Testimony of
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Introductory Remarks

Mr. Chairman, members of the Subcommittee, thank you for inviting me to testify as to how the National Science Foundation (NSF) is supporting ocean observing systems and coordinating with NOAA, Navy and the other agencies that are part of the National Ocean Partnership Program (NOPP) to support the development of regional and national ocean observing systems. I am Margaret Leinen, Assistant Director for Geosciences at the National Science Foundation. The three divisions in my directorate support research in Ocean, Atmospheric and Earth Science.

I also Co-Chair, with Dr. Richard Spinrad, the National Science and Technology Council's (NSTC) Joint Subcommittee on Oceans that reports to both the NSTC's Committee on Environment and Natural Resources and the Committee on Science. The Joint Subcommittee on Oceans is currently establishing an interagency Task Force on Ocean Observations to focus on national interests and needs in this area.

NSF's mission is to support basic research, including oceanographic research, primarily at U.S. academic institutions. Thus, our primary interest and involvement in ocean observations is through the researchers who successfully compete for NSF grants, as well as the broader ocean science community who provide guidance to our programs through workshops, National Academy reports and other venues.

Need for Ocean Research Observatories

Since the earliest expeditions of H.M.S. Challenger in the 19th century, progress in ocean research has been driven strongly by the ability to make new observations - either located in new *places* (i.e. classical exploration-going to places on Earth that have not been observed before) or using new *types* of measurements that permit natural phenomena or processes to be understood in different ways. As our knowledge of the oceans has improved, the realization has grown that few characteristics of the ocean are in steady state – the ocean and the seafloor beneath are highly dynamic environments. If these processes are to be understood, if new insights are to be gained, if quantitative models are to be validated satisfactorily, then observations are needed over the time scales appropriate to the dynamics of these processes. We know enough today to realize that these time scales span milliseconds to decades, centuries and beyond and that a new mode of observing the ocean will evolve over the next decade, driven primarily by the growing need for sustained time-series observations. This need is clear, not only in our most reliable source of information concerning research trends – the proposals that are submitted – but also in essentially all of the community-based planning documents that have been produced in recent years.

NSF continues to invest in research that explores new regions or explores new processes that have recently been discovered. In this mode of observation, we have invested in exploration that discovered deep sea hydrothermal vents, in exploration that discovered new underwater volcanoes, and in exploration that discovered new species of organisms in the ocean. However, today I would like to highlight another, equally important, kind of exploration. When investigators work to understand the ocean by making sustained time-series observations they are, in effect, "*exploring-in-time*". The earliest oceanographers made great discoveries by conventional spatial exploration - they traveled to new places in the oceans and discovered unexpected phenomena that catapulted their understanding of a particular process to a new level. Today, innumerable examples exist in the published literature of important and sometimes unexpected discoveries resulting from the collection of long time-series data sets**.** Some people have considered this type of ocean observing as "monitoring." It is not - it is the classical combination of hypothesis testing and exploration, but in the time domain, not the space domain. Researchers are continuously developing, changing, and improving measurement strategies and techniques to maximize understanding and insight.

What Have We Learned to Date from Sustained Measurements in the Ocean?

Sustained measurements at a few coastal, open ocean and sea floor locations have yielded some very exciting results, some with broad policy and management implications, and attest to the potential impact of research observatories currently under development. Some examples:

1. Measurements from a seafloor observatory show that fluids from aging ocean crust support microbial life of high diversity.
2. Sustained biological and nutrient measurements off Hawaii and Bermuda show changes in the basic life support system of the oceans--from nitrogen-limitation to phosphorus-limitation of biological production—that control life in the North Pacific gyre, and possibly in parts of the Atlantic.
3. Sustained measurements of the carbon dioxide system in seawater off Bermuda and Hawaii show that interannual changes in ocean mixing in the Atlantic, and changes in regional precipitation and evaporation in the Pacific, cause interannual variations in the amount of carbon dioxide that the ocean absorbs from the atmosphere.
4. Measurements in the Pacific reveal that long-period (about 50 years) shifts in air and ocean temperatures affect biological productivity and fisheries off Japan, California, Peru and Chile, as well as changes to the carbon dioxide sink and source flux of the equatorial Pacific.
5. Floats that recorded temperatures in the Southern Ocean throughout the 1990s show that the Southern Ocean has warmed by about 0.2 C just since the 1950s.
6. Measurements of salinity over the past several decades show that tropical ocean waters have become dramatically saltier over the past 40 years, while oceans closer to the Earth's poles have become fresher.

NSF's Ocean Research Interactive Observatory Networks (ORION) and the Ocean Observatories Initiative (OOI)

The US oceanographic research community and the National Research Council (in two recent reports), as well as the international oceanographic research community have all highlighted that modern ocean science research requires new types of infrastructure that are capable of providing long-term, high-resolution observations of critical environmental parameters on appropriate time and space scales. Consequently, NSF's Division of Ocean Sciences (OCE) is planning to construct and operate an innovative new ocean observatory network, Ocean Research Interactive Observatory Networks (ORION), of which the Ocean Observatories Initiative (OOI) is the infrastructure component. Funds for the OOI are being sought through NSF's Major Research Equipment and Facilities Construction (MREFC) account. OOI was listed in NSF's FY05 budget submission to Congress as a candidate new start for FY06. OOI infrastructure will provide the oceanographic research and education communities with new modes of access to the ocean. The OOI has three primary elements: 1) a regional cabled observatory (RCO) consisting of interconnected sites on the seafloor spanning several geological and oceanographic features and processes, 2) relocatable deep-sea buoys that could also be deployed in harsh environments such as the Southern Ocean, and 3) new construction or enhancements to existing systems leading to an expanded network of coastal observatories.

ORION Science Plans

The U.S. and international ocean science community is currently engaged in extensive planning efforts to determine how to focus ORION observatory assets on the most appropriate and exciting research questions. The ORION science plan is not yet final, but based on workshop and other reports (see Glenn and Dickey 2003 and Jahnke et al. 2003), I can provide a sampling of the types of science programs we expect to see in the final ORION plan.

The coastal research community will use ORION to determine and quantify the processes at the ocean boundaries that affect the global carbon and related cycles; to better understand the environmental factors that control the diversity and species composition of coastal biological communities – a key requirement to implement ecosystem-based management strategies; to better understand fluid flow and life in continental margin sediments, including the processes that form gas hydrate deposits; and to achieve a much better understanding of water circulation in the coastal ocean.

Researchers will use instruments on open ocean buoys and on the seafloor to improve our understanding of earthquakes that occur far from land; to develop the long records required to delineate climate cycles from long-term change; to quantify changes in the ocean's ability to absorb atmospheric carbon dioxide; and to determine the impact of anthropogenic CO2 on the ocean carbonate system – which is of critical importance to many ocean organisms, including corals. Other instruments will be deployed to study the circulation of water flowing through the upper ocean crust, which exceeds the flow of all the rivers that pour off of the continents, and its impact on subseafloor biological and chemical processes. For example, some of holes drilled deep by U.S. and Japanese scientific drill ships will be capped with elaborate structures called Circulation Obviation Retrofit Kits ("CORKS)". CORKS will enable scientists to monitor processes beneath the seafloor and conduct experiments. These advanced seafloor observatories allow measurements of temperature, pressure, fluid chemistry, and microbiology to be obtained from different depths in the borehole.

Canadian and U.S. scientists will connect CORKS and other instruments to the Regional Cabled Observatory (RCO), to be located on the Juan de Fuca plate, to answer questions about how the sea floor forms and subsides at plate boundaries; as well as the effects of geological processes on biological processes on and within the seafloor. Instruments connected to seafloor cables but extending up into the overlying water column will be used to quantify mixing between deep and shallow waters and the rate of gas exchange between the ocean and atmosphere.

An important ORION goal is to provide real-time observatory data to researchers, and to those involved in education and outreach. Thus, scientists will be able to respond and adjust to events as they develop. Educators and outreach specialists will be able to use the real-time information to spread the excitement of discovery to students and the general public.

Just as the U.S. academic research fleet is accessible to all investigators, the OOI will begin building an openly accessible network of ocean observatories to facilitate the collection of long time-series data sets needed to understand the dynamics of biological, chemical, geological and physical processes. The primary infrastructure for all components of the OOI includes both dedicated fiber-optic cables to shore and moorings capable of two-way communications with a shore station. Moorings are envisioned to be both freestanding, as for the global array of buoys, and they will also be attached to fiber optic cables to provide the capability for water column investigations. Seafloor junction boxes connected to this primary infrastructure will support individual instruments or instrument clusters at varying distances from cables as well as the moorings. These junction boxes include undersea connectors that provide not only the power and two-way communication needed to support seafloor instrumentation, but also the capability to exchange instrumentation in situ when necessary for conducting new experiments or for repairing existing instruments.

NSF will cooperate with other US Federal agencies and international partners to implement the ORION network and as described in the next section, to link the ORION researchers with IOOS activities. The RCO will be located on the Juan de Fuca plate in US, Canadian and international waters (off Washington and British Columbia) and will be designed, constructed and operated in cooperation with Canada. Institutions that are competitively selected to construct and operate coastal observatories will likely be members of the Regional Associations that are envisioned as part of the coastal observing component of IOOS. Thus, NSF-funded infrastructure and operations funds will help support the activities of the RAs. NSF and the ORION Project Office are also discussing direct cooperation with NOAA's Office of Climate Observation (OCO) to deploy some of the open ocean observatories to serve both research and NOAA operational needs and requirements for open ocean measurements.

Relation between ORION/OOI and the Integrated Ocean Observing System (IOOS)

The research-driven ORION (with its infrastructure construction OOI component) is part of a broader national and international effort to establish long-term ocean observatories, for basic research and education, as well as for operational oceanographic needs. The most fundamental relationship between the OOI and operational ocean/Earth observing systems at the national level is with the proposed U.S. Integrated Ocean Observing System (IOOS)- an operational observing system that is being planned under the auspices of the National Ocean Partnership Program (NOPP). As will be/was described by Drs. Spinrad and Winokur, the primary purpose of the IOOS is to provide data of societal interest to "customers," ranging from fishermen and shippers, to coastal zone managers, to the U.S. Navy. Data to be collected are aimed at supplementing current knowledge. In contrast, the NSF's OOI is focused on developing new knowledge and new technologies that will advance our understanding of the oceans. By addressing the ocean research community's needs for time-series measurements of ocean processes, the OOI will provide the infrastructure needed to advance knowledge and understanding of the ocean/atmosphere/earth system, as well as the technical capabilities for monitoring that system.

In a recently released National Research Council Report (NRC, 2003), a key finding states (p.158) :

"The OOI will greatly improve the ability of operational ocean observing systems such as the Integrated and Sustained Ocean Observing System IOOS and the Global Ocean Observing System (GOOS) to observe and, predict ocean phenomena."

"The research based OOI is an important complement to the proposed IOOS. IOOS is an operational system driven by the needs of potential users, and designed to improve the safety and efficiency of marine shipping, mitigate effects of natural hazards, reduce public health risks, improve weather and climate predictions, protect and restore a healthy coastal environment and enable sustainable use of marine resources. The OOI, in contrast, is driven by basic research questions and its principal products will be improved understanding of the oceans and new and improved technologies. The OOI will thus provide the key enabling research for IOOS, including fundamental advances in observatory platforms and, through the research of investigators using the OOI, basic understanding and in sensor technology that will enable IOOS to meet its longer term operational goals. The IOOS is important for the OOI because it will provide a larger framework of observations and background data necessary for interpreting the process oriented experiments that are the centerpiece of basic research."

The Preliminary Report of the U.S. Commission on Ocean Policy (http://www.oceancommission.gov/) reached a similar conclusion. The report states on p. 327:

The national IOOS will also have significant synergies with the NSF Ocean Observatories Initiative, which is being designed to address the ocean research community's needs for long-term, in situ measurements of biological, chemical, geological, and physical variables over a variety of scales. The NSF observatories will be used to examine the processes that drive atmospheric, oceanic, and terrestrial systems and will serve as an incubator for new technologies to monitor these processes. While the IOOS and the NSF observatories have thus far been planned independently, the basic research and technology development from the NSF Observatories and the information generated by the IOOS are in reality interdependent, with each program supplying ingredients essential to the other. Close coordination and cooperation between NOAA and NSF will be necessary to capitalize on these benefits.

NSF and the Interagency Process to Plan and Develop IOOS

NSF is part of the National Ocean Partnership Program (NOPP) and is one of the original signatories to the *NOPP MOU for Establishing a NOPP Interagency Ocean Observation Office (http://www.ocean.us/documents/doc).* The signatories of the MOU support the Ocean.US office, which serves as a national focal point for integrating ocean observing activities. Along with Navy, NOAA, NASA and other agencies, NSF provides funds to operate the office and supports two researchers to participate in Ocean.US planning and coordination activities. Dr. James Yoder, Director of the Division of Ocean Sciences, represents NSF on NOPP's Ocean Observations Executive Committee (EXCOM), which oversees Ocean.US activities and provides policy guidance, ensures sustained Agency support, and approves implementing documents. At present, Ocean.US and EXCOM are developing a draft Implementation Plan for IOOS to be vetted by the National Ocean Research Leadership Council, which NSF chaired last year.

NSF also participates in the annual NOPP solicitation for research projects and is one of the principal sources of funding for projects selected through the peer review process. Three of the topics that generally appear each year in the NOPP solicitation are chosen by the agencies to support ocean observations: Research Observatories, Observational Technique Development, and "Commons" for Ocean Observations. NOPP projects funded cooperatively by the Office of Naval Research (ONR), NOAA, NASA, NSF, Sloan Foundation and others during the past few years that are related to these ocean observing themes include:

- An Innovative Coastal-Ocean Observing Network (ICON), Naval Postgraduate School;
- Design Study for NEPTUNE: Fiber Optic Telescope to Inner Space, University of Washington;
- Coastal Marine Demonstration of Forecast Information to Mariners for the U.S. East Coast, University of Maryland, Horn Point Laboratory;.
- Developing Long Range Autonomous Underwater Vehicles for Monitoring Arctic Ocean Hydrography, Monterery Bay Aquarium Research Institute;
- Autonomous Profilers for Carbon-System and Biological Observations, Lawrence Berkeley National Laboratory;
- Incorporation of Sensors into Autonomous Gliders for 4D Measurement of Bio-optical and Chemical Parameters, University of Washington;
- Accelerating Electronic Tag Development for Tracking Free-Ranging Marine Animals at Sea, Stanford University and the University of California Santa Cruz;
- Developing Gene-Based Remote Detection, NOAA Atlantic Oceanographic and Meteorological Laboratory;
- The Environmental Sample Processor (ESP): A Device for Detecting Microorganisms In Situ Using Molecular Probe Technology, Monterey Bay Aquarium Research Institute;
- Development of an Integrated Regional, National & International Data System for Oceanography, University of Rhode Island;
- A Biotic Database of Indo-Pacific Marine Mollusks, Academy of Natural Science;
- Census of Marine Fishes (CMF): Definitive List of Species and Online Biodiversity Database, California Academy of Science; and
- Digital Archival of Marine Mammal/Bird/Turtle Data for OBIS, Duke University.

Recent NSF Development Efforts to Prepare for Ocean Observatories

In 2002, NSF's Division of Ocean Sciences funded the Monterey Accelerated Research System (MARS). MARS will complete the design and then install an advanced cabled observatory in Monterey Bay that will serve as the test bed for a state-of-the-art regional ocean observatory. MARS thus represents an important step toward harnessing the promise of new power and communication technologies to provide a remote, continuous, long-term, high-power, large-bandwidth infrastructure for multidisciplinary, *in situ* exploration, observation, and experimentation in the deep sea. MARS will be located in Monterey Bay offshore the Monterey Bay Aquarium Research Institute (MBARI). It will include one science node on 51 km of submarine cable with expansion capability for more nodes in the future. The science node will provide 8 science ports, and each port will have a 100-egaMbit-per-second, bi-directional telemetry channel. 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.

In 2004, NSF's Division of Ocean Sciences funded a joint venture of the Joint Oceanographic Institutes (JOI), Inc. and the Consortium for Oceanographic Research and Education (CORE) to support an ORION Project Office to coordinate science community planning in preparation for ocean observing projects, including the proposed OOI/ORION initiative. The small staff is co-located with JOI, Inc. in Washington D.C. An Executive Steering Committee comprised of renowned scientists from institutions throughout the U.S. and Canada, including Dr. Weller who is testifying today, was also established and is working closely with the ORION staff. The two immediate tasks for the Steering Committee and the Office staff are to synthesize science community input from workshops and other sources to develop an ORION Science Plan to be followed by an Implementation Plan. The Office will also work with Ocean.US and implementing offices, such as NOAA's Office of Climate Observations (OCO), to develop and coordinate ocean observing plans and activities.

In addition to these direct contributions to observation of the oceans, I would like to highlight other critical roles played through the support of the National Science Foundation. All ocean observing systems depend on sensors which have been developed through ocean research. The evolution of the observing systems proposed today will come about through research into improvements in existing sensors and through new sensor development. This research is supported through the basic research programs of the National Science Foundation.

With new sensors come innovative ideas for the sensor networks and arrays that can make such measurement. ORION is an excellent example of a state of the art sensor network that has evolved from the NSF-supported research community. Such systems must be tested and developed in a research environment before they can be deployed as operational systems. Research supported by the National Science Foundation provides a mechanism for the development of innovative new sensor networks.

Once data from observation systems are in hand, they need to be assimilated into quantitative computer models that reveal the relationship of the observations to the wealth of other ocean environmental data. The National Science Foundation has been a strong supporter of the research communities that develop such computer models of the ocean.

This end-to-end investment in new technologies for ocean observation, new paradigms for ocean observation, and new models for the interpretation of ocean observatory data is a hallmark of the National Science Foundation Ocean Sciences Division.

Priorities for the Future Interagency Attention

In addition to agency-specific planning and development activities, and to the Implementation Plan currently under development by Ocean.US and NOPP's EXCOM, NSF believes attention should be focused on two other high priority activities: (1) Development of a data system to serve both research and operational ocean observing requirements; and (2) as recommended by the U.S. Commission on Ocean Policy (SCOP) Preliminary Report, an approach and a plan for transitioning ideas and tools from research to operations. Ocean.US and EXCOM are currently discussing the data system issue and are receiving considerable input from NSF, Navy, NOAA, NASA and other agencies. A high priority is to agree on metadata and data standards that satisfies researchers, as well as other users of IOOS and ORION data. NSF is optimistic that a plan will soon emerge from these discussions that will lead to a flexible data system to serve research users as well as other customers for IOOS and ORION data. One of the NSF goals is for full and open exchange of data, emphasizing the importance of distributing as much as possible in near real-time. NSF and the ORION Office are also prepared to participate in interagency discussions on the transition issue, as well.

Mr. Chairman, Thank you for this opportunity to share these thoughts on the importance of ocean observations to researchers and the role NSF will play in the interagency efforts to develop a national ocean observing strategy and system. I am pleased to answer any questions.

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