling processes occur over a broad range of spatial and temporal scales cannot be simultaneously studied with solely ship-based platforms. The OOI will make possible *in situ*, continuous measurements of longer-term changes in coastal ecosystems. Adaptive sampling in near-real time will elucidate

the causes and effects of transient events such as harmful algal blooms and hypoxia, and the impact of human activities on the coastal ocean and its living resources.

KEY QUESTIONS

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

SCIENCE DRIVER

GLOBAL AND PLATE-SCALE GEODYNAMICS

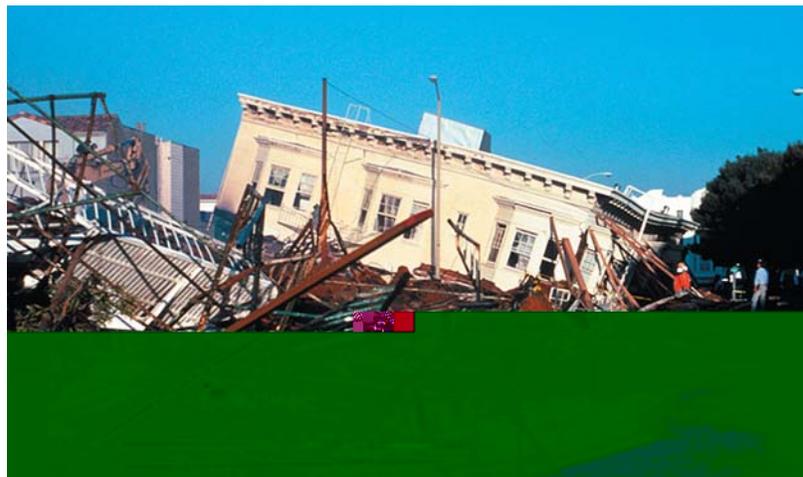
The movement and interaction of tectonic plates at Earth's surface are responsible over geologic time for the formation of ocean basins, uplift of mountain ranges, and rifting of continents. On human time scales, these plate motions cause earthquakes and volcanic eruptions that can have devastating consequences for people who live along plate boundaries. Although the kinematics of plate motions are now well known, there remain many fundamental questions regarding the forces acting on the plates, how plate boundaries interact and deform, and the linkages and feedbacks among magmatic, tectonic, hydrothermal, and biological processes at plate boundaries. The OOI will provide the infrastructure necessary to install the needed dense networks of continuously recording sensors in geologically active areas on the seafloor. The

OOI will also establish seafloor geophysical observatories that, in concert with land-based networks, will help complete the global coverage of geophysical observations and provide much-improved images of deep-Earth structure.

KEY QUESTIONS

- What is the pattern of convection in Earth's mantle and the origin and scales of mantle heterogeneity?
- What are the properties of Earth's core, core-mantle boundary, and lowermost mantle?
- What is the physics of earthquake nucleation and rupture propagation for different types of plate boundaries (subduction zones, transforms, spreading centers)?

The OOI will provide the infrastructure necessary to install dense local networks of continuously recording sensors in geologically active areas on the seafloor to capture episodic events such as earthquakes, tsunamis, submarine volcanic eruptions, and submarine landslides. These networks will provide the data needed to gain a better understanding of the fundamental geological processes that cause these natural events and assess the hazard they represent to populated coastal regions, such as the Cascadia margin off Oregon and Washington. Right: The Marina district, San Francisco after the Loma Prieta earthquake (C.E. Meyer, U.S. Geological Survey; <http://pubs.usgs.gov/dds/dds-29/screens/006sr.jpeg>). Bottom: Debris and standing water at Banda Aceh after the Great Sumatra-Andaman Islands earthquake and tsunami on December 26, 2004 (http://walrus.wr.usgs.gov/tsunami/sumatra05/Banda_Aceh/merge1.html).

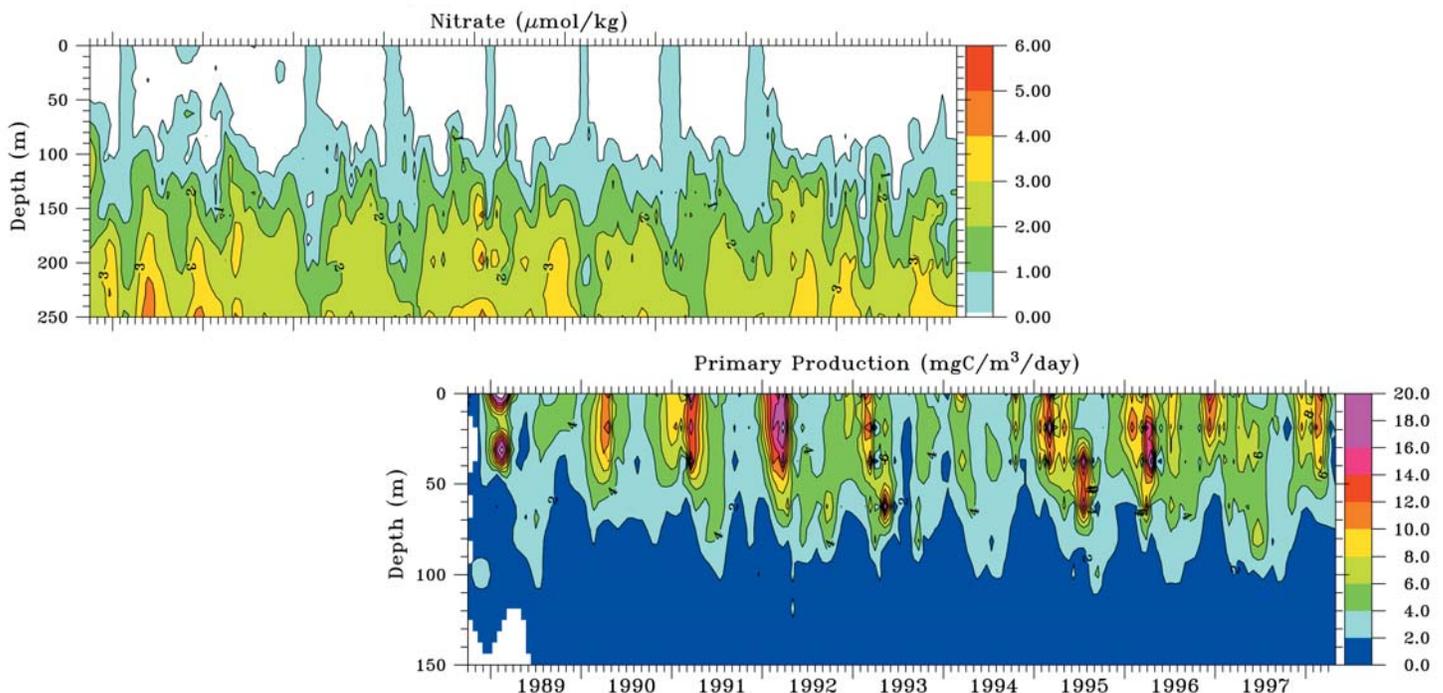


TURBULENT MIXING AND BIOPHYSICAL INTERACTIONS

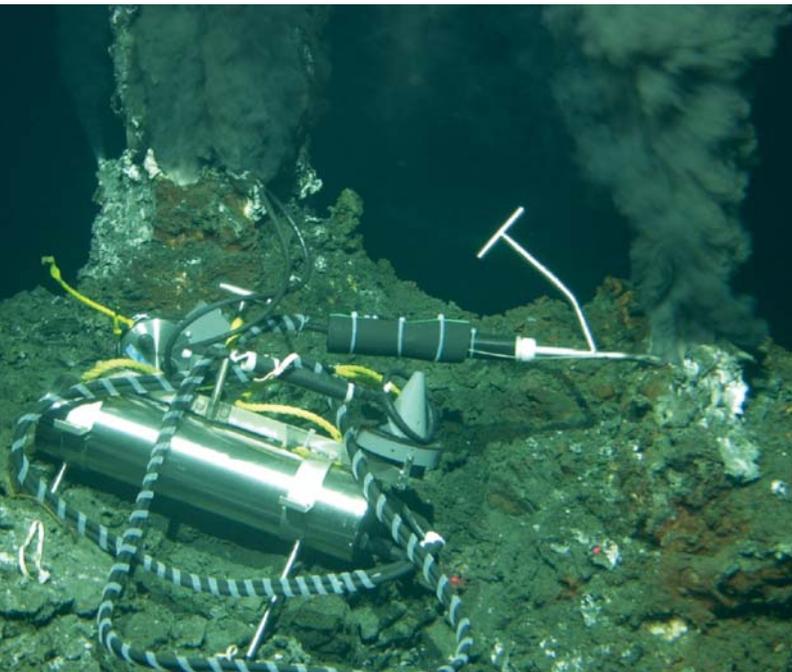
Turbulent mixing in the ocean plays a critical role in the transfer of heat and mass within the ocean, in the exchange of energy and gases between the ocean and atmosphere, and between the ocean and the seafloor. Horizontal and vertical mixing within the ocean also have a profound effect on a wide variety of biological processes, including phytoplankton community structure, cycles of primary productivity in the upper ocean, predator-prey interactions, larval dispersal, and the transfer of organic material to the deep sea. The OOI will provide the sustained time-series observations necessary to document variations in ocean mixing and marine ecosystems that are associated with interannual, and regional or global, changes in ocean circulation, and to study the infrequent, but intense, ocean-atmosphere interactions during major storms such as hurricanes.

KEY QUESTIONS

- What role does vertical mixing in the ocean's interior play in determining the global distribution of heat and nutrients in the ocean?
- What factors control the development of the mixed surface layer, the entrainment of stratified waters into the mixed layer, and the exchange of gases between the mixed layer and the atmosphere?
- What role does vertical and horizontal mixing play in determining plankton community structure in the upper ocean?
- How is benthic community structure affected by near-bottom turbulent events?



Our understanding of exactly how turbulence affects ecosystem structure remains primitive. One of the things we need to understand is how individual organisms behave and interact with other organisms on scales relevant to their environment. At the level of a single organism, turbulence influences the rate of supply of oxygen and nutrients to individuals as well as the removal of waste products. This example shows annual variations in nitrate concentrations and in primary production. Nutrients are mixed upwards into surface waters through eddy diffusion throughout the year; convective overturning deepens the mixed layer during fall/winter leading to further mixing. Figure modified from Steinberg, D.K. et al. 2001. *Deep Sea Research II*, 48:1405-1447.



Immediately following a volcanic or tectonic event, hydrothermal systems evolve rapidly as they exhaust shallow heat sources, expel fluids that phase separate during the event, and respond to changes in permeability structure. As the system returns towards equilibrium, it will continue to undergo slow change. The temperature-resistivity probe deployed for three months along the Juan de Fuca Ridge at Sully hydrothermal vent in 2000 (left), and the sulfide-microbial incubator deployed in June 2003 in the Mothra hydrothermal field at the Endeavour segment (right), are a first step toward recording changes in hydrothermal plumbing, chemistry, and biological activity. Continuously monitoring a mid-ocean ridge over complete volcanic and tectonic cycles (years to decades) is needed to fully constrain average hydrothermal fluxes and their impact on deep-ocean circulation and biological productivity. Photos courtesy of D. Kelley, University of Washington.

SCIENCE DRIVER

FLUID-ROCK INTERACTIONS AND THE SUB-SEAFLOOR BIOSPHERE

The upper oceanic crust comprises the largest aquifer on Earth. Fluid circulation within this aquifer influences the thermal state and composition of oceanic plates; interacts with hot, newly emplaced volcanic crust to form spectacular “black smoker” hydrothermal vents with their unique biological communities; concentrates massive reservoirs of methane and methane hydrates along continental margins; and hosts a vast, largely unexplored sub-seafloor microbial biosphere. There is increasing evidence that transient events—earthquakes, volcanic eruptions, massive slope failures—play a critical role in fluid-rock interactions and sub-seafloor microbial activity. These transient events, which may last only hours or days, are very difficult to observe and sample using conventional ship-based studies. Understanding the linkages and feedback

mechanisms among geological, chemical, and biological processes within these highly dynamic environments will only be achieved through the use of long-term, *in situ* observatories provided by the OOI infrastructure.

KEY QUESTIONS

- What is the extent, abundance, distribution, and diversity of the sub-seafloor 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?



PART OF A BROADER EFFORT TO OBSERVE THE OCEANS

The OOI infrastructure and the research-driven ORION Program are part of a broader national and international effort to establish long-term observatories in the ocean, both for conducting basic research and for operational oceanographic needs.

At the national level, OOI/ORION's closest relationship with operational ocean observational systems is with the proposed U.S. Integrated Ocean Observing System (IOOS). IOOS is being developed as a contribution to the international Global Ocean Observing System (GOOS), which in turn is a component of the international Global Earth Observation System of Systems (GEOSS). GEOSS is dedicated to the development of a comprehensive, coordinated and sustained Earth Observation System to collect and disseminate improved data and models to stakeholders and decision-makers. While GEOSS transcends the ocean sciences, the OOI represents a major ocean contribution to this new, international effort. The President's recent program to upgrade the global tsunami warning system motivates a signifi-

cant expansion of the Global Seismic Network (GSN) to the oceans and the use of seafloor pressure gauges at global, regional, and coastal observatories.

Planning for other research-driven ocean observatory and observing programs has been underway in a number of other nations, much of it in close collaboration with efforts in the United States. The OOI's closest international partner is NEPTUNE Canada, which is building a cabled observatory offshore of Vancouver Island. Other research-driven observatory programs exist in Japan (ARENA) and Europe (ESONET). Distributed sensor networks and observing systems are also being developed to address a broad range of Earth and environmental problems in the U.S. research community. Although many of these efforts are not specifically oceanographic, the connections with OOI can, nonetheless, be very strong. The scientific planning, management, and operational structure of the OOI will be organized in a manner to leverage these other efforts into a truly global, environmental observatory.



ENGINEERING. The engineering challenges that must be addressed in the design and construction of ocean observatories will also drive the development and application of cutting-edge technology for the field of oceanography. Four areas where this is already occurring include: (1) improvements in the design and development of highly reliable instrumentation and equipment that can operate unattended for long periods in the hostile ocean environment; (2) development of the cyberinfrastructure necessary to remotely manage sensors, data, and the observatory infrastructure; (3) use of mobile, autonomous vehicles and *in situ* remote sensing to extend the areal coverage and sample density around a fixed observatory; and (4) driving the design of new sensors for *in situ* measurements. Spin-offs in the academic, commercial, government, and military sectors can reasonably be expected to ensue from all of these aspects of ocean observatories. Many of the technologies required for ocean observatories have obvious applications for military surveillance, homeland defense, and environmental monitoring.



CONCLUDING REMARKS

The OOI represents a significant departure from traditional approaches in oceanography. It promises to transform the manner in which research is conducted in the oceans and expand our understanding of the role of the oceans in planetary processes. In particular, the OOI provides the infrastructure to integrate observations across vast scales from the microscopic and even submicroscopic (e.g., future DNA arrays deployed at observatories and the measurement of ground motion to the nanometer level) to the ocean-basin scale (e.g., for studies of ocean circulation, climate variability, and Earth structure). Data collected by ocean observatories will be fully open and available for use by researchers, educators, government, and industry. The paradigm shift in ocean research enabled by the OOI will open entirely new avenues of research and discovery in the oceans, foster the development and application of advanced technology to ocean science problems, provide exciting new opportunities for conveying the importance of the oceans to students and the general public, and acquire critical information for decision-makers in developing ocean policy.

INSIDE FRONT COVER. *Left.* View of the “ocean planet” from space. *Right.* A snapshot of sea surface temperature. Figure courtesy of Y. Chao, Jet Propulsion Laboratory. PAGE ONE. *Left.* Ocean plant productivity mapped from the backscattering signal derived from SeaWiFS observations. Figure from Schofield et al. 2004. *Oceanography* 17(2):24-27. *Middle.* An annual global chlorophyll a map illustrating areas of the ocean associated with high biological activity. Figure from Schofield et al. (2004). *Right.* Hydrothermal venting at a mid-ocean ridge. Photo courtesy of D. Kelley, University of Washington. PAGE TWO. Reaching student and public audiences.

Figures courtesy of the NEPTUNE Project (www.neptune.washington.edu) and the Center for Environmental Visualization. PAGE EIGHT. *Top.* A portion of the Monterey Accelerated Research System (<http://www.mbari.org/mars/>). *Bottom.* Two autonomous underwater vehicles (Webb Slocum gliders) flying during a red tide. Figure courtesy of O. Schofield, Rutgers University. INSIDE BACK COVER. *Top.* An air-sea interaction tower (<http://www.whoi.edu/mvco>). *Bottom.* The ABE autonomous underwater vehicle. Figure created by P. Oberlander, Woods Hole Oceanographic Institution.

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**Ocean Research Interactive
Observatory Networks**

The Science Plan is available
at www.orionprogram.org.

June 2005