OCEAN EXPLORATION AND COASTAL AND OCEAN OBSERVING SYSTEMS

JOINT OVERSIGHT HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT, TECHNOLOGY, AND STANDARDS
SUBCOMMITTEE ON RESEARCH

COMMITTEE ON SCIENCE

AND THE

SUBCOMMITTEE ON FISHERIES CONSERVATION, WILDLIFE AND OCEANS

COMMITTEE ON RESOURCES
HOUSE OF REPRESENTATIVES

ONE HUNDRED SEVENTH CONGRESS

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JULY 12, 2001

Appendix 4: Additional Material for the Record

OCEAN EXPLORATION AND COASTAL AND OCEAN OBSERVING SYSTEMS

JULY 12, 2001

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENVIRONMENT, TECHNOLOGY, AND STANDARDS,
SUBCOMMITTEE ON RESEARCH, COMMITTEE ON SCIENCE,
JOINT WITH SUBCOMMITTEE ON FISHERIES CONSERVATION, WILDLIFE AND OCEANS,
COMMITTEE ON RESOURCES,
Washington, DC.

The Subcommittees met, pursuant to call, at 1 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Vernon J. Ehlers [Chairman of the Environment, Technology, and Standards Subcommittee] presiding.

SUBCOMMITTEE ON ENVIRONMENT, TECHNOLOGY, AND STANDARDS

SUBCOMMITTEE ON RESEARCH

SUBCOMMITTEE ON FISHERIES CONSERVATION, WILDLIFE AND OCEANS

Joint Oversight Hearing on:

Ocean Exploration and Coastal and Ocean Observing Systems

Thursday, July 12, 2001

Witness List

Panel I:

MR. SCOTT B. GUDES
Acting Undersecretary for Oceans and Atmosphere, Department of Commerce

DR. RITA R. COLWELL
Director, The National Science Foundation

ADMIRAL JAY M. COHEN
Chief, Office of Naval Research, U.S. Navy

ADMIRAL CONRAD LAUTENBACHER, JR.
President, Consortium for Oceanographic Research & Education

Panel II:

DR. MARCIA K. MCNUTT
President and Chief Executive Officer, Monterey Bay Aquarium Research Institute

DR. ROBERT D. BALLARD
President, Institute for Exploration

Panel III:

DR. ROBERT A. WELLER
Director, Cooperative Institute for Climate and Ocean Research
Woods Hole Oceanographic Institution

DR. J. FREDERICK GRASSLE
Director, Institute of Marine and Coastal Sciences, Rutgers University

DR. ALFRED M. BEETON
Senior Science Advisor, National Oceanic and Atmospheric Administration

DR. ALEXANDER MALAHOFF
Director, Hawaii Undersea Research Laboratory, University of Hawaii

HEARING CHARTER

Ocean Exploration and Coastal and Ocean Observing Systems

On Thursday, July 12, 2001, at 1:00 p.m. in 2318 Rayburn House Office Building the Resources Subcommittee on Fisheries Conservation, Wildlife and Oceans, and the Science Subcommittees on Research, and Environment, Technology and Standards will hold a hearing on ocean exploration, and the development and implementation of coastal and ocean observing systems. The following witnesses are scheduled to testify:

Panel I

Mr. Scott B. Gudes, Acting Undersecretary for Oceans and Atmosphere, Department of Commerce

Dr. Rita R. Colwell, Director, The National Science Foundation

Rear Admiral Jay M. Cohen Chief, Office of Naval Research, U.S. Navy

Vice Admiral Conrad Lautenbacher, Jr., President, Consortium for Oceanographic Research & Education

Panel II

Dr. Marcia K. McNutt, President and Chief Executive Officer, Monterey Bay Aquarium Research Institute

Dr. Robert D. Ballard, President, Institute for Exploration

Panel III

Dr. Robert A. Weller, Director, Cooperative Institute for Climate and Ocean Research, Woods Hole Oceanographic Institution

Dr. J. Frederick Grassle, Director, Institute of Marine and Coastal Sciences, Rutgers University

Dr. Alfred M. Beeton, Senior Science Advisor, National Oceanic and Atmospheric Administration

Dr. Alexander Malahoff, Director, Hawaii Undersea Research Laboratory, University of Hawaii

II. BACKGROUND

This hearing follows up on hearings in the 104th, 105th, and 106th Congresses on Federal interagency cooperation on ocean research and particularly on the progress of, and plans for, the implementation of an integrated and sustained-ocean observing system. The hearing will also examine the need to coordinate the rapidly proliferating coastal observing systems. Finally, it will review the Report of the President's Panel on Ocean Exploration and the implementation of that report's recommendations.

Until the last decade, technological limitations confined oceanographic research to discrete observations that were not available in real time, continuously or over long time periods. These limitations in data acquisition, dissemination and analysis in turn limited our understanding of the structure and processes of the marine environment. Over the last decade, advances in the technology of in situ and remote sensors (data acquisition), and data transmission, distribution and analysis has greatly expanded our ability to monitor ocean and coastal processes in real time, continuously and over long time periods.

These new capabilities have already lead to enormous advances in. our understanding of the coastal and marine environment. However, these sensors have only been deployed on relatively small scales, and the systems that are deployed are have not been coordinated into an integrated system that will optimize our understanding of the oceans. Coordinating and, of course, funding an integrated and sustained coastal and ocean observation system will have many benefits. Such a system will assist in:

- detecting and forecasting oceanic components of climate variability;
- facilitating safe and efficient marine operations;
- ensuring national security;
- managing living resources for sustainable use;
- preserving healthy and restoring degraded marine ecosystems;

- mitigating natural hazards; and
- ensuring public health.

Recognizing the technological revolution that was underway in oceanographic research, and concerned that the fractured structure of Federal ocean oversight and research programs may be preventing the Federal government from capitalizing on those technological advances, the House Resources, Science and Armed Services Committees held a hearing in 1995 on leveraging Federal oceanographic resources. As a result of the hearing, Congress enacted the National Ocean Partnership Act (NOPA) in 1996.

NOPA established the National Ocean Partnership Program (NOPP), an interagency coordinating and grant making program lead by the Navy, the National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF). NOPP is operated under contract with the Consortium for Ocean Research and Education (CORE), a private group that represents U.S. coastal and ocean research institutions. The interagency coordinating functions are carried out by the National Ocean Research Leadership Council (NORLC) which is made up of 12 Federal agencies with significant ocean-related responsibilities. NORLC uses the 10 member Ocean Research Advisory Panel (ORAP) to assist in outreach to non-Federal governmental and research entities.

In 1998, as a follow on to the enactment of NOPA, the Subcommittee on Fisheries Conservation, Wildlife and Oceans held a hearing on a National Research Council paper, entitled "Opportunities in Ocean Sciences: Challenges-on the Horizon". That hearing examined recent advances in understanding the ocean through the application of up-to-date technologies, and future oceanographic research needs. The report concluded that technological advances have greatly expanded the ability of scientists to observe the depths of the ocean, and to establish real time, or near real time, long-teen monitoring of ocean phenomena. The most well publicized example of this is the El Niño/Southern Oscillation mooring array that allowed scientists to track the large 1998 El Niño and the subsequent La Niña in the equatorial Pacific Ocean. If these enhanced technological abilities are harnessed properly, they can generate the data needed to understand the many other annual and decadal trends that occur in the world's oceans and atmosphere. Decoding these large-scale, long-lived events can lead to improved weather and climate forecasts, and improved natural resources management. According to the National Research Council report:

> "Ocean observations have always been the driver of new knowledge and predictive capabilities in the ocean and its basins. Ocean drilling has produced sediment cores that provide our best long-term records of natural climate fluctuations. Submersible observations (both piloted and robotic) opened our eyes to hydrothermal vents and the unique life forms that surround them. Our present ability to forecast and assess El Niño variability depends critically on the coupling of extensive oceanic and atmospheric observations with increasingly accurate computer models. Despite these and many other accomplishments, the oceans remain vastly undersampled in time and space."
>
> "With new technologies, new kinds and levels of ocean, ocean/atmosphere, and ocean/solid earth observations can be made.. . . In the future, data from ocean sensors, undersea vehicles, and satellites can be combined with highly capable communications systems and computer models to assess the evolving daily state of ocean currents, temperature, nutrients, biota, ice, and air-sea fluxes. The overall system can then display for anyone, on the world wide web, accurate estimates of the present state of the ocean. The information can be put to practical use for such diverse purposes as improved weather prediction, safer offshore operations, better short-term climate forecasts (e.g., El Niño), and more successful management of living resources. The resulting system will be capable of providing as good an ongoing assessment of the ocean as is currently taken for granted for the atmosphere and land surfaces."

As a result of that hearing, the then Chairs of the Resources Subcommittee on Fisheries Conservation, Wildlife and Oceans and Armed Services Subcommittee on Military Research and Development wrote to the National Ocean Research Leadership Council (NORLC) requesting that the Council prepare a "plan to achieve a truly integrated ocean observing system". In response to that request, a NORLC-appointed Ocean Observation Task Team under the direction of ORAP drafted the plan. After an interagency review, that report, *Toward an Integrated Ocean Observing System,* was provided to Congress in April 1999. It was then used to prepare a December 1999 NORLC report entitled *An Integrated Ocean Observing System: A Strategy for Implementing the First Steps of a U.S. Plan.* The two subcommittees held a hearing on those report in May, 2000.

The implementation plan prepared by NORLC describes the process that needs to take place in order to develop that system of accurate, up-to-date ocean measurements in a way that integrates the needs of all of the ocean agencies. The reports did not specify the details of agency programs and budgets. It did suggest that an initial infusion of $30 million was necessary to begin system implementation, and that the cost could rise to $100 million per year over 3–5 years. No budget requests of that magnitude have been made. The December report concluded that there are no technical nor legislative impediments to implementing a National Ocean Observing System and, with proper and realistic investment, a comprehensive national ocean observing system can be built within ten years. It did, however, identify that there are two main components currently missing: a framework and the necessary funding.

The report concluded that the framework necessary to build an integrated ocean observing system need not be fully determined at the outset, rather it should be dynamic and respond to the needs of the system as it matures. In the beginning, however, the framework should build upon the existing NOPP statutory and management structure. In addition, NOPP should be used to allocate and coordinate funding decisions. NOPP provides a mechanism to augment ongoing activities and immediately start key near-term initiatives in a phased approach to implementation.

Recently NORLC has established Ocean.US, the National Office for Integrated and Sustained Ocean Observing and Prediction. This office will coordinate the framework for the integrated system. It is assumed that most of the elements of the system will be developed and operated by the Federal agencies whose mission those elements serve, or in the case of the coastal components of the system by local or regional research institutions. The connections, including data comparability standards will be organized by NORLC through Ocean.US. Currently NOPP funding is inadequate to address gaps in the system, establish data standards, or coordinate data storage.

Many potential components of an integrated system exist or are being planned. The El Niño/Southern Oscillation mooring array has already been discussed, but other ocean observing efforts are also underway. Examples include:

- The VENTS program was established in 1984 in order to better understand the spreading of the seafloor in the Pacific Ocean. Not only is the geology being reviewed at these hot spots under the sea but also the unique and only recently discovered ecology surrounding these vents. In 1996, the VENTS program deployed high-quality acoustic hydrophones which augmented the Navy's SOSUS hydrophone arrays, allowing underwater volcanic activity to be more closely monitored and studied. This understanding will shed light on the emissions stemming from these underwater eruptions as well as provide an understanding of the events that surround the spreading of the ocean floor. Additionally, the organisms found at these hydrothermal vents may have significant industrial biotech applications. The VENTS website is *http://www.pmel.noaa.gov/vents/home.html*
- NEPTUNE is establishing a fiber optic transmission system to bring data from sensors that surround the entire Juan de Fuca Plate on Washington, Oregon and British Columbia. NOPP is providing primary funding for this project. The NEPTUNE website is *http://www.neptune.washington.edu/*
- In the Mid-Atlantic, the Long-Term Ecosystem Observatory in 15 meters of water (LEO–15) has been under development for several years with most of the funding coming from NSF. LEO–15, operated from a field station in Tuckerton, New Jersey, and incorporates biology, geology, chemistry and oceanography through the monitoring of the marine environment at a depth of 15 meters. With the application of in-situ technology and satellite imagery, a better understanding of current systems and the associated sediment transport can be acquired, which may provide invaluable insights into areas suffering from recurrent hypoxia. Several projects in the Southeastern United States are now being planned. The LEO–15 website is *http://marine.rutgers.edu/cool/*
- Woods Hole Oceanographic Institution is currently developing the Martha's Vineyard Coastal Observatory for Meteorological & Oceanographic Studies. The Observatory's website is *http://www.whoi.edu/science/AOPE/airsea/observatory.html*
- NOAA and other agencies are funding the ARGO buoy program. These drifting profiling buoys provide data about temperature, salinity and current over large geographic areas, and relatively inexpensive to deploy and operate. The ARGO website is *http://www.argo.ucsd.edu/*

- The Gulf of Maine Ocean Observing System (GOMOOS) provides data for the New England coast. The Navy provides most of the funding for this project. The GOMOOS website is *http://www.gomoos.org/*
- NOAA operates tsunami warning buoys as part of the Tsunami Hazard Mitigation Program, a partnership between NOAA and several state governments. The Program's website is *http://www.pmel.noaa.gov/tsunami-hazard/index.html*
- NOAA operates Physical Real Time Oceanographic Systems (PORTS) that provide real time tide and current data at several major U.S. ports. The PORTS website is *http://www.co-ops.nos.noaa.gov/co-ops.html*

It is clear from this sampling of sites that coordination of coverage, and data comparability and storage are important issues that must be addressed.

OCEAN EXPLORATION

On June 12, 2000, President Clinton directed the Secretary of Commerce to convene a panel of experts to formulate a national strategy for ocean exploration. The Secretary did so, and on October 10, 2000, presented to the President the Report of the President's Panel on Ocean Exploration. This Report presents specific recommendations to increase the amount of time and funding that is available to carry out ocean research, actions to create a strategic plan, and highlights the need for a multidisciplinary exploration program for the U.S.

The Panel found that much of the ocean has not been subjected to scientific review, and that no specific program existed to fund and coordinate ocean exploration in the United States. The Panel recommended: 1) the mapping of the physical, geological, biological, chemical and archaeological aspects of the ocean; 2) exploring ocean dynamics and interactions at new scales to better understand the complex interactions of the ocean; 3) developing new sensors and systems for ocean exploration to regain a U.S. lead in marine technology, and; 4) reaching out to stakeholders and better educate all ages about the oceans through new methods of information dispersal. The Panel recommended a 10 year/$75 million per year program of dedicated exploration voyages to accomplish these goals.

After the report was delivered, NOAA established an Office of Ocean Exploration within the Office of Oceanic and Atmospheric Research. In fiscal year 2001, $4 million was appropriated to NOAA for ocean exploration. NOAA used this money to leverage existing ocean research initiatives including east coast research on the ALVIN, and work in the Gulf of Mexico, the Astoria Canyon off the mouth of the Columbia River, and at the MONITOR excavation site.

For fiscal year 2002, NOAA has requested $14 million for ocean exploration. This money would be invested in undersea exploration, research and technology in the deep ocean and areas of special concern. NOAA specifies that the money requested would support goals fully consistent with the recommendations of the President's Panel on Ocean Exploration. The new exploration effort would focus on five areas: new ocean resources, exploring ocean acoustics, American's maritime heritage, exploring ocean frontiers, and the census of marine life.

All the projects proposed in Fiscal Year 2001 and 2002 are conducted in partnership with other NOAA and Federal programs as well as academic institutions, and nongovernmental organizations. Recommendations for partnerships must also include a broader organizational strategy to ensure the needs of all the partners are met. The Panel suggested the President instruct the White House Science Advisor and appropriate Cabinet officials to design a management structure so that it is a recognized uniform process as ocean exploration expands and more interests become involved.

To encourage development of potential opportunities and new resources, the Panel recommended U.S. laws be reexamined to provide proper incentives for potential commercial users of ocean discoveries. Possible actions include: increasing funds to federal agencies to support early-phase research on discoveries with commercial potential; providing incentives to private industry to encourage the funding of research and development of discoveries with commercial potential, and; designing mechanisms whereby those who directly profit from the exploitation of marine resources support research on their environmentally sustainable use.

Finally, the Panel advocated a new national Ocean Exploration Program to permit exploratory expeditions because the initial phase of oceanographic discovery ended before the oceans were fully explored and new tools now exist that allow exploration in dimensions that were unachievable 50 years ago when oceanographic research expeditions were still broad based, and multidisciplinary. An exploration program differs from research that is currently being done in that an exploration expedition has no specific idea or theory it is gathering data to prove or disprove. An expedition would gather as much interdisciplinary data as possible about a site rather than just explore a single aspect of the site.

ISSUES

1) What funding did each of the Navy, NOAA and NSF request in Fiscal Year 2002 for ocean and coastal observing systems?
2) What are other countries contributing to the integrated ocean observing system? Is there an international structure in place to coordinate the contributions of various nations?
3) Will the ocean observing system help sort out natural versus human induced contributions to climate variability? How can additional ocean and coastal observation data and technologies best be integrated with existing meta data and observation technologies used to monitor global climate change?
4) How will data be retrieved from the various platforms to be deployed in the integrated ocean observing system?
5) What ocean and coastal observations can be made by satellites?
6) How will agencies coordinate information exchange so that the same research is not undertaken multiple times, including military research in areas that might have national security interests but also biological, chemical, geological or other area importance also?
7) To what extent can Department of Defense assets and data be utilized for greater civilian use in exploration and monitoring?
8) What new technologies should be developed to enable a more expansive and comprehensive ocean exploration capability?

Ocean Exploration and Coastal and Ocean Observing Systems

Chairman EHLERS. I am pleased to call this meeting to order. We just did a little re-juggling. The problem is we have a vote on the floor. We had planned to go and vote immediately and come back, but now, we discovered that there is going to be a second vote because there is an attempt by one of the parties, which shall remain unnamed, to delay things today. And so we decided to go with the opening statements and then we will—whenever we have to leave for the first vote, we will leave, try to get both votes and come back as quickly as we can.

I am Vernon Ehlers. I will also be sharing the Chairmanship with Mr. Gilchrest of Resources Committee and with Mr. Smith of the Research Committee—the Science Committee. And so I will begin with a fairly brief opening statement.

I want to thank my friends and colleagues, Chairman Gilchrest and Chairman Smith for working with me to put together this Hearing. I will keep my remarks brief, as we have many distinguished witnesses to hear from today. However, I must mention while it took me seven years before I was able to chair a Hearing in this room, it has taken Mr. Gilchrest only one month as the newest member of the Science Committee. That is what we call rapid advancement. We recognize talent when we see it.

But this is a Hearing that I have wanted to put together for some time. And I talked to Mr. Gilchrest about it months ago and said, oceanography and ocean sciences is too badly split. We have to put it together and this is our first attempt to do that.

Ocean science is clearly a topic that transcends jurisdictional lines. But that appears to be one of the biggest obstacles to advancing ocean science, whether in exploration or the creation and integration of ocean observing systems. While our subcommittees have made a commitment to work more closely together, we also need further cooperation and coordination among the various Federal agencies and the research community, in general, on ocean science issues. The problem is not just Congressional Committees, but also the Federal structure and the research community's interest.

With limited financial resources dedicated to ocean research, we must agree on specific priorities to achieve goals. I am particularly interested in how an integrated National and International ocean observing system will promote our understanding of climate change. Oceans are clearly a poorly understood but critical piece of our efforts to model climate change. Obviously, we must agree on what data needs to be collected, by whom and how in order to improve our climate modeling efforts.

After reviewing the written testimony, I am concerned about the seemingly disparate efforts toward this aim. I also want to make sure that that data and the information collected, analyzed and stored for all parties to use effectively. This is no simple task.

I hope that our witnesses will help provide some guidance on where our subcommittees can work together to help the ocean science community achieve a consensus on where to allocate resources and how to move these issues forward.

We will simply proceed down the line. I will next recognize Chairman Gilchrest for his comments—opening statement.

[The prepared statement of Vernon J. Ehlers follows:]

PREPARED STATEMENT OF THE HONORABLE VERNON J. EHLERS

I want to thank my friends and colleagues, Chairman Gilchrest and Chairman Smith for working with me to put together this hearing. I will keep my remarks brief as we have many distinguished witnesses to hear from today. However, I must mention that while it took me seven years before I was able to chair a hearing in this room, it has taken Mr. Gilchrest only one month as the newest member of the Science Committee.

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I hope that our witnesses will help provide some guidance on where our subcommittees can work together to help the ocean science community achieve a consensus on where to allocate resources and how to move these issues forward.

Mr. GILCHREST. I thank Mr. Ehlers—Dr. Ehlers, Chairman. I ask unanimous consent that my full statement be submitted to the record.

Chairman EHLERS. Without objection, so ordered.

Mr. GILCHREST. And basically, welcome all the witnesses here this afternoon. We look forward to your testimony. We do live on this infinitesimal blue-and-white speck in the midst of an infinite hostile environment upon which we have no place to go. So it is important to us, very simply, to take upon ourselves a difficult, complex task of taking care of our home.

I think we have the ability to do it. Richard Leakey said in his book, *Origins,* some 25 years ago, that we have the genetic predisposition for cooperation. So that we can include that understanding in the various Federal, State, local, private sectors initiative to understand the cooperative effort that will reveal a great deal about the heart and blood of the planet. And the co-evolution of species, along with the wonders and the mysteriousness of our blue oceans. We will get the job done. And succeeding generations will be very pleased with that effort. Whether it is sustaining the fishing industry by sustaining the fisheries in an ecological way, to understanding the nature of man's activities in the atmosphere and the climate. All these things can be done and now is the time to do it.

I thank Mr. Ehlers. I was here, though, in 1991, Vern. So it has taken me quite a long time, even though I left the Committee for a while. But I appreciate the rapid advancement.

[The prepared statement of Chairman Gilchrest follows:]

PREPARED STATEMENT OF THE HONORABLE WAYNE GILCHREST

Today's hearing follows up on efforts over the last three Congresses to improve interagency cooperation in oceanographic research, and on implementing an integrated, sustained ocean observing system. As a result of those hearings,

- Congress created the National Ocean Partnership Program, and,
- the ocean partnership agencies have
    - developed a plan for implementing an ocean observing system; and
    - created an office called Ocean.US [Ocean-dot-US] to coordinate the Federal ocean observing efforts.

I look forward to hearing today what progress we can look forward to in the near future on making the planned ocean observation system a reality. In other words: where's the money.

This hearing will also look at how to coordinate the work of current and proposed coastal observing systems. Data from these systems can greatly improve our ability to monitor and predict significant short and long changes in the coastal environment. Such knowledge can improve natural resources management, and lessen the damage from storms and other natural phenomena.

However, the data from these systems needs to be consistent and readily available in order to be useful. Clearly, the Federal government should assume this data comparability and access responsibility. I look forward to hearing how the ocean partnership agencies intend to fill this role.

Finally, this hearing will examine implementation of the Report of the President's Panel on Ocean Exploration. It is estimated that we have explored less than 5% of the ocean. However, since World War II broad-based interdisciplinary oceanographic research voyages that looked at all aspects of the ocean environment have been replaced by increasingly narrow single purpose research enterprises. This level of specificity has lead to great leaps forward in the understanding of ocean processes. However, these narrow efforts have failed to capture the public's imagination.

This failure may help to explain the extraordinary disparity in funding between ocean research and space and health research. Unfortunately, with the exception of a limited, though spirited, response from NOAA, the ocean partnership agencies have chosen to hide behind their narrowly focused mission needs rather than look at how to coordinate those needs and create interdisciplinary missions that may spark public interest and support. I hope we will hear today how such missions can be created without diverting or wasting limited agency resources.

We have a long afternoon ahead of us, but, given our distinguished witnesses breadth of experience in and knowledge about ocean exploration and research, it should be a very interesting day.

Chairman EHLERS. Yes. Thank you.

Mr. GILCHREST. I yield back the balance of my time. Thank you.

Chairman EHLERS. Thank you. We—the normal process is to recognize the Ranking Members, but the Ranking Members for the other Subcommittees have not come. But let me just, in the interest of fairness, turn next to the Congresswoman from Texas, Ms. Eddie Bernice Johnson, for her opening statement.

Ms. JOHNSON. Thank you, Mr. Chairman. I would like to ask for unanimous consent just to submit my full statement and simply say——

Chairman EHLERS. Without objection, so ordered.

Ms. JOHNSON. Thank you.

The oceans encompass seventy percent of our planet's surface and are the last frontier on earth to be explored, but we spend most of our time on 30 percent, which is ground level. And every now and then, we are reminded of the importance of the oceans when our weather patterns shift to El Niño, when commercial fish catchers decline, when our beaches are closed due to red tides and when pollution-related problems threaten the quality of coastal waters. We don't always give it the kind of attention needed. So I am very pleased that these Subcommittees are going to bring our efforts together to do that. I do think it is an important area. Thank you very much.

[The prepared statement of Eddie Bernice Johnson follows:]

PREPARED STATEMENT OF THE HONORABLE EDDIE BERNICE JOHNSON

I want to join my colleagues in welcoming our witnesses to this hearing on ocean exploration and ocean observing systems.

The oceans encompass 70% of our planet's surface and are the last frontier on earth to be explored. Since most of us spend our time on the other 30% of the earth's surface, we tend to focus more of our attention and research efforts on it.

Every now and then, we are reminded of the importance of the oceans when weather patterns shift due to El Niño, when commercial fish catches decline, when our beaches are closed due to red tides, or when pollution-related problems threaten the quality of coastal waters.

I am pleased that our three subcommittees are focusing their attention on this important area today. We will review the research opportunities that are now available. In doing so, we need to consider whether effective coordination and collaboration exists among the relevant federal research agencies, and whether the required resources are available to exploit those research opportunities.

I look forward to hearing from our witnesses, and I thank all of you for being with us this afternoon.

Chairman EHLERS. I thank the gentlewoman for her comments. We will recognize Chairman Smith for his opening statement.

Mr. SMITH. Thanks to all the Ranking Members of these committees and, certainly, the Chairmens of these committees. We held a—just about exactly 12 months ago, we did hold a Hearing on this subject. We have much still to learn. And, Mr. Chairman, also without objection, I would ask that my full statement be entered into the record.

Chairman EHLERS. Without objection, so ordered.

Mr. SMITH. As we explore more of the processes that drive the ocean and are driven by the ocean, it becomes apparent how much more we have to learn. And so I welcome this opportunity to examine all of these ways and I look forward to the testimony.

National Science, Dr. Colwell, of course, National Science Foundation is one of the keys in the funding of this area. In fact, of the four major Federal agencies that play a role in ocean sciences, the NSF, the U.S. Navy, NOAA, the National Aeronautics and Space Administration, NSF contributes the largest share. About $255 million. It is an important aspect and if there is any area that we need to pursue aggressively in terms of our knowledge and understanding, it is certainly this area of our earth and planet. And I yield back, Mr. Chairman.

[The prepared statement of Nick Smith follows:]

PREPARED STATEMENT OF THE HONORABLE NICK SMITH

Thank you, Mr. Chairman. Twelve months ago, at a joint hearing of the Subcommittees on Basic Research and Energy and Environment covering some of the issues we will examine today, I said, "If our oceans are a window on the life on our planet—and elsewhere—we have only just parted the curtains." Judging from the written testimony our witnesses have submitted, the statement is correct and we have much to learn. As we explore more of the processes that drive the ocean and are driven by the ocean, it becomes apparent how much more we have to learn. And so I welcome this opportunity to examine the way in which we manage the federal role in that exploration effort.

A key part of that effort is enabled by funding from the National Science Foundation. In fact, of the four major federal agencies that play a role in the ocean sciences—NSF, the U.S. Navy, NOAA, and the National Aeronautics and Space Administration (NASA)—NSF contributes the largest share, about $255 million. And, in light of the recent developments with the VA–HUD appropriation legislation, it appears that amount is likely to increase. So I am interested in how NSF views that investment and its role in the overall ocean exploration effort.

I am also very interested in examining how effectively the agencies represented here today—and all the agencies involved in ocean science—coordinate their research efforts. We must make the best use of the resources available at each agency. How would future research efforts like the Ocean Observing System or the Oceans Exploration program be implemented at each agency?

We have much to learn about how our oceans work including how they drive and shape our climate. In fact, it is clear that predictions about future climates are not reliable. So I am pleased that we will review our knowledge about oceans today, and talk about ways to increase it. I want to thank all of our witnesses, and I look forward to the testimony.

Chairman EHLERS. Thank the gentleman for yielding back. And I next recognize Mr. Underwood, who has probably come from the area most surrounded by water of any member.

Mr. UNDERWOOD. Well, thank you, Mr. Chairman. And, of course, oceans are very important to Guam. And I know it is frequently—the comment is made that I don't know, I guess some—a majority of our population lives within 50 miles of the ocean. 100 percent of my population lives within 4 miles of the ocean, so it is very important. But I have a statement that I will submit for the record.

I would just make one observation. NASA scientists said yesterday that they have found signs of water around a distant star, suggesting that there may be planets outside of our own capable of supporting life. How spectacular that is that we may have found water in space with life-sustaining capabilities, yet we don't really know all the life which exists in our own oceans.

While this doesn't prove that we have confused priorities, it certainly suggests that we need an ocean exploration strategy for planet Earth. Thank you.

[The prepared statement of Robert Underwood follows:]

PREPARED STATEMENT OF THE HONORABLE ROBERT UNDERWOOD

Thank you, Mr. Chairman. Some of the finest minds in ocean exploration, observation and research are with us today, which says a lot about the growing importance for Congress to develop a comprehensive ocean exploration and observation policy.

If there is one thing we can all agree on, it is that not enough is known about the oceans that cover 70% of the Earth's surface. This includes the more familiar waters immediately adjacent to the continental United States, and the lesser known portions of the EEZ further off-shore in the Western Pacific.

In recent years, a number of thoughtful reports, such as the President's Panel Report "Earth's Final Frontier: A U.S. Strategy for Ocean Exploration" and "A National Initiative to Observe the Oceans," prepared by the Consortium for Ocean Research and Education, have been circulated. These reports demonstrate that there is a legitimate need for a more robust national ocean exploration and observation program. There should be greater incentives to encourage cooperation across sectors in order to bring together the strengths of the Federal and non-Federal sectors. Most importantly, there is a need to establish a long-term Federal commitment to ocean exploration and to build and deploy a cohesive ocean observing system.

From the Resources Committee perspective, we ought to ask how a focused ocean exploration program or an integrated observation system would benefit the management of ocean resources, in particular biological resources such as fisheries. Where or what is the appropriate link from ocean exploration and observation to resources management?

The plans for ocean observation and exploration that have been brought to my attention focus on the general, large-scale picture. But it remains uncertain how the actual implementation of these programs would incorporate the expertise of local island communities, particularly researchers and resource managers in the Western Pacific. Local knowledge and capabilities should be tapped or we are missing something important in the equation for getting the most out of this investment in technology.

Finally, while we are developing this new program, we must ensure that the benefits of this investment in new technology for ocean exploration and observation is understood by the common citizen, not just scientists and researchers. For without broad public support, it will be impossible to sustain any long-term strategy. Thank you again, Chairmen, for holding this joint hearing and I look forward to the suggestions that our witnesses have worked so hard to produce.

NASA scientists said yesterday that they have found signs of water around a distant star, suggesting that there may be planets outside of our own capable of supporting life. How spectacular is that—we may have found water in space with life-sustaining capabilities, yet we don't even know what life exists in our oceans! While this doesn't prove the U.S. has confused priorities, it certainly suggests that we need an ocean exploration strategy for the planet Earth.

Chairman EHLERS. Thank you for the statement. We have two minutes and 33 seconds left to make it to the vote. So we stand in recess.

[Recess.]

Chairman EHLERS. The Hearing will come to order. I had intended to wait for all the other Chairmen to return, but let us begin. We have with us—joining us, Mr. Weldon, who is an active member of this Committee. And I believe, also, another—are you in Resources, as well? Natural. Okay. And who—he was a leader several years ago and, in fact, when my early years in the Congress. What I am trying to put together is a bill covering ocean research and oceanography, an immense, Herculean effort and Mr. Weldon is very active, very hard-working and I appreciate his effort on that. I would give him an opportunity to give an opening statement.

Mr. WELDON. Thank you, Mr. Chairman. And I applaud you and the other Subcommittee chairs for this Hearing. In fact, it was six years ago that we, in fact, had three full Committees join together, the Armed Services Committee, of which I have been a member for 17 years, the Science Committee, which I have been a member and the Natural Resources Committee. We held three Hearings around the country. One up in Rhode Island, one out in California and one here in Washington, on the whole issue of oceanographic research. And what we found during those Hearings was the fact that we had a disjointed effort that was not coordinated among our Federal agencies. In fact, at that time, we had nine separate Federal agencies. Each of which had at least a partial function involving ocean research. And not that I want to distort my good friend, Nick Smith, but I believe the largest funder of ocean research is actually the U.S. Navy, if I am not mistaken. And Admiral Cohen, you can correct me if I am wrong.

So as a result of those Hearings, what we did was we introduced that National Oceans Partnership Act, which Patrick Kenney and I co-sponsored. That did become law as a part of our Defense Bill. And actually was the vehicle to bring together, through dollar allocations, the nine Federal agencies involved in ocean research. Since the formation of NOPP, we have actually increased that, I believe, by two additional agencies. Our panelists can discuss that today. And we have begun to raise the awareness and the coordination of the need for more ocean cooperation.

As another direct result of that action, we formed the Oceans Caucus. The Caucus now has four co-chairs, two from each party.

I am one of the co-chairs and we now have about 60 Members of Congress who have agreed to work on an oceans agenda.

We also work very closely with Admiral Watkins, who could not be here today. He was Admiral Cohen's predecessor. Well, actually, the CNO, I should say. Admiral Gaffney was his predecessor. And working with Admiral Watkins, he, in fact, led the formation of the consortium for oceanographic research and education. Which for the first time, brought together all the Nation's oceanographic research institutions. From Woods Hole to Scripps, to all of those major universities that have a stake in ocean research.

So I would say, Mr. Chairman, that since the initial effort in 1995, there has been, in fact, significant progress. The focus on ocean research and the needs of our oceans has significantly improved. We have held several International Hearings and conferences in this country, one involving 200 delegates from 35 nations where Speaker Gingrich and Vice-President Gore, on the same day, spoke about the need for more proactive effort on the oceans.

The problem has been two-fold. First of all, we have a Federal agency system that requires us to try to bring together 11 separate and disparate agencies. The NOPP Program has begun to provide that coordination. And it is a beginning, but it is not enough. The New Oceans Commission, which I hope you all speak to today, in fact, should take that one step forward. I would be remiss if I didn't say I am somewhat concerned that the administration of which I am a strong supporter, has not moved, in my opinion, quickly enough to one, appoint the Ocean Commissioners and to name a Chairperson. In fact, during the questioning today, I will propose some ideas that I have about that function and that position. And hopefully, convince Admiral Watkins that he should step to the plate, if he would so desire and lead that effort.

The second problem is the Congress. We have a number of Subcommittees and full Committees that have various parts of jurisdiction on ocean issues. I chaired the Research Committee for National Security, which had a major chunk of that for six years. I now Chair the Readiness Committee. I have a separate chunk of those operational dollars. We need to find a way in the Congress to convince the leadership to allow us to bring together, as you are doing here, an ongoing legislative agenda focused around an oceans agenda.

Because the problems of the oceans are real. They are severe. There are many opportunities for us. You are going to be exploring one of those today. There are many other opportunities that we should be using. It is also a way for us to build coalitions with some of our potential adversaries. In particular, Russia and China. Where we can, in fact, work together on a common oceans agenda.

So I would applaud these Subcommittee chairs for this Hearing. I would say as a senior member of the Armed Services Committee and a senior member of this Committee, I will continue to be an outspoken voice for further cooperation, so that we, in fact, have a coordinated oceans agenda hopefully led by the new Oceans Commission with the kind of coordinated support that you are seeing from these panels. And trying to make sure that legislatively, we are putting more resources into the oceans.

Sylvia Earl, who is probably one of the most renown people on the oceans in this country, when she was the Chief Scientist for NOAA, she used to say that we spend more on the development of the waste removal system for our space launch capability than we do on studying the oceans. We spend more on studying the oceans of Mars than we do on studying the oceans of the U.S. That is an absolutely unacceptable reality. And we have got to change that.

So hopefully, this Hearing will help continue what I think has been a very positive movement over the last several years to bring forth the more coordinated and positive and cohesive agenda on the oceans and how the U.S. can affect, in a positive way, that agenda. Thank you, Mr. Chairman.

Chairman EHLERS. I thank the gentleman for his comments and for all his hard work in this issue over the years. And I hope that, indeed, this is the first step toward creating the agenda that you are referring to.

It is the policy of the Science Committee that the Chairman and Ranking Members make opening statements, that all other statements be entered into the record. I exceeded that only for Mr. Weldon because of his long-standing role in this. And if a member of the minority wants to make an opening statement to counteract that, I will be happy to recognize Mr. Faleo for—sorry. John Wayne Vega.

Mr. FALEOMAVAEGA John Wayne is just fine, Mr. Chairman.

Chairman EHLERS. You actually look like him.

Mr. FALEOMAVAEGA. He's more handsome.

Chairman EHLERS. You may proceed.

Mr. FALEOMAVAEGA. Mr. Chairman, thank you for the opportunity. And I, too, would like to echo your sentiments and express my sense of appreciation to the gentleman from Pennsylvania for his leadership and tremendous efforts in raising a higher sense of consciousness, not only among the members, but certainly in our National policy about the importance of the ocean.

And probably no two members can appreciate more what the ocean is about than myself and the gentleman from Guam. Where every time we have to travel to our home districts, we have nothing but the ocean. Not only is the Pacific Ocean $\frac{1}{3}$ of the Earth's surface, but culturally and historically, our people have always been part of it and in a very historical and in a very personal way. A couple of years ago, maybe 10 years ago, I was privileged to sail on a Polynesian voyaging canoe from Tahiti to Hawaii. Non-instrument navigation without sextants and all of that, Mr. Chairman. We used the stars, as it was done by my ancestors thousands of years ago. And we do have a very, very close affinity and association with the ocean.

Unfortunately, it has been my observation, and I think our National policy toward the ocean has always been military and strategic. I think we need to get away from that, even though it is important, as it is. But the fact of the matter is, and I am sure that this has already been stated. We are able to land a man on the moon, but we don't even know what is underneath—in the ocean. Now, let alone the Marianas Trench and the Tohman Trench, some of these resources have diminished potential on some of the things that we need to look into, very, very valuable and important.

And I think from this perspective, Mr. Chairman, two—a classic example, in my opinion, in the years that I have followed the issues of the oceans, policies of our Nation, we have a National Program known as a Sea Grant Program with an annual appropriation of only $60 million a year that is supposed to give some sense of understanding and appreciation of our communities about the ocean and the viability and the importance of it not only as a resource, but so many other programs that we can do in association with the needs of our country. Compare that to the Land Grant Program that gets well over $1 billion in funding. And I am not putting down the Land Grant Program, Mr. Chairman, and its importance.

The fact of the matter is that this is an area that—and I am talking about the oceans and the resources—we—our Nation is far behind what other Nations in the world are going into, not only in developing technology, not only in learning from the resources of the marine environment, the fisheries and so many other things that we know we must understand a little more in appreciation of this valuable resource. We are not ahead, in my humble opinion, as far as if we compare ourselves comparatively to other countries.

I say this, also, with the real sense of concern about the seabed minerals. The law of the Sea Conference has real, serious implications, especially in the area Mr. Underwood and I represent. I can cite you an example, Mr. Chairman; the Cooke Islands government. I know many people who probably never heard of the Cooke Islands. It is a little island with about 30,000 people, but three million square miles of jurisdictional ocean and as equivalent, a value over $200 billion estimates of the seabed nodules that contain magnese, cobalt, nickel. These are the kinds of things that I think that nothing has been done about, as far as our National policy is concerned, Mr. Chairman. And I hope in your efforts as Chairman of the Science Subcommittee that relates to this, let us push oceans a lot better and with greater intensity as we have done in the past. Thank you, Mr. Chairman.

Chairman EHLERS. Thank you for your comments. And we—I am pleased that the Pacific Islands and the Pacific Oceans are so well-represented here. Without objection, all other statement—opening statements will be entered into the record. And we will proceed with our panel.

PANEL I: SCOTT B. GUDES, DR. RITA R. COLWELL, ADMIRAL JAY M. COHEN AND ADMIRAL CONRAD LAUTENBACHER, JR.

Chairman EHLERS. We are pleased to have an outstanding panel here. Mr. Scott Gudes, Acting Undersecretary for Oceans and Atmosphere at the Department of Commerce. Dr. Rita Colwell, Director of the National Science Foundation. Admiral Cohen, Chief, the Office of Naval Research at the U.S. Navy. And Admiral Lautenbacher, who is the President of the Consortium for Oceanographic Research and Education. Sometimes called CORE. When I was a student at Berkeley in the sixties, there was another CORE that I became better acquainted with.

It is a pleasure to have you all here and I thank you for taking the time and we will just simply go down the line. Mr. Gudes?

STATEMENT OF SCOTT B. GUDES, ACTING UNDERSECRETARY FOR OCEANS AND ATMOSPHERE, DEPARTMENT OF COMMERCE

Mr. GUDES. Good afternoon, Chairman Ehlers, Chairman Gilchrest, Members of the Subcommittee and Staff. On behalf of Secretary Don Evans and the men and women who make up NOAA, it is my pleasure to represent all of them here today to talk about a few issues that are at the core of NOAA's mission. We are talking about a different core: ocean exploration, ocean observations and coastal observations. And I should note, as I was listening to the opening statements, there are a number of other issues in the oceans that are of great interest to us, from Sea Grant, the marine sanctuaries that we talked about. But I was asked to talk about these three areas. And that is what my testimony will revolve around.

The President's budget includes some $170 million for these programs in fiscal year 2002 to conduct NOAA activities in these areas. And I want to thank the Resources and Science Committees for your strong support for them. But, Mr. Chairman, I want to note at the outset that my own view is that these are interrelated subjects. That they are really all about understanding the oceans. So let me turn first to ocean exploration and our role at NOAA.

Ocean exploration is an area that NOAA takes very seriously and I believe it is an area, frankly, where we really haven't stepped up to the plate of what the original mandate was for NOAA when we were created in 1970 by the Stratton Commission recommendations. It is an area of personal interest to me. In fact, this Monday, a few days ago, I was over at the Monitor Marine Sanctuary in North Carolina, watching the joint Navy/NOAA effort to recover elements of that wreck. Most people know the ironclad from 1862. It was the first National Marine Sanctuary in our system. And it is really a great example of joint agency efforts on the oceans. Literally, after this hearing, I am going to be flying off to Oregon to be in Newport tomorrow morning to welcome back an effort by Oregon State University and other researchers in NOAA. It is an exploration mission of the Astoria Canyon, which really continues the legacy of Lewis and Clark, if you will.

Last year, at Secretary Mineta's request, a blue ribbon panel of marine scientists and explorers was convened by the previous administration to review this Nation's efforts in ocean exploration. The panel was chaired by Dr. Marsha McNutt and included a number of prominent experts in the oceans, Dr. Bob Ballard. Both of those people are testifying on a later panel. It recommended the United States undertake a National program of ocean exploration and discovery, of which discovery and spirit are the real cornerstones. And we have set up an office of ocean exploration headed by Captain Craig McLean, who is here and Dr. Steve Hammond, our Chief Scientist, is here, as well, today.

On the slide before you are a few of those examples. That is Astoria Canyon and the Monitor. But also, is a picture—an image of a squid that was discovered in a joint NOAA, Texas A&M, University of North Carolina-Wilmington mission with Woods Hole's ALVIN Submersible in the Gulf of Mexico last year. Which makes the point of just how many species we really haven't discovered that we know are out there. This is just from a year ago.

Next slide, please. I have made the point to both of your Committees before, that for NOAA, the O in NOAA is not only the oceans—the saltwater around the United States—but it also includes the Great Lakes. That goes back to the very origins of our Agency. And NOAA and Dr. Bob Ballard jointly conducted an acoustic mapping and survey of shipwrecks and geological phenomena in our Thunder Bay National Marine Sanctuary in Lake Huron, Michigan. That is our newest marine sanctuary. My slide shows an image of the Montana, which sank in 1914. And, finally, about ocean exploration, I will just point out that we have set out the program so that 10 percent of any dollars that are appropriated by the Congress for this Program will go to education and outreach. Because that is a big part of what our NOAA Ocean Exploration Program is about.

Next slide, please. Turning to ocean observations. I want to make the point that we really don't have the same amount of measurements in systems in the oceans that we do on land. And I asked our satellite service yesterday to give me a recent image. I think that is from two days ago. I don't know if all the members can see that, but red are the land-based observations of the atmosphere. And in blue are the observations in the oceans just a few days ago. And it—it is not perfect as an image, but it does sort of represent this point that we have a lot more measurements on a daily basis on land than we do in the oceans. And that is part of what ocean observations and, frankly, coastal observations are about. It also points out another point that for NOAA, we are the Civil Operational Remote Sensing Agency.

We operate two types of satellite systems. And, in fact, ocean remote sensing is part of what we are about. And, in fact, it is also atmospheric measurements. Over the Southern oceans, it is our polar satellites, actually, that are the main source of data that we get for weather and climate around the world. Our polar satellites provide sea surface temperatures—there is an image for you there—on a daily basis. And the National Polar Orbiting Environmental Satellite System, which I have talked about before with both of the Committees, which is a partnership between the Department of Defense, NOAA and NASA, will really, also be an ocean satellite. And that will provide sea surface temperatures, ocean colors, scatterometry, if you will, surface winds and altimetry.

The next slide shows two observation programs that are important to NOAA. First, the TOGA TAO or atlas buoys that we maintain across the equatorial Pacific. This is how we are able to monitor and predict El Niño, La Niña and other ocean temperature changes. And on the upper right are the ARGO floats, which dive down to 2,000 meters, drift and surface while taking salinity, temperature and current measurements and then broadcast these data to satellites. The ARGO float then dives back down and drifts again for 10 days. I should note, again, this is an example of partnership. The ARGO floats' research and development was done at Scripps in California, with funding by the National Science Foundation. ARGO, if you will, is a radiosonde system or weather balloon system for the world's oceans. Our budget proposes about $8 million, which will get us up to 275 floats per year to get to this 3,000 worldwide system. And NOAA puts this funding out through the National Ocean Partnership Program or NOPP, along with the Navy, NSF and other agencies.

And to go back to the comments, I think, that were made by Congressman Weldon and others, NOPP is an excellent mechanism to bring all the agencies together. And I think that CORE does a super job in supporting this.

Let me just go to the last slide. I see that I am on the red light. I think this always happens when I get a chance to testify about the oceans, which I care about. It is about port systems—Chesapeake Bay. Let me just get to the final system on tsunamis. Just one thing we don't think about that much; our tsunami warning devices. These are if—I am not sure if they are coastal or ocean, frankly. They are out in the deep ocean, but they are about doing coastal hazards for communities. These were developed by the Pacific Marine Environment Lab. And they actually measure very minute changes in ocean pressure that enable us to tell whether or not earthquake generated waves or tsunamis are coming across so we can get warnings out.

About two weeks ago, I took part in the first Tsunami readiness program in Ocean Shores, Washington. I know there are members here from the Pacific. This is a big issue we don't talk a lot about on the East Coast. But it is a very big issue about coastal hazards and about using these observational systems to really protect life and safety.

There are a number of other issues I would like to talk about. But let me just thank you again, Mr. Chairman, Chairman of the— and all the members of the Subcommittee for giving us this opportunity today. Thank you.

[The prepared statement of Scott B. Gudes follows:]

PREPARED STATEMENT OF SCOTT B. GUDES

Good afternoon, Chairman Gilchrest, Chairman Ehlers, and Chairman Smith, members of the subcommittees and staff. My name is Scott Gudes, and I am the Acting Administrator and Deputy Under Secretary of the National Oceanic and Atmospheric Administration (NOAA). It is my great pleasure to be here this afternoon to testify on three important topics that are at the core of NOAA's mission-ocean exploration, coastal observations and ocean observations. NOAA believes that these three topics are components of one mission—to understand the complex dynamics—physical, biological and geochemical—that shape the world's oceans and Great

Lakes. History shows us that voyages of discovery-like Charles Darwin's expedition on the HMS BEAGLE, are often followed by longer term observation and monitoring efforts. I expect that our initial exploration efforts will also be followed by the implementation of ocean and coastal observing systems which will routinely collect, record and transmit data on the state of our fragile ocean and coastal regions. Conversely, I expect that our coastal and ocean observing systems will uncover secrets or anomalies that are beyond our ability to decipher and must be investigated further by targeted voyages of exploration.

Ocean Exploration

Thirty-one years ago, the Stratton Commission proposed the creation of an agency that we know today as the National Oceanic and Atmospheric Administration. In their final set of recommendations, the Stratton Commission included an entire chapter that indicated that this new ocean agency should develop U.S. leadership in ocean exploration. Over the last three decades, NOAH has successfully pursued a course of ocean management, ocean resource protection, and of primarily management-focused ocean research and monitoring. Much of our resources are consistently directed toward specific resource crises, and narrow scientific investigations. As a result, we know a lot about a few things, such as specific fish stocks and coastal water quality, but we actually know very little of our total oceans. Ocean science experts tell us that we have seen only five percent of the world's ocean, and that the U.S. lags behind Japan, France, and Russia in our technical ability to explore and study it in at least one dimension, sending scientists into the sea. The challenge of fulfilling the original Stratton Commission vision, of a NASA-like exploration of the sea component, remains to be filled. The President has requested $14 million for NOAA's ocean exploration activities in FY 2002 and these funds would provide NOAA with a solid start on fulfilling the Stratton Commission's original vision of exploring the seas.

In FY 2000, the President convened a panel that included some of the Nation's best ocean scientists, explorers, and educators. The panel, convened as a subset of the NOAH Science Advisory Board, was ably led by Dr. Marcia McNutt of the Monterey Bay Research Aquarium Institute and included Dr. Robert D. Ballard. The Panel's report, "Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration," recommended a new era of exploration which could become as remarkable and ambitious a chapter in the history of human exploration of our planet as were the achievements of Balboa, Columbus, or Lewis and Clark. While stressing the importance of partnerships, the panel recommended that a single lead agency be responsible for the program and its budget. NOAH, with over thirty years of experience in ocean science, management, and stewardship, has already stepped into a leadership role by requesting and receiving funding specifically to establish a program of ocean exploration and has established the NOAH Office of Ocean Exploration. I believe that NOAH has a significant leadership role to play in ocean exploration and in implementing the President's Panel Report recommendations.

The American public seems to agree that we need to focus more effort on exploring the oceans. In 1996, the Mellman Group conducted a nationwide survey to better understand the public's view of ocean policy issues. The results of that survey indicated that more than 80 percent of Americans believe our oceans are threatened by human activity, and 85 percent agree with the statement that the "federal government needs to do more to help protect the oceans." Seventy-five percent believe ocean exploration is more important than space exploration. With a $4 million appropriation in FY 2001, Congress endorsed the need for such a program; NOAA created a dedicated program, the Office of Ocean Exploration. The Administration has reaffirmed the requirement and requested $14 million in the FY 2002 President's budget. I am hopeful that as this budget makes its way through the Congress that the full amount is enacted. Clearly, most of us agree on the need to explore and understand this most important component of our planet and on the enormous impact it may have on all aspects of our daily lives.

The U.S. Panel on Ocean Exploration

First, and foremost, NOAH is the Nation's ocean and atmospheric agency and was created for that specific purpose. We have been given the responsibility for the focused study of the oceans and atmosphere and for the application of these findings to fulfill our stewardship role. As such, we are responsible in a clear and direct chain of command to the Cabinet level of the Executive Branch, the Secretary of Commerce, and enjoy the benefit of constructive guidance from multiple Congressional oversight committees. Our agency focus is to generate sound scientific knowledge and apply it to ocean and atmospheric issues. In this regard, we fill the appropriate role defined by the Panel as a focused lead ocean agency and accountable for results.

We are not alone in the ocean community, and we certainly do not work alone. Other agencies, such as the Navy and the National Science Foundation, are responsible for much larger subject matter areas and, perhaps, more challenging missions. The Navy goes to sea to understand that component of ocean science that will benefit our national security and keep our Nation safe. The National Science Foundation conducts scientific investigations in all environments, including the ocean, to promote the progress of science, generating valuable knowledge wherever it is found. Partnership institutions, such as the National Oceanographic Partnership Program (NOPP), serve valuable coordinating and implementation roles for such multilateral projects as the Argo Project, in further technology development, and in the coordinated handling and processing of oceanographic data. We look forward to addressing the data management and availability issues raised by the Panel through the National Oceanographic Partnership Program. We are also working through the National Oceanographic Partnership Program to achieve an ocean observation system. The role NOAA can fill in a national ocean exploration strategy is one of leadership. We responded to the challenge of the President's Panel by instituting a national program, embracing multiple partners of many disciplines, and creating the NOAH Office of Ocean Exploration.

NOAA's Response to the Report of the President's Panel on Ocean Exploration

The NOAA Ocean Exploration program identifies unknown areas of the ocean and seeks to reduce this information deficit. Specifically, the program targets the oceans in areas or subject matter that is missed or bypassed by our current management-focused science and subject matter driven research programs. The science activity in NOAA today, and largely throughout our thirty-year history, has been targeted to answer specific and necessary questions to support climate prediction, fisheries management, resource recovery, safe navigation, and environmental monitoring. NOAA's Ocean Exploration program takes a broader approach to scientific inquiry and subject matter, as the President's Panel suggested. We conduct multidisciplinary scientific expeditions to characterize ocean areas with modern technologies, employ sound scientific methodologies, and convey these results in an exciting and informative manner to the science community and the general public. The knowledge gained through exploration will extend our ability to conduct more focused research on a wider array of subjects and better perform our overall mission of ocean stewardship.

This year, FY 2001, we are engaged in a number of multidisciplinary expeditions in the manner suggested by the Panel Report. We are examining benthic communities along the east coast with the submersible *Alvin.* We are teaming up with the National Geographic Society to document the marine sanctuaries from Belize, through the Gulf of Mexico, to Cape Hatteras. At Cape Hatteras, with the U.S. Navy, we are rescuing the steam engine and turret of the famed Civil War ironclad, the *USS Monitor,* now a National Marine Sanctuary. And we are engaging some of the best technology in what I would describe as a definitional exploration cruise, in the Astoria Canyon. This is the basin into which the Columbia River flows, and where Lewis and Clark ended their amazing journey of discovery. We begin ours there. Using a commercial survey ship with multibeam and high frequency side-scan sonar, we have mapped the bottom at a new scale of resolution. The cruise will be completed tomorrow with the arrival in port of the NOAA Ship *Ronald H. Brown,* which has carried NOAH and university scientists with expertise in biology, geology, and geophysics, and the Canadian Remotely Operated Vehicle, *ROPOS,* which will have visually explored the canyon areas identified in the sonar surveys. The combination of these tools and combined disciplines will enable a more complete understanding of this dynamic part of the ocean that, although close to shore, is scarcely explored. We have several other projects underway, but I would prefer to return and report on their completion at an appropriate time and turn now to our implementation of the President's Panel Report.

Principal Objectives of the President's Panel on Ocean Exploration

The President's Panel on Ocean Exploration provided four principal objectives for a national strategy to achieve an invigorated ocean exploration program. These were: to map the physical, geological, biological, chemical, and archaeological aspects of the oceans; to explore ocean dynamics and interactions; to develop new sensors and systems for ocean exploration and regain U.S. leadership in marine technology; and to reach out in new ways to stakeholders.

Mapping: The Panel's recommendation to map the oceans is squarely within NOAA's domain, at least so far as the Nation's Exclusive Economic Zone (EEZ) is concerned. NOAA's precursor agency, the Coast Survey, was responsible for charting the Nation's marine waters, and NOAA continues this mission today. The United States has the largest EEZ of any nation in the world, over three million square nautical miles, but only five percent of the U.S. EEZ is mapped. As such, we agree with the Panel report's suggestion that NOAA increase its efforts to chart and map the Nation's EEZ.

Exploring ocean dynamics: The Panel identified the need to explore ocean dynamics and interactions at new scales. Our sampling methodologies, regularly applied throughout our decades-long data streams, do not fully sample the biota of the ocean. We use techniques that have only slightly advanced in the previous hundred years. While incremental progress in acoustic surveys continues, an invigorated ocean exploration initiative would allow the United States to become a leader in the use of this promising technology. NOAA is working with multiple institutions and agencies to explore the dynamics of submarine regions, such as deep sea hydrothermal vents, through partnerships with universities and the National Science Foundation. The President has requested funding that would allow NOAA to work collaboratively with the larger scientific community.

New technologies: The Panel identified the need to develop new sensors, technologies, and platforms. The merit of this recommendation is apparent. We clearly need new and improved technologies, devices, and craft to take our exploration of the oceans to a point not only beyond where we are today, but to a position of regained international leadership, a position we have lost. NOAA is working to advance undersea technologies through Ocean Exploration, the National Sea Grant Program, and the National Undersea Research Program (NURP). We look forward to working with academia, industry and the National Oceanographic Partnership Program to develop the new ocean sensors and technologies that the Panel recommended.

Education and outreach: The Panel recommended that ocean exploration reach out in new ways to stakeholders. Our own website, *oceanexplorer.noaa.gov*, has already proven a great success with thousands of students of all ages around the world tuning in, even though most schools have not even been in session since it launched on June 1 of this year. NOAA is allocating ten percent of our Ocean Exploration budget to education and outreach. I consider the education and outreach component of the ocean exploration program to be essential to the success of this initiative.

New Approaches and the Future of Ocean Exploration

The President's Panel also stressed the importance of partnerships for pooling limited resources and multiplying the accomplishments achieved from ocean exploration activities. We have engaged the university community, private industry, and other government agencies and services. In fact, less than half of NOAA's $4 million appropriation in FY 2001 for ocean exploration activities remained "in-house"; the remainder passed through the agency to the private sector, academia, or other agencies. We have chartered or engaged nine vessels belonging to the private sector or other agencies for our Ocean Exploration missions this summer. Those vessels ranged from University-National Oceanographic Laboratory System (UNOLS) sources, such as the Harbor Branch Oceanographic Institution, the Woods Hole Oceanographic Institution, Scripps Institution of Oceanography, and Monterey Bay Aquarium Research Institute, to commercial fishing vessels, private survey ships, and a commercial diving barge. We also gained support and participation from an EPA ship and two Navy salvage ships. This demonstrates NOAA's desire to work cross-agency, collegially, and through meaningful partnerships.

The President's Panel recommended several opportunities and implementation strategies, and I have detailed how NOAA is responding to these challenges. But NOAA is also embarking on exploration activities that will be based on the needs defined, in part, by the larger scientific community. Beginning in the fall of 2001, we will conduct a series of at least 6 regional planning workshops in the northeast, southeast, Gulf coast, west coast, Alaska, and Hawaii. Through this geographic distribution, we will learn from an integrated body of participants from academia, industry, and other government agencies about local and regional informational needs. We will identify those needs and knowledge deficits, prioritize them, and thereby generate a strategic plan and implementation agenda of exploring our oceans and the oceans of the world. The value of these workshops will be to represent the collective wisdom and experience of the combined scientific and technical communities and not those singularly in NOAA. I am confident that the product will be a well supported agenda of exploration.

In FY 2002, we will continue to take projects to sea and, hopefully, at a level supported by the funds requested in the President's budget. Much of this effort will be proposal driven and result from the peer review of proposals submitted by scientists and explorers from government, industry, and academia. The emphasis of this research and discovery-based science will be in five thematic areas: (1) New Ocean Resources—in which we seek to discover living and nonliving resources that may have a significant beneficial potential, such as gas hydrates or bioprospecting; (2) Exploring Ocean Acoustics—to expand the network of hydrophones monitoring marine sound of natural and human origin, thereby determining the effects of noise on marine animals, developing new methods of counting and identifying whales, and accomplishing the early detection of underwater seismic activity; (3) America's Maritime Heritage—in which we will survey, locate, and inventory shipwrecks and archaeological sites of historic interest, plus compile a National Shipwreck Inventory from which we can make informed management decisions; (4) Exploring Ocean Frontiers—for which we will employ modern technology to survey, characterize, and define diverse marine environments and the processes therein, particularly in areas not well known or understood; and (5) Census of Marine Life—in which we will join global academic and government institutions in collecting data on the distribution and abundance of marine organisms and improve our assessment capabilities.

NOAH led the effort to support and staff the President's Panel on Ocean Exploration. NOAA is the dedicated ocean agency of the Nation and is currently the only Federal agency administering and requesting specific funds for an ocean exploration program. We understand mapping. We have been doing it since 1807. We understand partnership. More than half of our appropriation for ocean exploration is being spent outside of NOAH, and our projects sail on ships other than NOAA vessels. We understand and support ocean education and outreach through such partners as the Jason Foundation, the National Geographic Society, and such esteemed ocean leaders as Dr. Robert Ballard, Dr. Sylvia Earle, and Jean Michel Cousteau. NOAH has a role in implementing the President's Panel Report on Ocean Exploration. That role is one of leadership, as the ocean agency, and as the ocean exploration program. It is one we will not do alone. It is one we cannot do alone. For us to regain the leadership position in the world community of ocean science, we must continue to work with the other Federal agencies, academic institutions, and private-sector industries. Working together, our national ocean exploration efforts will yield even greater results.

President Bush recently announced his intention to appoint 16 distinguished individuals to serve on the Commission on Ocean Policy. The Oceans Act of 2000 tasks this Commission to develop a report over the next 18 months to address a very broad range of oceans policy issues. These include existing and planned activities of State and Federal entities, facilities associated with private and public activities, and ocean and coastal resources. We look forward to following the efforts of the Commission and to working with other agencies to develop the National Ocean Policy required by the Act once the Commission completes its report.

Coastal Observations

I would now like to address the Subcommittee's request for information on developing and implementing a system of compatible coastal observatories. Throughout history people have had many reasons to settle by our coasts, and they have long recognized that the oceans critically affect human endeavors. Cargo, fishing, and military ships have always been affected by winds, waves, ice, ocean currents, as well as hurricanes and typhoons. Primitive observing systems were initiated centuries ago to measure and try to predict these phenomena.

As uses of the ocean and coastal waters increase, evidence of widespread impacts of these activities on land, the oceans, and the atmosphere is steadily mounting. These interrelated earth systems have been strongly affected by the direct and indirect consequences of human population growth, industrialization, and demand for natural resources. It is increasingly evident that changes in the environment need to be monitored, that effective action must be taken to mitigate damage based on these measurements, and that future changes to the environment must be anticipated.

A sustained coastal ocean observation program to detect, track, and predict changes in physical and biological systems and their effects is needed to measure not only the impacts of humans on the ocean, but also the impact of the ocean on human endeavors. The oceans are currently monitored far less effectively and completely than terrestrial systems; yet humans depend strongly on the sea as a source of food and for transportation and trade, among many other uses. Such a program would build upon integrated existing monitoring efforts by both government and academia.

NOAA's mission is to describe and predict changes in the Earth's environment and conserve and wisely manage the Nation's coastal and marine resources. An integrated coastal observing system is needed to monitor the "state" of the coastal ocean in order to understand and ultimately predict how the coastal ocean responds to weather, climate, and human activities. Just as continuous measurements of weather and climatic conditions are maintained on land, similar sustained measurements of the coastal ocean are required to monitor change and to assist in understanding and predicting its impacts.

It must be noted that there are already many U.S. coastal observing systems and monitoring programs in place that serve the needs of many users. It is equally important to state that these observing elements are not yet integrated and do not constitute a complete system. The systems provide data that help mitigate losses to life and property, enhance profits to industry, ensure national security, and provide information to mitigate anthropogenic changes to the environment. They are not, however, as cost effective or as useful as they could be, even at present levels of funding. These elements do not serve the complete needs of users. The Congress recognized these gaps and, in 1992, passed the National Coastal Monitoring Act calling for "a comprehensive national program for monitoring of the Nation's coastal ecosystems." However, lack of funding has limited progress. Today, growing needs add urgency, and advancing technologies make major improvements possible. An integrated coastal ocean observing system would serve better a much wider array of users.

There are many indications that coastal environments are experiencing rapid changes as a consequence of human activities. These include habitat loss and modification (e.g., wetlands, coral reefs, oyster reefs), coastal erosion, excessive accumulations of algal biomass, oxygen depletion, harmful algal events, fish kills, shellfish bed closures, declines in fish stocks, the growth of exotic species, chemical contamination, and the loss of biodiversity. These changes are making the coastal zone more susceptible to natural hazards, more costly to live and recreate in, and of less value to the national economy.

In the absence of scientific understanding of coastal ecosystems and how they change in response to human activities and natural variability, the formulation and implementation of environmental policies has become, and likely will be increasingly, controversial. Substantial advances in the predictive understanding of environmental changes in coastal ecosystems and their effects on people cannot be achieved in the absence of long-term and large-scale observations.

Nowhere do the missions of so many Federal and state agencies overlap as in the coastal zone, and this region is the subject of more monitoring and research activity than any other place on Earth. Yet we still do not have a predictive understanding how people are changing the environment and how these changes are affecting people (e.g., wetland loss and coastal flooding, hog manure and *Pfiesteria).*

Clearly, we must make more effective use of the combined resources/assets of Federal and state agencies (environmental monitoring for the purposes of research and management, fisheries stock assessment, habitat surveys, etc.), the private sector, and academia to get a clearer picture of the dimensions of change and make more timely and meaningful forecasts of changes and their impact.

The first step is to coordinate and integrate existing efforts to collect, manage and analyze data to minimize redundancy, maximize access to diverse data, and produce timely analyses that are useful to a broader spectrum of users. The second step is to enhance and supplement the observing to achieve a more comprehensive and useful view of changes and their impact.

Benefits of an Integrated Coastal Ocean Observing System

An effective, efficient, and useful coastal ocean observing system would:

- facilitate safe and efficient marine operations, ensure national security, support managing living resources, preserve healthy marine ecosystems, mitigate natural hazards, and protect public health;
- build upon existing coastal and ocean monitoring and be responsive to the needs of those who depend on the Nation's coastal waters for work, security, research, and recreation;
- provide sustained, continuous, long-term, reliable, and, as appropriate, real-time observations and analysis of ocean events and phenomena;
- provide a common set of parameters deemed to be in the national interest, using uniform methods and protocols, with augmentation as desired by regional and local concerns;
- provide a consistent national framework for regional efforts yet allow for flexible design at all levels; and
- engage and support a wide range of participants from Federal, state, and local governments; academia; and the private sector.

Future Plans and Needs of an Integrated Coastal Ocean Observing System

The first step in establishing a comprehensive coastal ocean observing system is to integrate existing data and networks and provide access to this data. Working through NOPP and the OCEAN.US Office, NOAA could coordinate with components offered by other Federal Agencies to provide the backbone of an integrated coastal ocean observing system. This effort could be initiated with coastal elements of existing national networks and could support additional National needs and/or needs identified through the regional efforts.

NOAA currently operates several relevant monitoring and observing systems that would contribute to this backbone for coastal ocean observing system. These include:

National Water Level Observation Network (NWLON), which includes approximately 175 continuously operating water level measurement systems, providing basic water level data for all coastal and Great Lakes states.

Physical Oceanographic Real-Time Systems (PORTS) operating at five extremely busy harbor entrances, provide measurements from water levels, currents, meteorological data, and water temperature in real time.

National Data Buoy Network provides real-time data on the sea state and meteorological conditions at buoys in the Great Lakes and coastal ocean, and the 60 shore-based *Coastal-Marine Automated Network* (C–MAN) stations provide similar information to NOAH, state, and private weather forecasters.

National Status and Trends Program measures the status and changes in levels and effects of toxic contaminants at about 280 locations in the U.S. Coastal and Great Lakes ecosystems. In addition, temporal trends are being monitored through the *Mussel Watch* project that analyzes mussels and oysters collected annually at about 200 of those sites.

National Estuarine Research Reserve System (NERRS) System-Wide Monitoring Program (SWMP) monitors physical, chemical, and biological parameters at each of the 27 Reserves, covering over one million acres of estuarine waters and lands. The President's Request for a $1.7 million increase for NERRS operational grants will help expand the SWMP by increasing spatial coverage of water quality stations, and by monitoring additional biological indicators.

Harmful Algal Boom monitoring program works in conjunction with states and other Federal agencies to monitor levels of toxic algae, including *Pfiesteria,* and related water quality properties to determine the threat posed to human health and the ecosystem by this organism.

Tsunami Warning System (TWS) in the Pacific, comprised of 26 participating international Member States, monitors seismological and tidal stations throughout the Pacific Basin, providing real-time information needed for the early detection of tsunamis and for assessing and forecasting the threat to coastal communities.

Land-cover and Habitat mapping. The Coastal Change Analysis Program (C–CAP), Effects of Fishing on Essential Fish Habitat (EFH), and Seafloor EFH Characterizations programs provide routine observations on the habitats of managed species.

Long-term ecosystem data collection programs, including the *California Cooperative Fisheries Investigation* (CalCoFI), the *Marine Monitoring and Assessment Program* (MARMAP) in the Northwest Atlantic, *SEAMAP* in the Southeast U.S., and the *Fisheries Oceanography and GLOBEC* programs in the Pacific Northwest, Gulf of Alaska, Bering Sea, and Gulf of Maine provide essential information on abundance and distribution of marine fish and invertebrates, and environmental changes which affect them.

Coast Watch provides near real-time access to high-resolution satellite remote sensing data from NOAH and other platforms, including sea surface temperature and ocean color.

The second step of a strong integrated National coastal ocean observation program would be support for a federation of regional observing systems that could provide additional full national coverage at higher-resolution, tuned to regional issues. These regional systems would collect and exchange data on a free and open basis and according to national standards and protocols. These regional enterprises composed of consortia of state, academic, private, and Federal partners would be most effective in understanding and responding to the needs of the regional users. Working with NOAA's national data centers, these regional efforts would also ensure that their observations are made available for long-term stewardship.

The third, equally important step is a strong Data Management and Data Sharing effort. This would include working with all of the relevant data stakeholders to develop standards and protocols for storing, sharing, and accessing coastal data. This should include protocols for the transfer of data among regional and national backbone systems, the user community, and a national repository; as well as the documentation of data type and quality via approved metadata standards. A key component of the data management program should be a coastal data portal through which users from all sectors should find, view, access, integrate, and share data from national, regional, state, and academic sources regardless of original formats. NOAA's National Environmental Satellites, Data, and Information Service and National Ocean Service stand ready to provide its extensive expertise and experience in data management, sharing, and archiving to all of its partners in this effort.

These enhanced coastal observation systems would serve as the basis for two programs. The first is a concept we are working with our partners to develop an ecological forecasting capability to parallel our weather and climate forecasting service. Ecological forecasts predict the effects of biological, chemical, physical, and human-induced changes on ecosystems and the components. Being able to forecast, for example, harmful algal bloom outbreaks, the impacts of decisions on coastal hypoxia (dead zones), the impacts of water use on oysters and other estuarine species, the impacts of changes in the distribution of precipitation and temperature on coastal habitats all depend on a robust and sustained observation system. Data from this system are required to both drive the forecasting process and test the forecasts against the real world.

The second is an initiative called Coastal Storms, for which we are asking $3 million in the President's FY 2002 Budget to do a pilot project in Florida. Coastal Storms proposes to build on and enhance existing coastal observation systems such as our National Water Level Observation Network and Physical Oceanographic Real Time System, to help dramatically reduce the loss of property and life in regions vulnerable to natural disasters. Recent estimates for disaster losses are between $10 and $50 billion per year, with an average cost of $50 million an event. Over 70% of disaster losses occur in coastal states or territories and much of this damage occurs in inland areas adjacent to the coast resulting in costly impacts throughout coastal watersheds. Coastal Storms will enable NOAH to provide an integrated suite of capabilities that capitalize on our coastal observations to predict and reduce the watershed impacts of coastal storms.

Partnerships

NOAA is committed to working with other agencies, academia, and the private sector in arrangements such as the National Oceanographic Partnership Program (NOPP) to make this coastal observing system a reality. NOAH worked hard with other agencies to facilitate the implementation of the NOPP Observation Office, OCEAN.US, for the coordination of these efforts. A strong partnership would allow each organization to execute its own research and/or operational-driven mission while deriving maximum benefit from interagency coordination.

Ocean Observations

Now I'd like to turn to a different category of ocean activities, in particular the essential observations necessary for understanding and predicting the ocean's role in climate. Last month, the President announced a new Climate Change Initiative, dedicated to reducing uncertainties in climate change knowledge and identifying priority areas where research can make a difference. Clearly, our observations of the ocean will be a major factor in clarifying the future course of climate change.

An important difference between ocean observations for climate and those for exploration is the sustained nature of the data collection. A useful analog is the system we use to observe the weather. We could not expect to predict the weather based on an occasional weather balloon or an intermittent Doppler radar image. It is necessary to keep the system going to see change on the horizon. Similarly, an ocean observing system must be sustained to see a developing El Niño or longer-term changes in ocean circulation that will influence the evolution of climate.

We have known for some time that we must observe the ocean to predict the course of climate, and NOAA has a strong track record in this endeavor. In 1997–98, the strong E1 Niño and its effects on the U.S. and the world were anticipated well in advance. By contrast, an El Niño of similar strength in 1982–83 was largely a surprise to the world. The difference in predictive skill was largely the result of an ocean observing system deployed in the tropical Pacific, together with the understanding and computer model development that was the result of decades of research. This provides the basis for our ocean observing system of today.

The Present System

Presently NOAA's major ocean observation system, centered on the tropics and designed to enhance climate prediction on seasonal to interannual time-scales, is the El Niño-Southern Oscillation (ENSO) Observing System. The ENSO Observing System has four elements. It consists of approximately 70 fixed buoys in the tropical Pacific that provide surface atmospheric and ocean mixed-layer observations, several hundred drifting buoys in all of the major ocean basins, a Volunteer Observing Ship (VOS) program of about 40 commercial ships, and a network of tide gauges. NOAH recently expanded the fixed buoy system to the tropical Atlantic sector, and has maintained a monitoring system for the Florida Current for many years. The resulting data are used to initialize climate models, verify model results, and monitor the changes in the upper ocean. Complementing this system are NOAA's environmental satellite systems, which provide regional and basin-wide observations of sea surface temperature and estimates of rainfall.

There is also an emerging observational system—called the Argo Array—that, in combination with satellite remote sensing, will provide the backbone of sustained global ocean observations needed to improve climate forecast skill. Argo will consist of three thousand autonomous instruments that can change their buoyancy to rise or sink in the ocean. Argo builds on the observations, extending their spatial and temporal coverage, depth range and accuracy, and enhancing them through addition of other measurements. For the first time, the physical state of the upper ocean will be systematically measured in near real-time and used in models.

Here's how Argo works. The instruments cycle to depths up to 2000 meters every ten days, travel submerged for a specified period, then surface and relay data to satellites about the ocean temperature, salinity, and currents. Each instrument has a four to five-year lifetime. With a design based on experience from the present observing system and on estimated requirements for climate and high-resolution ocean models, Argo will provide 100,000 temperature and salinity profiles and reference velocity measurements per year from the 3000 floats distributed over the global oceans. All Argo data will be publicly available in near real-time and in scientifically quality-controlled form within a few months. Essentially, the Argo array will be the ocean analog of the radiosonde—or weather balloon—system; it will initiate the oceanic equivalent of today's operational observing system for the global atmosphere.

Objectives of Argo fall into several categories. Argo will provide a quantitative description of the evolving state of the upper ocean and the patterns of ocean climate variability, including heat and freshwater storage and transport. The data will enhance the value of NASA's Jason altimeter through measurement of subsurface vertical structure and reference velocity, with sufficient coverage and resolution for interpretation of altimetric sea-surface height variability. Argo data will be used for initialization of ocean and coupled forecast models, data assimilation, and dynamical model testing. A primary focus of Argo is seasonal-to-decadal climate variability and predictability, but a wide range of applications for high-quality global ocean analyses is anticipated. The Argo program will be coordinated through the National Ocean Partnership Program described earlier.

The current proposal before Congress includes a requested funding increase of $3,190,000 for the Argo system as part of the Climate Observations and Service budget. These new funds will allow NOAH to reach an annual deployment rate of about 275 floats. With an annual expected loss rate of 10 percent, this level of funding will bring the U.S. to the 1000 float target that is the U.S. contribution to the international goal of 3000 floats by FY 2005. Other nations will contribute the majority of the system.

In addition to Argo, the other components of the sustained ocean observing system being requested in NOAA's $7.3 million initiative include the following:

> *Ocean Reference Stations:* NOAH plans to implement a global network of ocean reference station moorings, expanding from the present three pilot stations to a permanent network of 16. These fixed buoys provide the long-term record of ocean climate, often at sites with long historical records.
>
> *Volunteer Observing Ships:* Ships of opportunity provide global atmospheric and oceanic data that is the foundation for understanding long-term changes in marine climate. The data are also essential input for climate and weather forecast models. VOS need improved monitoring capabilities, better observer training, and improved data quality in order to reduce both systematic and random errors. NOAH wants to expand operations from 17 to 22 shipping lines over the next five years.
>
> *Ocean Carbon:* Cross-ocean sections measuring dissolved ocean carbon were taken during the World Ocean Circulation Experiment of the last decade. It is critical for our understanding of the global carbon cycle to ensure that the long-

line measurements of ocean carbon are maintained so that we can see any changes in carbon dioxide uptake by the oceans.

Arctic Ocean Fluxes: Over the past 20 or more years, significant changes have been noted in the Arctic, such as thawing of permafrost, earlier break-up of ice on rivers, and thinning of the ice cover on the Arctic Ocean. Recent studies conclude that changes seen in the extent of the Arctic ice are unlikely to have been caused by natural variability. In partnership with other Federal agencies, NOAA proposes to begin a long-term effort to quantify the flux of "fresh" water from the Arctic to the North Atlantic. An international team has identified five key mooring sites suitable for a program of long-term observations.

Data Management: A robust system for managing data is essential to the vision of a sustained ocean observing system. The value of the observations does not end with their initial use in detecting and forecasting present conditions. The data must be retained and made available for retrospective analyses to understand climate change, and for managing observing system operations and improvements.

Data Assimilation: To make use of these observations, an enhanced program of assimilating the data into ocean models is required as well. This is similar to the process used in weather prediction models, where observations are used to give the best possible description of the atmosphere before running the prediction.

Future Plans and Needs: An Integrated, Sustained Ocean Observing System

The ocean system as envisioned internationally and by NOAH will include platforms and sensors (both remote and in-situ), data management, and assimilation and analyses. This end-to-end ocean system will provide the critical data and products needed for forecasts, research, and assessments. The ocean system will be effective only through continuing interaction with other national and international communities. To fulfill its responsibilities for providing climate services, NOAH will lead the U.S. effort to enhance its present components, establish new components, and maintain the global operational ocean observing system necessary to deliver needed forecasting and assessment services to the Nation and the world.

The present international observing-effort is about 25% of what will be needed over the long term. An international plan for a comprehensive global ocean observing system was drafted by over 300 scientists from 26 nations in October, 1999. When completed, the composite ocean system, including the satellites, will deliver continuous, long term, climate quality, global data sets and a suite of routine ocean products:

- For the global ocean, four-times-daily distributions of sea surface pressure, sea surface wind, and marine weather and sea state conditions.
- For the global tropics, daily distributions of precipitation, sea surface temperature, and air-sea fluxes.
- For the global ocean, weekly distributions of upper ocean temperature and salinity, sea surface temperature, and sea level.
- For the global ocean, an ocean carbon inventory once every ten years and seasonal (four-times-yearly) analyses of the variability of ocean-atmosphere carbon exchange.
- At fixed climate reference stations, documented long tern trends in sea level change and ocean/atmosphere variability.

These observing system deliverables comprise the essential raw data from the ocean that will be needed by the climate forecasters and researchers to help deliver assessments and predictions of climate, on time scales of seasonal to decadal and longer. In addition to completion of the Argo array, a system to deliver these products would require completion of the global drifting buoy network, establishment of an enhanced array of tide gauges for documenting sea level change, completion of ocean reference station moorings described above, and occupation of new volunteer observing ship lines. Completion of the U.S. array of coastal moorings, described in the previous section, will also be a critical part of the ocean observing system for climate. From the satellite perspective, continuous altimeter and scatterometer measurements will be needed for determination of global sea level and surface winds, respectively. Finally, the system-wide infrastructure requirements, including research vessels, data systems, and modeling capabilities, will need to be in place to support this system.

All Three Efforts Are Important

On a summer day, our eyes and ears can sense an approaching thunderstorm. Our senses are extended by radar and satellites to detect advancing storm systems. Our senses are being extended yet again to anticipate changing states affecting coasts and oceans, our environment, and our climate. To truly understand the consequences of our actions on the environment and the environment's impact on us, data obtained through ocean exploration, coastal observations, and ocean observations will be critical.

"Coastal observations" include observations in the Nation's ports, bays, estuaries, Great Lakes, the waters of the EEZ, and adjacent land cover. Some of the properties measured in coastal zones, such as temperature and currents, are the same as those measured in the larger, basin-scale ocean observation systems. However, the users and applications of those data can be quite different. For those properties that are similar, there should be a consistent plan for deployment in the coastal and open ocean systems so that coastal observations represent a nested hierarchy of observations collected at higher resolution than those from the open ocean.

As I mentioned earlier, NOAA is prepared to begin coordinating existing coastal observing data and networks working through NOPP and the OCEAN.US Office to provide the backbone of an integrated coastal ocean observing system.

Ocean exploration includes the examination of the temporal components of the sea, and that includes the long-term monitoring of ocean characteristics, and an integrated ocean observation system. NOAH is engaged in multiple ocean observation programs already, and recognizes that an integrated ocean observation system is worthy of its own identity and will hold merit to future aspects of scientific inquiry.

Mr. Chairman, on behalf of Secretary Don Evans and the 12,500 men and women who make up NOAA, thank you for this opportunity to address how NOAH can contribute to expanding the frontiers of human knowledge. As I've stated, ocean exploration, ocean observations and coastal observations are at the core of NOAA's mission and we look forward to working with the Subcommittees on charting the future course of these important endeavors.

Chairman EHLERS. Thank you for the testimony. Dr. Colwell?

STATEMENT OF RITA R. COLWELL, DIRECTOR, NATIONAL SCIENCE FOUNDATION

Dr. COLWELL. Mr. Chairman and members of the Committee, I appreciate the opportunity to testify today on ocean exploration and ocean observations because these are areas of really great interest to the National Science Foundation, as well as our fellow agencies, as you will hear today, and to the academic community and the private sector, also. And it is a pleasure to be here with Admiral Cohen and with Admiral Lautenbacher and Mr. Gudes.

NSF has a very proud history of supporting basic research and education in the ocean sciences. This includes the tools that are necessary to access the oceans from the surface to below the sea floor. Even though NSF accounts for less than about four percent of the total Federal R&D budget, the Foundation does provide about 70 percent of Federal funding to academic institutions for oceans research. The Foundation has a broad, encompassing role that advances the frontiers of discovery and seeks to engage the public. And to illustrate this, I would like to take us on a very brief journey to the depths of the sea floor.

The footage that we would like to show you was taken from the submersible ALVIN two miles below sea level. NSF has supported ALVIN since the 1970's, along with NOAA and ONR. And we also helped to support this filming. The deep sea vent called nine Degrees North is located in the Pacific Ocean South of Mexico. These scenes will be released next year in the film, Volcanoes of the Abyss. And this IMAX feature will bring the astonishing life of this environment to millions of people throughout the world. These unique features are called black smokers. They are mineralized chimneys that tower above the communities of life at the hydrothermal vents. The mouths of the vents spew forth boiling water full of chemicals. And these conditions are toxic to most life forms, yet, the list of known species inhabiting the vents now is greater than 300.

Understanding these remarkable ecosystems can help us explain the origins of life and open up new avenues of research in biotechnology. Now, that amazing footage embodies both the NSF's research and education activities. And these efforts are right in line with the recent recommendations from the Panel on Ocean Exploration. The panel opens their report by stating that over 95 percent of the oceans remain unknown and unexplored. NSF is dedicated to reaching into this untapped realm. And one way we are doing this is through the support of ocean observations.

Last January, one of these projects, the Hawaii Ocean Times Series, made headlines with the discovery of a new group of microorganisms in the Northern Pacific Oceans. Now, these microorganisms, we call them Archaea, we microbiologists, were previously thought to exist only in extreme conditions, such as volcanic vents or in the hot springs like at Yellowstone. Now, they appear to comprise a very large percentage of the biomass, the living things in the open ocean. And marine scientists have yet to determine how these Archaea absorb nutrients. How do they multiply? What role do they play in the ocean ecosystem? There are so many of them, they must play some role.

NSF is working with the academic community and with the Federal agencies, my fellow agencies, to provide a new infrastructure to gain access to the oceans—on the coast and in the open sea. And this network of ocean observatories will facilitate the collection of time series data, and the time series data will help us to understand the basic biology, the basic chemistry, geology and physics of our oceans.

Now, this network will also help us fill in these gaps, that you have eloquently spoken about, in our knowledge of the Earth's climate system.

So, in closing, let me say again that this is a time of unparalleled opportunity to advance research and exploration in oceanography. As the new observation systems are put in place, we are going to learn a lot more about the changes that are occurring across our planet. And if we make the right investments, the coming decades in ocean research, exploration and education will be truly extraordinary. NSF looks forward to working toward this goal with our many partners across the government, in academia, and in other nations. Mr. Chairman, thank you very much for the opportunity to share the exciting work being supported by and the work we plan to do at the National Science Foundation. And I will be very pleased to respond to any questions that you and the Committee may raise.

[The prepared statement of Rita R. Colwell follows:]

PREPARED STATEMENT OF DR. RITA R. COLWELL

Mr. Chairman, members of the Committee, I appreciate the opportunity to testify today on ocean exploration and ocean observations, activities in which the National Science Foundation plays an important role. These are areas in which many agencies, as well as the academic community and private sector, have a substantial interest and it is a pleasure to be here with Admiral Lautenbacher, Admiral Cohen, and Mr. Gudes.

For generations, the search for knowledge and understanding of the oceans has captivated the human imagination. It will continue to do so for generations to come. But it is quite clear that our generation has a tremendous opportunity, and a keen responsibility, to fuel discovery in this realm. Technological and computational advances, as well as fundamental breakthroughs in understanding, are transforming the ocean sciences. At the same time, we are becoming increasingly aware of the economic, public health, and environmental significance of our oceans. Ocean exploration and the potential implementation of an integrated ocean observing system are two areas that can advance discovery.

EXPLORATION

NSF funds basic research and education in ocean sciences, and the facilities and instruments necessary to gain access to the oceans, from the surface to deep in the seafloor and from pole to pole. Exploration is a fundamental component of basic research. It is where science begins—with general ideas or broad hypotheses that seek to characterize new areas and processes in the ocean. The resulting knowledge provides a framework for further inquiry through subsequent, more specific investigations.

Last fall, the President's Panel on Ocean Exploration, convened by the previous administration and chaired by Dr. Marcia McNutt, produced a report highlighting the fact that oceans remain largely unexplored and calling for establishment of an ocean exploration program. The report identifies many areas offering high potential for scientific advances. NSF is currently active in and seeks to expand activities associated with relatively unexplored areas and aspects of the oceans, incorporating both educational and data management and dissemination components, as well as technology development.

Let me highlight a few of the areas in which we see NSF playing an important role.

Relatively Unexplored Regions

- The deep biosphere (including the subsurface biosphere) found along seafloor volcanic ridges still remains a mystery. We are continuing to discover new hydrothermal vent locations, with their associated and remarkable ecosystems that may help to explain the origins of life on earth and open new avenues of research in biotechnology. These seafloor volcanic ridges and vents also help us develop an understanding of plate tectonics and how the earth itself was formed.

  A particularly compelling example of the kind of exploration activity the Panel has described is a recently completed expedition to the Indian Ocean. NSF funded an interdisciplinary team of 34 scientists, technicians and engineers to explore a newly discovered vent field by collecting biological samples and samples of vent and smoker fluid and plumes, rocks and sediment samples from the seafloor, and by precisely mapping the area. The research project is fully integrated with an educational component entitled "Dive and Discover", co-funded with Woods Hole Oceanographic Institution and Ohio's Center of Science and Industry, with live webcasts (through NASA), interactive opportunities between students and scientists, and companion materials that assist teachers in explaining the science and technology behind the cruise and in providing classroom activities. The "Dive and Discover" web site has been nominated for the "Webby Award" for its educational and scientific content.

  The ALVIN research submarine, in which I've had the privilege of diving, has been an extraordinary tool for reaching the deep ocean over the past thirty years. A design study for an ALVIN replacement with even greater capabilities will start this summer.

- As noted by the Panel, both the Arctic and many areas of the Southern Ocean offer tremendous opportunities for exploration.
  - The Arctic is data-poor. It is difficult to reach much of the region, especially in the winter. NSF is presently developing robotic aerosondes, small pilotless planes, to sample the marine atmosphere and monitor sea ice. These planes can fly in hazardous conditions and over an extremely wide range—assets for obtaining measurements where manned missions would be costly and dangerous.

We have also established an environmental observatory at the North Pole. This year we carried out a hydrographic survey from the North Pole toward Alaska. Automated instruments at the station transmit data by satellite from the ice surface and from instruments anchored to the sea floor.

In cooperation with the Office of Naval Research and the Navy, we used Naval submarines to explore the Arctic Ocean from below and to chart the seafloor as part of our Scientific Ice Expeditions (SCICEX). We are now moving to a new way of exploring under the sea ice using Autonomous Underwater Vehicles (AUVs). They are designed to make long duration (11 day) forays under ice-covered oceans, and can transmit their position and data while underway using mini-torpedoes that heat their way through the ice and report by satellite.

- The Southern Ocean—the southernmost reaches of the global oceans—is uniquely placed to contribute to understanding of many global environmental issues. In recent years it has been the site for regional global research programs, and more efforts are planned to understand the dynamics of Antarctic ocean circulation processes, the global dispersion of Antarctic water masses, and the region's contribution to the carbon cycle.

  The cold temperatures, long periods of darkness, and episodes of high UV radiation place extreme stresses on biological systems in the Arctic and Southern Oceans. Scientists are discovering species of fish that have evolved specific genetic adaptations that enable them to live in freezing waters.

Exploring in Time

The Panel emphasized the need to explore ocean dynamics and interactions, often referred to as "exploring in time." Many of the most revealing discoveries today are coming from measurements made at the same location but over sustained time periods. NSF is vitally active in this area.

The availability of long time-series data that extend over several decades is recognized as a key element to understanding the role of the oceans in modulating the behavior of the earth system. For several years, we have supported time-series projects near Hawaii and Bermuda to enable understanding of processes that cannot be captured by snapshot visits. The data collected cuts across disciplines and sets the stage for further scientific inquiry.

We have also invested in technology development and emplacement of prototype seafloor observatories off of the New Jersey coast and Hawaii. Consistent with numerous recent reports, including one by the National Academy of Sciences highlighting both interdisciplinary research and educational benefits, NSF is planning for an enhanced investment in seafloor observatories. I will discuss this further in the context of the proposed Integrated Ocean Observing System (IOOS).

Ocean Drilling Program

I would be remiss to discuss ocean exploration without mention of the Ocean Drilling Program, a longstanding program dedicated to ocean exploration and basic research which advances many areas highlighted by the Panel. The program is an international partnership involving over 20 nations with NSF providing about $50 million annually to support U.S. academic community involvement. It explores aspects of Earth's history, structure and processes by taking core samples of the Earth's crust from all of the world's oceans.

NSF has been working with its international partners to develop the Integrated Ocean Drilling Program (IODP), the future phase of scientific drilling. The Integrated Ocean Drilling Program envisions an expansion of exploration beneath the oceans, made possible by increasing drilling capability, from the single-ship operation currently in use, to a multiple-drilling platform operation of the future. The new drilling, sampling and observing capabilities would allow scientists to conduct experiments and collect samples in environments and at depths never before attempted. The IODP would recover cores from the subseafloor ocean and from as yet poorly sampled environments, such as the Arctic Ocean basin. The results assist efforts to "explore in time" by studying sediments which record historical changes in the Earth's environment.

Technology Development

Research in technology development and subsequent capital investments in such technologies is critical to exploration as well as other areas of basic research. I have already mentioned many of these technologies, such as aerosondes, AUVs, through ice communications, submersibles, and seafloor observatories, in the context of the science they support. Development of these important tools must proceed hand-in-hand with the development of scientific questions requiring their use.

One such technology development effort resulted in the Autonomous Benthic Explorer or "ABE." The concept of a roving robot that could remain on station in the deep sea for up to a year was developed in discussions between engineers and scientists studying hydrothermal systems. ABE is capable of performing detailed survey work with video cameras, sonar, and other sensors at pre-programmed areas and time periods. Between surveys, ABE remains parked on the seafloor awaiting the next pre-programmed survey, or a direct command to start a new survey. By being able to remain on the seafloor in an unattended mode over long time periods, ABE allows us to study seafloor processes on space and time scales that we are unable to by using surface ships and manned submersibles alone.

While the kinds of technology I've just described are fundamental to exploration activities, their importance is by no means exclusive to them. In the remainder of my testimony I will discuss the proposed Integrated Ocean Observing System, including coastal observatories, which would profoundly influence the conduct of basic research, exploration, and, for our sister agencies, operational activities.

COASTAL OBSERVATORIES AND INTEGRATED OCEAN OBSERVING SYSTEM

In establishing the National Oceanographic Partnership Program (NOPP) in 1997, the Congress found that "understanding of the oceans through basic and applied research is essential for using the oceans wisely and protecting their limited resources. Therefore the United States should maintain its world leadership in oceanography as one key to its competitive future."

A major focus of NOPP has been the development and implementation of a comprehensive, integrated national ocean observing system. NSF-supported researchers would contribute to, and would benefit from, an ocean observing system in fundamental ways.

Design and Development

Effective and efficient oceanographic observation systems cannot be designed without some knowledge of the active processes that they are intended to study. Only with an understanding of the underlying processes can we make good decisions about what measurements will best characterize changes in the ocean, and, most importantly, how many measurements are required, and where they should be located. NSF-supported researchers contribute to an understanding of these processes and the intimate links that exist between the chemical, physical and biological variables.

Observational Activities in the Coastal and Open Ocean

In addition to the valuable operational uses of data that would be made available through a national Integrated Oceans Observing System (IOOS), access to long time-series data is imperative for basic research. The need is outlined in a variety of reports, the most recent of which is "Ocean Sciences at the New Millennium" published in April 2001. The report, developed by a committee of distinguished scientists with extensive community input, states that *"the lack of extensive, more-or-less continuous time-series measurements in the oceans is probably one of the most serious impediments to understanding of long-term trends and cyclic changes in the oceans and in global climate, as well as episodic events such as major earthquakes, volcanic eruptions or submarine landslides. We recommend strong support for the development, deployment and maintenance of long-term observing systems."*

As part of its ongoing activities in both the coastal and open oceans, NSF's Division of Ocean Sciences has been working with the academic community to develop an Ocean Observatories Initiative. The effort would provide basic infrastructure for a new way of gaining access to the oceans, by starting to build a network of ocean observatories that would facilitate the collection of long time-series data streams needed to understand the dynamics of biological, chemical, geological and physical processes. Just as NSF supports the academic research vessel fleet for the spatial exploration of our oceans, the system of observatories provided for by the Ocean Observatories Initiative would facilitate the 'temporal' exploration of our oceans. The effort envisions implementation of a set of seafloor junction boxes connected to a series of cables running along the seafloor to individual instruments or instrument clusters. The junction box, with undersea connectors, provides a source of power to the instruments, and a means of transmitting two-way communications to and from the instruments. A data/operations center would be established that would function within the framework of the proposed Integrated Ocean Observing System and would be responsible for insuring unified data handling and dissemination procedures using the most advanced information and communications technologies.

The location and types of observatories to be established would be determined through a competitive peer review process. This new ability to continuously receive and record ocean data and to communicate with scientific instruments on the seafloor would greatly advance our knowledge and predictive capabilities in ocean science.

Data Collection, Management, Access, and Analysis

Advances in instant communication, vast databases, computational power, and extensive analytical capability contribute to making IOOS possible. One of the key aspects of IOOS would be a network for the system that links together various components (e.g., observatories, data archives, modeling groups) to form a distributed "hub-node" system that is centrally coordinated.

NSF is providing support, along with its NOPP partners, for a consortium of private, academic, state, federal and international partners to plan and implement a network based system for the integration of regional, national and international oceanographic data.

In addition, NSF and the Office of Naval Research have tasked an Ocean Information Technology Infrastructure Steering Committee to develop a flexible and comprehensive implementation plan for a distributed information technology infrastructure that can be readily integrated with the "hub/node" enterprise.

Support for Management Structure

With its agency partners, NSF is currently supporting the recently established OCEAN.US office to coordinate implementation of the proposed IOOS.

CONCLUDING REMARKS

We are in a time of rich opportunity for research and exploration in oceanography. The advances that have been made are impressive. As new observation systems are implemented we will learn more about the changes that are occurring on our planet on time scales of days, years, decades and centuries. With the right investments the coming decades in ocean research and exploration will be truly extraordinary. NSF looks forward to working with other agencies, institutions, and nations to see that this happens.

Thank you again, Mr. Chairman, for the opportunity to share with you and the members of your committee the exciting work being supported and planned by NSF. I would be pleased to respond to any questions that you might have.

Chairman EHLERS. Thank you very much for your thoughtful comments on a very deep subject. Admiral Cohen?

STATEMENT OF REAR ADMIRAL JAY M. COHEN, CHIEF OF NAVAL RESEARCH

Admiral COHEN. Chairman Gilchrest, Chairman Ehlers, Chairman Smith and members of the Subcommittees and Staff, on behalf of the Secretary of the Navy, Mr. Gordon England, Chief of Naval Operations, Admiral Vern Clark, and the Commandant of the Marine Corps, General Jim Jones, we want to thank you for giving the Department of the Navy an opportunity to discuss the national importance of ocean exploration and our efforts to develop and implement an integrated and sustained national ocean observing system. I am, like my fellow panelists here, honored to share this desk with them and to be amongst true friends.

I have submitted written comments, Mr. Chairman. I thought I might just share with you a few verbal thoughts. Several of us, at noon, were at the Naval Observatory on Massachusetts Avenue where we recognized the contributions of Admiral Watkins as the Oceanographer of the Navy dedicated a conference room at the Naval Observatory to Admiral Watkins. Admiral Watkins, of course, with his great respect and deference to the Congress, looked at the three of us and said that our time would be better spent preparing our testimony. And I hope we were able to do both well.

But I thought I would share with you from the pamphlet, on the back, a little summary, which I think is apropos. It says, “Why are we so concerned with the nature and condition of the ocean everywhere, everyday?” Because the ocean covers over 70 percent of the Earth’s surface. It is changing all the time. And it happens to be the Navy’s operating environment. To keep the U.S. Fleet safe, to get it where it needs to be for any given global crisis, to get our weapons on the right targets and all our systems and sensors operating to their best tactical advantage, the Navy must continually collect data from all the world’s oceans.

I don’t know who wrote it, but I think they said it very well. I can tell you, being the Chief of Naval Research, it is a fulfillment of a lifelong dream for me to support meaningful ocean research in support of our sailors and Marines who sail the seven seas everyday, often in harm’s way in support of our great Nation.

So why did this New York City boy join the Navy at age 17? Well, simply said, I joined the Navy to see the world. The advertising really does work. And I have seen the world. I have spent my life, both under and at sea. And why at age 23 would I return to the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution to study oceanography and become an oceanographer? Well, because in 1970, in my opinion, the oceans, as has been addressed here, were the last great frontier. Thirty years later, they remain the last great frontier. And that is really what we are here to discuss today.

Now, given the Navy’s budget, I don’t have the graphics. And I know I am not making Dr. Ballard proud with this humble attempt. But it occurred to me that it is difficult to get members and staff and the public to Naval research. And so I feel an obligation to bring Naval research to them. And what I have right here is a little poster board. And we can pass it around. But at the top, it is what Admiral Clark refers to as my flagship. It is a surplus shark patrol craft from the Naval Academy. Because we have downsized a little. We have painted on the side, “powered by Naval research.” And you see that Fleet Week in New York last month where we had English and Spanish placards. We had three dozen technology and science kiosks. And the middle picture shows the faces of the young people who visited that ship during Fleet Week. And you can see the awe that they hold that research in. It was really heartwarming.

And based on that, we have brought that YP here on the Potomac. Many of the staff members have had a chance to ride it. We invite you too. We are going to bring it to Baltimore. We are going to take it down to Norfolk so that the good taxpayers understand the kind of research that we are doing in the Navy and Marine Corps in the oceans. And we have not forgotten the Pacific or the West Coast. This lower left-hand version, it is my Nascar version of a Swath Ship, which is an interesting hull form. High speed, very stable. It was built in Pacific Marine in Hawaii. And we have painted it up and we are going on a West Coast tour, starting in Alaska, working down to San Diego for each of the Fleet Weeks. And to inspire the young people, we are going to have adjacent kiosks, which Dr. Ballard is providing to inspire them as to what the Navy is doing and what ocean research is all about.

So I thank you very much for this opportunity. I look forward to your questions.

[The prepared statement of Rear Admiral Jay M. Cohen follows:]

PREPARED STATEMENT OF REAR ADMIRAL JAY M. COHEN

Ocean Exploration and Observation—A Navy Perspective

Chairman Gilchrest, Chairman Ehlers, Chairman Smith, members of the subcommittees, and staff, on behalf of Secretary England, the Chief of Naval Operations, Admiral Vern Clark, and the Commandant of the Marine Corps, General Jim Jones, thank you for giving the Department of the Navy this opportunity to discuss the national importance of ocean exploration and our efforts to develop and implement an integrated and sustained national ocean observing system.

Since its inception, the U.S. Navy has been in the business of exploring the world's oceans. One naval pioneer was Lieutenant Charles Wilkes, first head of the Depot of Charts and Instruments—the precursor to the Naval Observatory—who charted almost 300 islands in the Pacific, explored Antarctica and circumnavigated the globe in the 1800's. Another innovator was Lieutenant Matthew Fontaine Maury, the "Father of Oceanography," who compiled charts of ocean currents, winds, weather patterns, and bathymetry (depth measurements of large bodies of water), creating links between ocean science and national and commercial interests.

Today, we are building on this same foundation of ocean knowledge with ocean surveying conducted by the Oceanographer of the Navy and ocean research supported by the Office of Naval Research, which I oversee. This information base is vital to naval forces because our domain of ocean interest spans the globe, and we cannot afford to be surprised by ocean phenomena that impact our operations. Because the Navy and Marine Corps are on a continual quest to discover new phenomena and illuminate the ocean's mysteries, I am pursuing the recommendation from the President's Panel for Ocean Exploration to extend our definition of ocean exploration into the time domain. That is the ability to continuously monitor and measure the coastal and deep oceans, permitting the investigation of the ocean in a comprehensive fashion that cannot be achieved by isolated observations, cruises, or visits. We are making progress towards establishing a national capability for sustained and integrated ocean observations and predictions.

A year ago, my predecessor, Vice Admiral Paul Gaffney II, came before you to stress the need for an integrated ocean observing system. The National Oceanographic Partnership Program (NOPP) through its Ocean Research Advisory Panel, proposed a strategy for giving users such as operators, managers, teachers, industry engineers, researchers, and the general public, broad and easy access to ocean data, tools, knowledge and products.

Last year you were told such an integrated and sustained ocean observing and prediction system could be assembled through a relatively simple web-based federation managed by an interagency joint program office. Today, we have the Ocean.US program office in place, which has been established, funded, and staffed by a number of NOPP agencies.

Chartered by an interagency Memorandum of Agreement on October 25, 2000 to establish a national sustained ocean observing system over the next decade, Ocean.US is dedicated to:

- Detecting and forecasting oceanic components of climate variability;
- Facilitating safe and efficient marine operations;
- Ensuring our national security;
- Managing marine resources for sustainable use;
- Preserving and restoring healthy marine ecosystems;
- Mitigating natural hazards; and
- Ensuring the public health.

Ocean.US is designed to improve access to already existing agency ocean observing and predicting activities while filling in gaps so that the end sum will be greater than a simple compilation of the parts, creating a fully integrated system. As this integrated system develops, a number of powerful synergies need to happen.

Fully integrated ocean observing systems bring together communities using space-borne, remotely-sensed data with those making direct ocean measurements and also foster collaboration between operational observational efforts and long-term research programs such as ocean observatories. Ocean observing partnerships need to be further developed amongst the federal, state, and local governments as well as with the private and academic organizations and Non-Governmental Organizations (NGOs). We must continue to build bridges between oceanographers and meteorologists while also facilitating meaningful cooperation between ocean physicists, biologists, chemists, geologists, and others who will be able through this integrated ocean observing system, to collaborate in addressing pressing problems. Indeed, the test of our success will be whether we can deliver these tools to the people who use them—those who actually do the work we all depend upon to address these problems.

Ocean.US will be in the unique position of being able to get information currently held by individual federal agencies, state and local governments, private industry, academia, NGOs and other nations into the heads of the people who can put the information to work. This centralized effort will reduce unnecessary duplication of data-gathering efforts while also fostering cooperative research projects. Our goal in accomplishing this task remains, as we stated last year, to have the initial framework in place in the next year and a half, with the system fully functioning by 2010.

The interagency collaboration and cooperation facilitated by NOPP allowed us to move forward quickly and decisively in establishing Ocean.US. In just the last four years with an investment of $57 million, NOPP has supported 54 separate ocean science research and education projects. The NOPP investment portfolio is based on the seven societal needs identified by Dr. Worth Nowlin of Texas A&M University and Dr. Tom Malone of the University of Maryland in the report "Towards a U.S. Plan for an Integrated, Sustained Ocean Observing System." These are the same societal needs I mentioned earlier that Ocean.US is addressing.

In 2000, NOPP invested $15 million towards an Integrated Ocean Observing and Prediction System; the Ocean Biogeographical Information System; Regional and Special Ocean Observing Initiatives; and the renewal of Education and Outreach projects funded since NOPP's inception. This year, the Alfred P. Sloan Foundation teamed with NOPP to fund eight projects under the Ocean Biogeographical Information System endeavor, marking the first-time collaboration for the Partnership Program with a private entity. NOPP's research solicitation is again this year mirroring the Partnership Program's focus towards an integrated and sustained ocean observing and prediction system. There are proposals addressing satellite-derived ocean surface winds, improvements to the sensing suite of profiling ocean floats, the exploration of robust telemetry technologies for ocean sensors, and the planning and implementation of data assimilation and modeling nodes in a "commons" for the oceanographic community.

I am gratified to note the interagency cooperation in this joint effort to establish an integrated ocean observing system. Organizations signing the Memorandum of Agreement establishing Ocean.US are the Navy, the National Science Foundation, the National Oceanic and Atmospheric Administration, the Minerals Management Service, the National Aeronautics and Space Administration, the U.S. Geological Survey, the Department of Energy, and the Coast Guard. We need the synergy of this interagency collaboration and cooperation, which is the true strength of NOPP and is indicative of the powerful role the oceans play in our national life.

Within the Navy and Marine Corps., both the research and operational sides of our Department are fully committed towards this endeavor. The Office of Naval Research is now funding and will continue to fund the scientific and developmental aspects of this system and will remain an active participant in the NOPP process and Ocean.US. On the operational oceanography side, the Oceanographer of the Navy, Rear Admiral Dick West, is equally supportive of NOPP and Ocean.US and has provided resources to the office and a senior naval officer to serve as the first director of Ocean.US. Additionally, the Oceanographer has firmly articulated the need for an integrated ocean observing system in a formal document, "The Importance of Ocean Observations to Naval Operations" that he promulgated in 1999.

We continue to take steps to further ease the accessibility of the Navy's oceanographic data holdings, some of the most robust in the world, as well as make available our real-time ocean observations to the national community. For example, the Navy provides real-time, satellite-derived, sea surface temperature and satellite altimetry sea surface height information to the nation from the Naval Oceanographic Office. Further, much of that office's oceanographic data is available to the public through its "White Front Door" effort designed to speed the delivery of appropriate Navy oceanographic data to general users.

The Global Ocean Data Assimilation Experiment (GODAE) is a similar effort sponsored by both the Oceanographer of the Navy and the Office of Naval Research at the Fleet Numerical Meteorology and Oceanography Center in Monterey, Ca. GODAE is designed to assimilate vast amounts of ocean information into powerful numerical models to serve many national needs. The Navy expends effort in such experiments because it needs to accurately characterize the oceanic environment in which we operate and relies on observations in the open ocean and coastal zones for all Naval and joint warfare missions.

High quality ocean observations, taken more often and in more locations around the world, will yield improvements in mission planning as well as safety and effectiveness of operations, enabling Naval forces to make more informed and higher confidence decisions. Knowledge of the ocean is power, and our Navy and Marine Corps must possess that knowledge if we are to remain dominant in our control of the seas.

The Navy fully and absolutely endorses and supports the development and maintenance of an integrated, sustained ocean observing and predicting system for the country. We are providing resources, information, and personnel. We are convinced that the interagency NOPP model shows how an effective, multi-agency partnership effort can contribute to the creation of an integrated and sustained ocean observing system.

In closing, I would again like to thank the Members for their support, and for inviting me here today to talk about these very important topics.

Chairman EHLERS. Thank you very much. And I just want to tell you that you still have better graphics than we have in the Congress. We only have black and white Xerox machines. Admiral Lautenbacher.

STATEMENT OF VICE ADMIRAL CONRAD C. LAUTENBACHER, JR., PRESIDENT, CONSORTIUM FOR OCEANOGRAPHIC RESEARCH AND EDUCATION

Admiral LAUTENBACHER. Thank you, sir. Chairman Ehlers, Chairman Gilchrest, Chairman Smith, Mr. Weldon, Mr. Underwood, other distinguished members of our Committees today and the staff members, thank you very much for the opportunity to appear before you.

We, in the CORE organization appreciate the hard work that went into bringing this Hearing together and to bring all of the folks together to provide a good background on the need for ocean science and ocean exploration and ocean observing. The—I have no graphics at all, so we—you don't have to worry about that.

I just want to make three points so that there is time to hear from the distinguished scientists that we have right here. I have, of course, the honor and the pleasure of representing CORE, which is a consortium of 64 premier oceanographic institutions of our great Nation. It represents a wealth of scientific knowledge and a storehouse of just about everything that is good for our country. And I also want to note that the agencies that I am with today have a number of great scientists, too. And when you go out there and look at what is happening, you will see these folks working together. It is a community that is interested in doing the right thing for the country and building the best science that you can build the best public policy and they work together well. And I am proud of that.

The three points I want to make, first of all, the Hearing today is about ocean exploration and about ocean observing. And there have been a number of comments about which is the best approach. Which deserves the best support. How should we get this together. We, from—in the CORE organization view them as two ways to get at the same answer. So we believe they are both important and we need to emphasize the values that we get from each of these attacks to the problem.

The second issue is that the timing is right. We have the technology available and we have the need to do this. And the third point that—and I will embellish in a few minutes on this. Is that we have the mechanism and it is time to take the leadership and go and do these things. And this is just some additions to what Congressman Weldon has also so eloquently stated about the Oceanographic Partnership Act.

But let me go back to the needs or go back to the exploration and observation piece of this. Really, there are two ways to get at the same thing. I like to look at this as the two bookends that you would put up on a shelf. And that shelf right now is mostly empty. We need to write the volumes in the middle. And that is going to come from both ends. We are going to do it by exploration and we are going to do it by observing. We are still, today, as you will hear from our good scientific folks that are waiting for the next panel, of the many discoveries that are being made out there on the exploration front. You will also hear from folks who understand the need for observations, who realize that we have gotten to the stage where we have to get sustained time series data from around the globe and from around our coastal areas in order to answer the difficult questions in such things as management and the environment. Now, so both of these things are needed and we need to write those volumes in the middle. We need everyone's support.

Now, the timing is right. The technology is such today that we are doing some incredible things. Certainly, the tape that Dr. Colwell showed is an indicator, as well as some of the projects that Scott Gudes mentioned. We have technology today in the information world, in computing processing, in moving data and information management that has been unheard of. And it is growing everyday. We have AUVs, Underwater Autonomous Vehicles that can do things people never dreamed of before. So the technology is being developed that can do some of the things that were only dreamed about several years ago.

We also have the need at this point. So the timing is right. If you look at the issues on the climate, you look at determining what the economic health of this country will be in the future if we do not do the things today to uncover and find the right—the science that is out there waiting to be discovered and built upon and the knowledge that is needed to produce good public policy. The need is there. And the need is there for the United States to take the leadership.

That brings me to the third point. The mechanism of the Oceanographic Partnership Act that was so thoughtfully worked out here in this building, signed by Members of Congress, signed by the President, enacted, has been put in place, is now in the fourth year of operation. And as—things work slowly in the government. So after three years, this may be a glacial pace, but in government, this is a rapid time frame. If you look at the way that is operating today, it has become inculturated into our system. It is a way in which all of our agencies work together, along with our private foundations and academic institutions.

So I encourage that whatever we do, we look at this superagency mechanism to support and to finance the proper level of exploration and observations. Thank you, Mr. Chairman.

[The prepared statement of Vice Admiral Conrad C. Lautenbacher, Jr. follows:]

PREPARED STATEMENT OF VICE ADMIRAL CONRAD C. LAUTENBACHER, JR.

Good afternoon, Chairman Ehlers, Chairman Gilchrest, Chairman Smith, Committee members and staff. Thank you very much for the opportunity to testify on ocean exploration and on development and implementation of a coastal and ocean observing system. I am Vice Admiral Conrad C. Lautenbacher, Jr., new President of the Consortium for Oceanographic Research and Education (CORE). Many of you knew my predecessor, now CORE President Emeritus, Admiral James D. Watkins. CORE is the Washington, DC-based association of U.S. oceanographic research institutions, universities, laboratories and aquaria. Our 64 members represent the nucleus of this Nation's ocean research and education.

This hearing is extremely timely because today we are truly at a crossroads in the ocean sciences. Exciting new technologies for exploration and observations provide an intersection with real world challenges such as climate prediction, fishery management, maritime safety, and energy needs. CORE's position is that we must use available new technologies to answer key questions and make progress down a path towards constructively addressing these challenges. Our member institutions believe that ocean exploration and ocean observations are complementary activities that together move us forward. Thus both need to be supported.

Today I would ask you to consider three key questions. The first is—what are the physical, chemical, biological, and geological components and processes that make up the oceans? This may sound simplistic, yet today we know more about other planets than we do about the ocean depths. Only about 5% of the world's oceans have been mapped and our knowledge of their living inhabitants is similarly rudimentary. Nor do we understand many of the complex interactions among the biota and the physical environment. We have a severe knowledge gap that needs to be closed for a number of reasons.

We know that there are marine animals and plants with the potential to enhance human health and provide new products, but until such useful organisms are identified, we derive no benefit. As examples, the pharmaceutical industry has developed several drugs from ocean sponges, doctors use horseshoe crabs for surgical sutures and dressing wounds, and researchers study sharks for clues to a cure for cancer. These preliminary findings demonstrate the opportunities awaiting those willing to look into the oceans. I recognize that ocean exploration may be more costly than terrestrial exploration, but can assure you it is not as expensive as exploring space and we may derive more immediate benefits.

We also know the ocean contains abundant deposits of methane hydrate that have substantial energy potential. However, we need to better understand the chemical and physical properties of hydrate deposits in order to discern their possible role in meeting our Nation's energy needs. I thank all of you for your support and passage of the Methane Hydrate Research and Development Act of 2000 in the 106th Congress (P.L. 106–193). This was a good first step that should prove very beneficial now and in the years to come for evaluating investments in our ocean and energy future.

One impetus for the current interest in ocean exploration was the 1998 Oceans Conference held in Monterey, California. As a result of that meeting, the National Oceanic and Atmospheric Administration (NOAA) was tasked to conduct an assessment and develop an action plan on ocean exploration. NOAA, with the aid of academic and agency partners, produced "Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration." The plan calls for a $75 million investment over 10 years with funding to be divided equally among NOAA, the National Science Foundation (NSF) and the U.S. Navy. Equally important, the report places a new emphasis on educational partnerships, recognizes the need to involve students of all ages, and sets as a goal "to improve the scientific literacy of America's schoolchildren and to realize the full potential of a citizenry aware of and informed about ocean issues."

In fiscal year (FY) 2002, the Bush Administration requested $14 million in the NOAA budget for its role in implementing that plan. It is our understanding that the House Appropriations Subcommittee on Commerce, Justice and State proposes to include $6 million for this initiative for FY 2002. CORE believes these are positive developments that should be supported by the full Congress.

Other Federal agencies also have recognized and are supporting programs of ocean discovery and scientific exploration. NSF has already taken major steps to develop ocean science programs that balance regional, national and global information needs. Among the most successful are the Global Ocean Ecosystems Dynamics (GLOBEC) program, the U.S. contribution to the Program on Climate Variability and Predictability (CLIVAR), the Ocean Drilling Program, and the Joint Global Ocean Flux Study (JGOFS). Working with the Navy and the University-National Oceanographic Laboratory System (UNOLS), NSF has long recognized and supported the need to invest in a research infrastructure for exploring the oceans, including the academic research fleet. CORE members support these ongoing activities and have enthusiastically endorsed the agency's proposal to fund ocean and seafloor observatories as a major research equipment project.

Bridging the technological gap between ocean exploration goals and capabilities is the Office of Naval Research (ONR). The Navy and ONR have pioneered efforts to develop deep submergence vessels like Alvin and autonomous underwater vehicles like REMUS and the University of Washington's ocean gliders. Another long-term supporter of the academic fleet, the Navy has spent more than $25 million over the past five years to support ocean surveys by the UNOLS vessels. In addition, they are working on an innovative design for the newest UNOLS member, a twin-hulled SWATH vessel that will be operated by the University of Hawaii. The oceanographic community has come to rely on the Navy for leadership in diverse areas ranging from acoustic research and sensor development to exploration of such inhospitable environments as the Arctic Ocean. As the Ocean Exploration panel report suggests, NOAA, NSF and ONR together offer unique capabilities for exploring the Earth's marine frontier.

The second key question focuses on one of the most serious scientific issues confronting us today—what is the role of the oceans in climate? If we think of ocean exploration as providing 'snapshots' of the ocean at its frontiers, understanding the oceans' role in climate requires full-length "videos" across 70% of the Earth's surface. In order to achieve the long time series and observational coverage that is needed, scientists agree that an integrated and sustained ocean and coastal observing system is essential. In addition to providing vital climate information, the system also would supply ocean information for such diverse users as weathermen, fishermen, coastal managers, shipping companies, boaters, the Navy and Coast Guard, and the offshore oil industry.

One of the great ironies of climate research is that for years we dealt with the ocean and atmosphere as two distinct systems. New insights and advanced computer capabilities now allow us to examine the ocean and atmosphere as a single, coupled system. No climate issue has made the need for this approach more apparent than efforts to understand and predict El Niño events. Today, farmers, water managers in the Great Lakes, Pacific salmon fishermen, and home heating suppliers in the northeast all rely on accurate predictions of an El Niño or La Niña. The economic ramifications of a correct forecast are staggering.

If the oceans have a profound effect on seasonal climate events, we know that they must also play an important role in the longer climate outlook and significantly influence atmospheric warming. However, our current understanding is limited, in large part because we simply do not have the same observational capabilities in the oceans that we have on land.

The World Meteorological Organization (WMO) currently runs the World Weather Watch. The WMO collects data from member-operated observation systems and provides this as a service to participants in the program. The WMO program includes information from four polar-orbiting and five geostationary satellites, about 10,000 land observations, 7,000 ship stations and 300 moored and drifting buoys carrying automatic weather sensors. The fact that we have twice as many land-based as marine observations highlights the data problem. Now you may say, "Wait a minute, there are 7,000 ship stations—that's a lot of ocean data points" but the problem is that the ship observations come from well worn ship tracks rather than an evenly distributed spatial net across the ocean. The simple fact is that even at the sea surface *large areas of the ocean are never sampled.*

One of the first steps to remedy this data gap and implement an ocean observing system is the Argo Program. Argo, of course, is a global array of profiling floats that measure the ocean's upper layer in real time. Argo buoys are about 3 feet long and descend into the ocean depths taking key measurements down to 2,000 meters where they loiter for 10 days and then pop back up to the surface and relay their data to a satellite. When the program is fully implemented, the United States and its international partners will maintain a network of nearly 3,000 Argo buoys and greatly enhance basic knowledge of our oceans.

The Argo system was developed under the National Oceanographic Partnership Program through the collaboration of NOAA, Navy and NSF, and currently is being funded through NOAA. For FY 2002, the NOAA budget request included funding of almost $8 million for the program and I understand that the House Appropriations Subcommittee mark three weeks ago provided full funding. I know that Chairmen Ehlers and Gilchrest wrote letters supporting funds for this program and I want to take this opportunity to thank you personally for your efforts.

Last month, the Bush Administration announced that U.S. policy on climate change would be shaped by the best science and pledged to work aggressively to improve our scientific understanding. The Secretary of Commerce, working with other agencies, was asked to conduct a review to set priorities for additional investments in climate change research. Responding to these Administration objectives, CORE proposes that highest priority be given to funding for an integrated ocean and coastal observing system.

While there are many contentious aspects of the climate issue, one area where there is little disagreement is on the central role of the oceans in storing carbon dioxide (CO_2) and heat. We know the oceans contain 50 times more CO_2 than the atmosphere and the upper few hundred feet of the ocean stores 1,000 times more of the sun's heat than the atmosphere. This relates to climate change in a very direct way because if we want to slow or reverse greenhouse warming, the oceans may respond very slowly to our efforts. The scientific problem is we currently don't know how sluggish the ocean response is, and we will need better data in order to improve our estimates.

We also need to better define how the oceans sequester CO_2, and how the oceans store energy to understand the ocean's role in the total climate picture. We know CO_2 is stored in the ocean but we do not understand the processes in detail and it will be critical for us to get the science right on this very important issue. These examples illustrate why it is essential that we secure the initial funding this year to begin implementation of an integrated ocean and coastal observing system for the United States.

You may recall that in the late 1980's this country embarked upon a $4.5 billion modernization effort for the National Weather Service. A key component of that modernization was better observational systems integrated by a common software platform. Over the next decade, the Weather Service improved its predictive capability because it improved its observational capability. This national investment in improved observing systems paid off both economically and in enhanced public safety. Similarly, an integrated ocean observing system could give us more accurate predictions of seasonal and interannual climate events. It also would greatly advance and enhance our understanding of longer-range climate issues. Fundamental knowledge of our climate system processes so vital for the development of sound policy options would be available on demand to members of Congress.

There is wide consensus in the oceanographic community on the need to fill our climate knowledge gaps and that those gaps can only be bridged with an ocean and coastal observation system. That leads me to my final question.

The third key question is—what is the most cost-effective method for implementing an ocean and coastal observing system, as well as an ocean exploration program? Many of the elements of an ocean and coastal observing system currently exist, funded by numerous entities and for a variety of purposes. The need for ocean and coastal observations is similar to the need for weather information—they promote public well-being. Unlike the weather system, however, ocean and coastal observations are funded, managed, and used by different agencies, organizations, and institutions and for a variety of purposes. Thus, a major challenge is to integrate diverse observational systems and data sets to maximize their usefulness and minimize costs. The goal must be to develop a national system that responds to local and regional needs.

In 1997, Congress approved, and the President signed P.L. 104–201 establishing the National Oceanographic Partnership Program (NOPP). NOPP grew from the need to better understand the ocean and coasts and their role in national security, economic growth and quality of life. It provides an effective approach for addressing national needs, such as an ocean observing system, that do not fall under the purview of a single agency. A key provision of the NOPP legislation was the establishment of the National Ocean Research Leadership Council (NORLC) that brings together the heads of the Federal ocean agencies to form partnerships and work cooperatively toward common goals. Together the members of the NORLC can identify strengths and weaknesses in Federal ocean research programs and plan where future investments in the ocean sciences should be made.

Members of the NORLC recognize that collaboration is necessary to advance our understanding of the world's oceans and meet Federal mission requirements. Their representatives meet monthly to discuss NOPP funding priorities and levels, and work collectively to address critical ocean science needs. In this way, the NORLC can focus and direct Federal oceanographic research dollars.

At present, only a small fraction of the national ocean sciences budget or less than $16 million annually is allocated using the NOPP process. Of that annual total, the U.S. Navy provides $10 million, NSF provides slightly under $5 million, and NOAA provides a little less than $1 million. Furthermore, the partnership process has used federal funding to leverage investments by private, state, and local government agencies so that the total funding for the program is increased by a factor of two. While federal government investments to date have been relatively modest, the NOPP process is developing a record of achievement demonstrating that it is cost-effective and does work.

To date, several of these NOPP achievements foster and support implementation of an integrated ocean and coastal observing system. Dr. Fred Grassle will discuss one notable example, the Rutgers University Long-term Ecosystem Observatory (LEO–15), in his testimony later this morning. While the list of other related NOPP projects is extensive, I would like to mention a few examples, including:

- The design of the NEPTUNE project to establish a linked array of undersea observatories on the Juan de Fuca plate in the northeastern Pacific Ocean.
- The development of a Virtual Ocean Data Hub (VODHub) that builds on rapidly growing distributed oceanographic data systems to implement a network-based system and provide seamless access to ocean information.
- The modeling of the coastal upwelling ecosystem within the Monterey Bay National Marine Sanctuary to guide management and direct future observational efforts within the sanctuary.
- The South Atlantic Bight Synoptic Offshore Observational Network (SABSOON) that uses Navy “Top Gun” training facilities as a platform for an ocean observing system.
- The BRIDGE: Ocean Sciences Education Teacher Resource Center that offers teachers an on-line, easy-to-navigate collection of resources for ocean science education.

As the projects listed above indicate, the NOPP process has been used to develop successful approaches to both ocean exploration and ocean observing systems. In addition, the Ocean.US office has been tasked under a NOPP memorandum of agreement to being the process of designing and implementing a national system. Thus, I would propose that NOPP is the right mechanism to coordinate a coastal and ocean observation system as well as an ocean exploration program. I hope that you can join CORE in supporting these ocean endeavors and in using the NOPP process for their implementation.

An old adage claims that what you don’t know can’t hurt you, but I would argue quite the contrary in this situation. Exploration and observation are hallmarks of scientific endeavor, and both by discovery and by observing nature over time we are better able to understand and to model critical ocean and atmospheric processes. At present, our knowledge of the oceans is insufficient and hinders efforts to monitor the coupled climate system. However, we stand at a unique moment in history where we can now probe the depths of the oceans with new technologies and get the information we need to better understand our ocean planet. Moreover, the National Oceanographic Partnership Program offers us a mechanism for using Federal resources to achieve that goal.

Thank you for the opportunity to testify today. I look forward to working with you on these issues and would be happy to answer any questions.

PANEL I DISCUSSION

Chairman EHLERS. Thank you for your testimony. While I was sitting here listening to the testimony, I scribbled a short note to Mr. Weldon suggesting a mechanism by which we could coordinate our Congressional Committees to work better. He sent an even shorter note back saying, good idea, we will pursue it. So let us hope we can develop something that will work. We have now reached the time to ask questions of the panel. And I would first of all, like to recognize Mr. Gilchrest for the opportunity to question.

Mr. GILCHREST. Thank you, Mr. Chairman. I wasn't quite ready, but I will go with what I have. Admiral Lautenbacher, you made a comment about bookends that need to be filled in and have some sense that the bookends—that the framework that we are looking for for this whole integrated process and that if so, what are—what, in fact, are the bookworms—bookends, if that is the framework for the integrated process. Then how were you going to fill that in? And what do you estimate the cost of that to be and how long will that occur?

Admiral LAUTENBACHER. Chairman Gilchrest, let me clarify. I was talking about the bookends being the approaches to fill in the knowledge. The subject of today's Hearing has been the need for ocean exploration and the need for ocean observing. So we could get caught up in semantics as to whether the right way to go about discovering and developing science in the ocean should be done from the exploration path or from an observation path. What I was saying is that we need both of these. Our organizations contribute to both of these, as well as the Science. . .

Mr. GILCHREST. The bookends are exploration and observation.

Admiral LAUTENBACHER. Absolutely. You have got to have both of these. We are still at a point in the ocean, we know more about the dark side of the moon than we do about the bottom of the ocean. There are discoveries being made everyday. So that the exploration theme, the way of going about exploring—obviously, it needs to be done with some thought and done at a level where it is efficient——

Mr. GILCHREST. I think we should agree that exploration is on one end, observation is on the other end. I guess my question was, how do we—is there some sense right now as to integrating the various agencies, departments, military, private sector scientists on how to prioritize the exploration and the observations and then how to integrate that information with the various agencies and the technologies? And when I say prioritize, I guess I am—leave this open to the other panel—if—and I think it is important for us to view the oceans in such a way that we don't take away the various diversity of the talent among the different agencies or private universities, but in some way, we enhance their ingenuity, I think, by the exchange of information. When you do that, you are going to hopefully have some sense of prioritizing the nature of the exploration and prioritizing the nature of the observation. What is going to be observed? What are we out there looking for? And, certainly, there will be crossovers in between. But is there a sense, Admiral, about how, once we have framed exploration and observation, to fill that integration of information?

Admiral LAUTENBACHER. I think there is. And I would offer the National Ocean Research Leadership Council, which was created by the National Oceanographic Partnership Act. That is what I call a superagency-level body. It is essentially the National Security Council of oceans. It includes, you know, Cabinet-level departments and agency heads working together. This Act created this superagency mechanism three years ago or four years ago. It is in the fourth year of work. There is a working group set up where each of the agencies talk together. It created partnerships not only with the—among the agencies, it created them with our institutions with local and regional authorities and industry, as well. Now, we haven't explored as much of the industry and regional as we ought to. And that, you know, is kind of the next step. But that mechanism is there. Now, in terms of filling out the priorities, what I would suggest is that this council has created something called ocean.us, which is essentially an integrated program office. If I were in the Pentagon, I would tell you this is the equivalent of a joint program office.

Mr. GILCHREST. What is the status of—because my time is limited.

Admiral LAUTENBACHER. Yeah.

Mr. GILCHREST. I have a question to Dr. Colwell. But I would like to maybe in the next go around, I would like to find out what the status of ocean.us, whatever that is, is.

Admiral LAUTENBACHER. This man can answer the question.

Mr. GILCHREST. Are there people employed there now?

Admiral LAUTENBACHER. Yes.

Mr. GILCHREST. Are they working?

Admiral COHEN. I am pleased to tell you I was there yesterday.

Mr. GILCHREST. Okay.

Admiral COHEN. You are looking at the employee right behind—we are hiring. We have the spaces. We are moving the furniture in. I would tell you in a matter of months——

Mr. GILCHREST. I see.

Admiral COHEN [continuing]. It will be full up in operation. This is going to be a success story.

Mr. GILCHREST. I am going to try to get one question in before the red light. Dr. Colwell, when microbiology, I guess, do you see that there has been a lot of discussion about the change of—and the potential damage to ecosystems if there is global warming over the next 50 or 100 years? Will that same impact in climate change happen in the same timeframe or over a longer period of time in the oceans?

Dr. COLWELL. We are already observing that in places like Antarctica, the increased ultraviolet light is causing a change in the community structure; that is, the kinds of species of bacteria that you see there and other microorganisms that are chlorophyll-bearing that are involved in the whole photosynthetic cycle. So the answer is yes, there will be changes. And there will be geographic changes that we can already measure. And interestingly, there probably will be public health effects that we didn't expect. For example, in my own research, we have been able to show that just an elevation in sea surface temperature of a fraction of a degree or so in a place like the Bay of Bengal can affect the organisms that cause the disease cholera. So that the epidemics are directly related to the sea surface temperature. Now, that is a serendipitous finding, but it is a very exciting one because it suggests very strongly—does more than suggest—it demonstrates that we are fragile beings and that we are all interconnected as living beings on this planet. And we can't eradicate or eliminate or shift without changes in our own hill. I could go on, but the answer to your question is that, yes, there are profound changes that we are only just beginning to determine because we now have the tools of molecular biology that allow us to actually measure, at the DNA level, changes that are occurring.

Mr. GILCHREST. Well, I would ask for unanimous consent that you go on for about another hour. I might hear an objection. Thank you, Mr. Chairman.

Chairman EHLERS. The gentleman's time is expired. Next, we turn to Mr. Faleomavaega. Sorry. For——

Mr. FALEOMAVAEGA. It is all right, Mr. Chairman.

Chairman EHLERS. For your five minutes.

Mr. FALEOMAVAEGA. Just to follow-up on Chairman Gilchrest's statement, Dr. Colwell. You know, we have some members, a dear friend who serves not only as a leader of the Science Committee, but we served together in the International Relations Committee. And he considers global warming as global baloney. And I wanted to ask you, based on our scientific—from our scientists, are we really serious about this issue? Because there seems to be a strong difference of opinion on the—among the scientists about—there—is there really a serious problem of global warming? Because we are getting different feedbacks. And I wanted to say that I happen to disagree with my good friend, who makes these descriptions. A member of the Congress considers global warming as global baloney. Can you respond to this?

Dr. COLWELL. I would say that the evidence for an increase in temperature is quite genuine. It has been reproducibly demonstrated in the increase in CO_2. The question is, over a very long period of time, is this a natural series of events or is this, in fact, an induced event? I think the data are beginning to be fairly dramatic. And I do agree with the President's position that we do have gaps in our knowledge and fundamental research is badly needed. And I think with my colleagues here, we understand that there is a lot of work we need to do, especially in the study of ocean atmosphere interactions. Very important. But we need to include the biological component. That has not been present in many of the studies that have been done, especially the earlier studies 10, 20 years ago. It is now time to incorporate the biological component.

Mr. FALEOMAVAEGA. I won't get into the Kyoto Protocols and the differences of opinion we have on that issue. But just—I just wanted to get a sense from our own American scientific community if there is support from our scientists of our country that there should be some serious concern about global warming. That is my concern here.

Dr. COLWELL. There really needs to be——

Mr. FALEOMAVAEGA. There is consensus.

Dr. COLWELL. There is need for research.

Mr. FALEOMAVAEGA. Okay.

Dr. COLWELL. No question. I think the consensus on that is pretty strong.

Mr. FALEOMAVAEGA. Okay. As I heard earlier from my good friend Curt Weldon about the need for consolidation of so many different Federal agencies involved in research and all of this dealing with the oceans, if I were to shuffle these four basic categories together for the members of the panel, strategic, economic, environmental, scientific, how would we place a sense of priority in terms of what our current National policy in that order of those four basic areas? Could any member of the panel respond to this? Because in—let me tell you my sense of opinion. I think our number one policy is military strategic. It is not any of the others. But I may be wrong. Could you correct me on this?

Dr. COLWELL. I won't correct you, but I certainly would like to offer a beginning discussion and ask my colleagues to join in. And I would say that what we are finding is that it continues to be military, but in a very different way. It is an economic competition and it is a—an environmental security that is necessary. For example, if there is devastation to wheat crops or let us say to our fisheries, which is a very important source of protein for the public——

Mr. FALEOMAVAEGA. But collate—I know, but I just wanted to ask in terms of—I know where you are coming from.

Dr. COLWELL. Yes.

Mr. FALEOMAVAEGA. Because I could just simply say, why do we have to import $9 billion worth of fish? Why can't we not domestically produce the fish for our own consumption? Why do we have to import from the—why do we have to buy fish from foreign countries? Because that indicates that we are not up to par in providing fish for domestic consumption in terms of our own National needs. So I just want to get a sense of number from the members of the panel, what do you consider to be the number one priority among those four categories?

Mr. GUDES. Am I the fish person?

Mr. FALEOMAVAEGA. Whatever you want to call it. Whatever—I am sorry. My time is. . .

Mr. GUDES. Do—I mean, let me just. . .

Mr. FALEOMAVAEGA. Our current national policy, in your best opinion, how do you place these four basic areas that I think are basic as far as where our resources are going into, how we are going about and doing these things? Because it does relate to exploration and observation. Doesn't it?

Mr. GUDES. Sure. I think it is legs of a stool, as you have in other areas. That—I mean, obviously, there is a National security issue, which we have talked about before here, where the oceans relate to that. Obviously, there is an environmental issue.

Mr. FALEOMAVAEGA. Oh, I know. I know. I know.

Mr. GUDES. Are you saying—I—I can't—I'm sorry. Go ahead.

Mr. FALEOMAVAEGA. I am saying that we cannot all put the four of them equally on the same stool. That is my—I just wanted to get a sense, where are we really making the most emphasis in terms of our resources or——

Mr. GUDES. Well, I suppose that is it maybe—this is one of the areas where maybe it is a little different and the different agencies that are a part of all these issues. In the case of the Navy, I would assume it is first on the strategic. In the case of NOAA, I would assume that it is first and foremost on environmental. And fisheries, which you mentioned, is definitely one of the areas that we have a mission that we deal with.

Mr. FALEOMAVAEGA. I am sorry, Mister—yeah.

Mr. GUDES. I think it all—I don't think it is that easy to distinguish between them.

Mr. FALEOMAVAEGA. I am sorry, Mr. Chairman. My time is up. I will wait for the second round.

Chairman EHLERS. I thank the gentleman from Samoa. Next yield to myself 5 minutes. I—following up on the question of the previous questioner about the climate change issue. Mr. Gudes, first of all, I know you are putting some more solar polar satellites in orbit soon. And I know much of that is to try to measure properties of the ocean. Will you be able to get data accurately enough to really assist you in climate change models or are we really going to have to go out there and disburse these clever little devices all over the ocean, which will bob up periodically and give reports on temperature and other conditions?

Mr. GUDES. I think that it is an integrated system. My only point before was that it includes space-based systems. And some of the other panels I sat on with this Committee—Mr. Goldin was here and talked about several systems. But definitely, they play a role in it. But I think that most of the climate experts would say, no, you have to have in situ measurements. You have to have these long-term measurements. And it is about understanding the oceans. I think it is one of the key areas. The oceans are the driver of the world climate system. And definitely to get the kind of measurements one needs to really understand what is happening in the world climate system, you need those sort of ocean measurements. ARGO is one way to do that, in a broader sense. The TOGA TAO atlas buoys I talked about are another one. The only other point I was going to make as I rushed through my presentation earlier, Mr. Chairman, is that this is sort of a dual use issue, if you will. Clearly, ARGO floats are probably first and foremost about climate. But they are also about understanding the oceans and about understanding the currents and really unlocking some of the secrets of the oceans at the same time. I know that some of these answers come across similarly that these things are interrelated, but it is an interrelated system. And I—but I definitely do think the answer to your question is you definitely do need ground-based systems.

Chairman EHLERS. Now, the satellites are going to be about 6½ billion. How much will the ARGO system cost?

Mr. GUDES. The ARGO system, I don't have the total out. It is $7.9 million in our budget this year to get up—per year to get up to a U.S. contribution toward a 3,000 float system. I think about a thousand, basically, are United States floats. Most of which would be contributed by NOAA, but not solely NOAA. And I have some papers here, which I can provide for the record on other countries.[1] But the idea is to get to a 3,000 system. And that would probably get us about where we need to be. So about $8 million a year. And these floats last, I believe, for about five years. So there is a replacement to them. It is not as though you put them out one time. It is not as though you put them out one time, just like you don't put out any system one time. But there will be a replacement and 275—I think that is about where we need to be.

Chairman EHLERS. Okay. Thank you. On the ocean exploration program, I—Dr. Colwell and Admiral Cohen, are you both intending to put in appropriate amounts of money into that program for the next year?

[1] See document entitled "International Commitments for Argo Floats" in Appendix 4.

Dr. COLWELL. We plan to do so. It is a very, very important program. Having continuous measurements as opposed to sort of snap shot measurements gives us a much better understanding. I defer to Admiral Cohen for further comment.

Admiral COHEN. Mr. Chairman, the answer is yes. The oceans are where we operate. As I think many of you are aware, the Office of Naval Research invests about $400 million a year in category 6.1 basic discovery and invention. Of that amount, approximately $100 million goes into ocean studies. Of that amount, about half goes into acoustics. Now, acoustics is unique to the Navy because it is not only a censorious part of our weapons systems, it is integrated, et cetera. And it may not have other commercial or scientific spinoffs, except when you retrieve that data and are looking for things that you may not have looked at in the past. So we feel we are strongly committed in the tens of millions of dollars to this area.

Chairman EHLERS. Thank you. And I am sure NOAA is also fully involved in that. I yield back the remainder of my time. I will next recognize the gentleman from California.

Mr. MILLER. Thank you, Mr. Chairman. I believe that some science is necessary in making any decision. I mean MTBE in California is a great example. It sounded good. But we found once it mixed with water, you couldn't remove it from the water. And now, we have polluted water in California we are trying to figure out how to clean up. And all of you had testified about the inadequacy of observation in the oceans as it relates to climate. In fact, just as complicated powers of problems involving models, it seems that we have learned today from all of your testimony that ocean observation is a problem, as well. And, first—and this is for all of the panelists. Do you believe that the models used in the Intergovernmental Panel of Climate Change, IPCC, assessments adequately incorporate the role of oceans in climate? Why or why not in your answer.

Mr. GUDES. The models do integrate the ocean. They—definitely we could do—we could get more measurements and integrate and develop better models. One of the efforts that we are always involved in, Congressman, is actually improving these models. A big issue is actually the supercomputing power to run these models. And NOAA, through our Geophysical Fluid Dynamics Lab, is one of the key areas. In fact, had one of the key models that is used by the climate community. Dr. Colwell and I were just at a Hearing in Alaska, actually, where we looked—before the Senate Appropriations Committee—where we looked at several models that the IPCC uses, as well as the general climate community.

Mr. MILLER. But all of you have testified about the inadequacy of observation of the oceans. If you have not adequately addressed the issue of oceans and how that does impact it, how could you feel that it is adequate in coming up with a reasonable answer?

Mr. GUDES. I think that it is an issue of continually getting better measurements. Just as it is, actually, in the atmospheric sciences. But the National Academy of Sciences Report, which just was done recently, actually supported the IPCC modeling that was done.

Mr. MILLER. And you think there is an adequate understanding of oceans as it applies to climate?

Mr. GUDES. I think there is a good understanding. And as I said before, we need to do better. I think that a great example is actually the TAO Array across the Pacific. This, back in the early '70s or so, this was a forecast by our scientists that the equatorial Pacific temperatures affected weather in your State. Now, in the latest El Niño that we experienced, we came up with a forecast ahead of time that was largely made possible through those buoys and through those measurements. It is definitely just like with weather forecasting, Congressman. It is definitely an issue where you can get better and better. Better, in terms of models. Better, in terms of the observations. And better, in terms of the integrating, getting that data into the models, simulating into the model in the way that the model improves.

Mr. MILLER. Well, I don't disagree with that. But you could apply that to water quality in the same question. You could say, how pure is pure? Are the water quality standards today, are they adequate to provide safe drinking water? And my question would be, is our understanding of the oceans adequate in order to use that portion in the equation of climate?

Mr. GUDES. Right. It is not—it is obviously not just about understanding the oceans. It is about a lot of other measurements that we have taken. Our understanding of the oceans is good in terms of the interaction and coupling with the climate model, but it could definitely be better. And it is definitely, as I said, an issue of where—getting better information, getting better measurements, getting better measurements within the whole water column on a regular basis. Sometimes, it is—as I pointed a lot of times, these climate measurements are not dynamic. They are these long-term data sets by getting them everyday, it is—again, it is not just the oceans, Congressman. If you will, cooperative observers and improving—one of the things that we do in NOAA is about improving the quantum measurements on land. I know I showed you an image earlier of a lot of red dots across the land surface. But definitely, those measurements can be improved, as well. It is one of the things that we are working on all the time. Getting those same measurements, temperature—exact temperature measurements and getting them on a regular basis and then getting those into the models is all about putting together this puzzle and about understanding the whole earth dynamic that is driving our climate system.

Mr. MILLER. And recently President Bush made a decision not to support the Kyoto Protocol. And he did that—he made the decision based on what he perceived to be inadequate understandings of the global warming issues and the environment and such. I saw some other heads when you were answering—kind of yessing a question, kind of going no. So Admiral Cohen, I believe you had a comment. You might have a different opinion.

Admiral COHEN. I think you have to frame this—and I do like your analogy, how pure is pure? From the warfighter's point of view, we have to worry about how good a prediction capability do we have for an area and for what length of time in advance of the needed information. And so for small areas and for near term, we are doing okay. If we would like to be able to predict the length of time it takes to get across an ocean using current and ship speeds for an amphibious landing that would occur upon arrival, we are not doing well. I like the competition that we have with NOAA models and the Navy Meteorology Command models, which are complementary, tend to leap frog each other. And, in fact, NOAA came to Navy during Hurricane George, which did so much damage to our East Coast because of the flooding issues, because for that environment, the Navy Meteorology model was better suited than the NOAA model at that point of time. And I understand subsequently, they have integrated that. So it is a continuum that moves on. It is not a black or white kind of issue. And I know you are sensitive to that, based on the question.

Mr. MILLER. Well, thank you for your patience, Mr. Chairman. Thank you for your answers.

Chairman EHLERS. The gentleman's time has expired. We would like to move on to the next panel, but Chairman Gilchrest has asked for two quick questions of this panel before we move on.

Mr. GILCHREST. Given the sensitivity of the time, Mr. Chairman, I had a couple more questions, but I think I can contact the witnesses myself outside the Hearing. I do want to say, Mr. Gudes and I were planting marsh grass a few weeks ago on the Chesapeake Bay improving that estuary for habitat for the entire ecosystem of the oceans of the world. And I want to thank him for that. Mr. Gudes.

Chairman EHLERS. My question is how do you mow it after you——

Mr. GILCHREST. With Canada Geese and Tundra Swans.

Chairman EHLERS. I want to thank the panel very much for their appearance and their testimony and their comments. This will be extremely helpful to us.

Dr. COLWELL. Mr. Chairman, if you would indulge me just very briefly. I wanted to acknowledge Congressman Smith and Congressman Eddie Bernice Johnson for two superb articles in today's *Capitol Hill.* Thank you very much.

Chairman EHLERS. All right. Fine. Thank you. We are pleased to call up the next panel.

PANEL II: DR. MARCIA MCNUTT AND DR. ROBERT BALLARD

Chairman EHLERS. Panel II, Dr. Marcia McNutt and Dr. Robert Ballard. And I ask Chairman Gilchrest to take the Chair at this point.

Chairman GILCHREST. Our next panel is Dr. Marcia McNutt, President and Chief Executive Officer of Monterey Bay Aquarium Research Institute. Welcome. And Dr. Robert Ballard, President, Institute for Exploration. Dr. Ballard, thank you for coming today. We look forward to your testimony. Dr. McNutt, you may begin.

STATEMENT OF MARCIA K. MCNUTT, PRESIDENT AND CEO, MONTEREY AQUARIUM RESEARCH INSTITUTE

Dr. MCNUTT. I'm glad to be here to speak today about a topic that I care about most passionately. That is ocean exploration.

I am speaking to you today not only as the President and CEO of the Monterey Bay Aquarium Research Institute, but also as the President of the American Geophysical Union and as the Chair of the Ocean Research Advisory Panel for the National Ocean Partnership Program.

Since time is limited, I just want to cut right to the important issues regarding ocean exploration. First of all, why does the U.S. need a program in ocean exploration? I am very heartened by the comments that have been made so far today by the distinguished Members of Congress. Clearly, you get it. The ocean is essential to life on earth. The ocean is the earth's largest living space. It contains most of it's biomass. 80 percent of all phyla are represented only in the ocean. And most photosynthesis occurs there. The ocean moderates our climate, it keeps earth habitable and it processes our waste. It provides an inexpensive source of protein to feed our population. Yet 95 percent of the ocean is unknown and unexplored.

To be sure, much has been learned about the oceans through research programs funded by our Federal agencies. But research is distinct from exploration. Exploration leads to the questions. Research leads to the answers. Everyday, Congress and other legislative bodies are asked to make policy decisions concerning the ocean based on the best scientific answers to those posed questions. But what if we don't know enough to ask the right questions?

For example, right now, we are considering direct sequestration of carbon dioxide into the ocean below three kilometers depth to mitigate global warming. But how can we assess the biological impact of ocean sequestration when we know practically nothing about what lives at those depths? Everyday when the submersibles of my institution go out to those depths, we find new creatures that have never been seen before. As another example, observatories that were installed by my institution at Monterey Bay saw that during the decade of the '90s, for a mere one degree increase—one degree Fahrenheit increase in temperature, the productivity of the ocean plunged 25 percent. That extreme effect was not predicted by any of the sophisticated computer models and it was because they did not have the resolution and had not explored—we had not explored the ocean sufficiently in the time domain to ask the right questions of those models. In order to know those questions to ask, the U.S. needs a program in ocean exploration.

So what is ocean exploration? It is the systematic observation of all facets of the ocean in the three dimensions of space and in the fourth dimension of time. Ocean exploration leads to great but largely unpredictable rewards. Cures for diseases, untapped mineral energy and biological resources, insight as to how the ocean system functions, geological and biological vistas of unsurpassed beauty. Appreciation for our maritime past. Ocean exploration captures the attention of the public and provides engaging content for improving math and science literacy.

When should we begin a program in ocean exploration? Well, probably 20 years ago. But better late than never. Right now, even Ireland is better off than the U.S. in terms of its ocean exploration program. Japan, France and Russia all have ocean exploration tools that are decades newer than what is currently available for the U.S. research community. I personally can't understand why a country that has won World Wars, walked on the moon, and increased the standard of living for its citizens through superior technology could allow itself to sink to second-tier status when it comes to something as important as the oceans. To own the technology is to own the oceans.

So who should be involved in ocean exploration? Well, it should involve all stakeholders: Federal laboratories, businesses, universities, educators, conservation, students, all of the relevant Federal agencies. Each brings an important element to the table. The efforts of all of these groups will need to be well-coordinated through some effective management structure, including coordination of Federal funding. The Ocean Exploration Panel felt that NOPP was a perfect mechanism for doing this. But what the agencies need to hear from the White House and what they need to hear from Congress is that they will cooperate through NOPP and that they will route their funding for ocean exploration and ocean observation through this mechanism.

The fruits of exploration should be equally available to all stakeholders so that policy decisions can be well-informed from all viewpoints.

So, how should we explore the oceans? The program will be most effective and systematic with built-in mechanisms for educational outreach and information dissemination. The Ocean Exploration Panel felt that we should center the program around a signature mission, a poleward circumnavigation of the entire planet, concentrating in areas under U.S. jurisdiction. In each region, the exploration would begin with reconnaissance mapping of the sea floor and water column. Next space would involve detailed exploration by the state of the art flagship equipped with new generation submersible technology and high bandwidth satellite communication to bring the real-time discoveries to aquaria, schools, homes and offices.

My institution does that right now, everyday in the Monterey Bay Aquarium. There is no reason why we can't do that nationwide. The flagship would also be set up to archive samples and distribute validated data to data repositories and over the Internet. In the wake of the flagship's observations, ocean observatories would be installed in key locations to continue that exploration into the time domain.

In summary, I hope that Congress will support ocean exploration because the ocean is a mysterious living universe critically important to the functioning of the planet. But even if you support ocean exploration only because of its potential to increase National wealth, encourage ocean conservation, improve public health, regain U.S. technological superiority and promote science literacy for the public, aren't those reasons good enough? Thank you.

[The prepared statement of Marcia K. McNutt follows:]

PREPARED STATEMENT OF MARCIA K. MCNUTT

Thank you, Chairmen Gilchrest, Ehlers, and Smith, for this opportunity to speak to you about a topic that I care about most passionately, Ocean Exploration.

Since time is limited, I will cut right to the important issues regarding ocean exploration: Why, What, Where, When, Who, How, and How Much.

Why does the U.S. need a program in ocean exploration?

It is very simple. The ocean is essential to life on Earth. The ocean is Earth's largest living space and contains most of its biomass. Eighty percent of all known phyla are found only in the ocean, and most photosynthesis occurs there. The ocean moderates our climate to keep Earth habitable, and it processes our wastes. The ocean provides an inexpensive source of protein to feed the global population. Yet 95% of the ocean is unknown and unexplored. How could that have happened? During the great era of exploration from the 15th through the 18th centuries, the target was unknown lands: the New World, the Dark Continent, Terra Incognita. Many of the explorers of that era were indeed superb mariners—Columbus, Magellan, Drake, Cook—but the ocean itself was not the target of their journeys. It was merely a barrier that needed to be crossed in order to claim new lands and discover new riches. The technology did not even exist at that time to explore the ocean itself. By the time we developed the platforms and instruments that could explore the ocean and its depths, exploration had gone out of favor as most of the land surface had already been catalogued, and the vast resources of the oceans were unappreciated. To be sure, much has been learned about the oceans through research programs supported by Federal agencies, primarily NSF, the Navy, and NOAA. But research is distinct from exploration. Exploration leads to questions. Research finds answers. Every day Congress and other legislative bodies are asked to make policy decisions concerning the oceans, based on the best scientific answers to those posed questions. But what if we don't know enough to ask the right questions? For example, some are now proposing direct sequestration of carbon dioxide in the ocean, below 3 km depth, as a way to circumvent the atmospheric release that leads to global warming. But how can we assess the biological impact of ocean sequestration when we don't know all of the creatures that live in those regions, much less the role they play in the overall health of the ocean ecosystem? As another example, my institution's ocean observatories documented a 25% drop in ocean productivity in Monterey Bay in the decade of the 1990's caused by a 1 degree Fahrenheit rise in ocean surface temperature. This extreme effect was not predicted by the sophisticated computer models because we have not explored the ocean sufficiently in the time domain to ask the right questions of the models. In order to know the right questions to even ask, the U.S. needs a program in ocean exploration.

What is Ocean Exploration?

Ocean exploration is the systematic observation of all facets of the ocean (biological, physical, chemical, geological, archaeological, etc.) in all three dimensions of space and the fourth dimension of time. Ocean exploration leaves a legacy of carefully documented information for posterity, to address questions we do not know enough to even pose at the time that the data are collected. Ocean exploration pushes the envelope for technology as we attempt to gain access to Earth's most challenging environments. Ocean exploration leads to great, but largely unpredictable, rewards: cures for diseases from novel biological compounds, untapped mineral, energy, and biological resources, insight as to how the ocean system functions, geological and biological vistas of unsurpassed beauty, appreciation for mankind's maritime past. Ocean exploration captures the attention of the public and provides engaging content for improving math and science literacy.

Where should we explore?

The highest priority for U.S. ocean exploration should be the underwater territories under our jurisdiction. As stewards of these areas, we have a moral obligation to concentrate our efforts there. It is also in these areas that we are most likely to protect and profit from new discovers. The second priority is the Arctic Ocean, largely unexplored and yet the sentinel for global climate change. Other priorities are the vast Southern Ocean and inland seas, where a significant portion of our cultural heritage awaits discovery.

When should exploration begin?

Probably twenty years ago. But better late than never. A number of other nations have already begun programs to explore their territorial waters. Even Ireland has an ambitious program to map its entire (and large) Exclusive Economic Zone, and is already reaping rewards in terms of new discoveries from its efforts. A number of other nations (Japan, France, Russia) have invested in technology for ocean exploration that is decades newer than what is currently available to the U.S. research community. I don't understand that why a country that has won world wars, walked on the Moon, and increased the standard of living of its citizens through superior technology could allow itself to sink to second tier status when it comes to something as important as the oceans. To own the technology is to own the oceans.

Who should be involved?

Expeditions should be led by explorers, with broad interdisciplinary backgrounds, who understand the importance of observing everything, regardless of whether it relates to a specific area of their own interest. Ocean exploration should involve all stakeholders: public, private and non-profit. Business interests, universities, federal laboratories, educators, conservationists, students. NOAA, NSF, Navy, NASA, USGS, MMS, EPA, DOE. Each brings an important element to the table. The efforts of all of these groups will need to be well coordinated through some effective management structure, that includes the coordination of Federal funding. The fruits of exploration should be equally available to all stakeholders so that policy decisions can be well informed from all viewpoints. International collaborations will be essential in territorial waters of other nations and desirable in international waters as well.

How should we explore the oceans?

The program will be most effective if it is systematic, with built-in programs for educational outreach and information dissemination. A plan that appealed greatly to the Ocean Exploration Panel was to center the program around a signature mission: a poleward circumnavigation of the globe. The mission would begin in Maine, continue down the U.S. eastern seaboard, into the Gulf of Mexico, to the Equatorial and South Atlantic, around Antarctica, back up through the Indian Ocean to the western Pacific, across to Hawaii and California, northward along the Pacific Coast to Alaska, and culminating with a mission under the Arctic ice cap. In each region, the exploration would begin with reconnaissance mapping of the seafloor and water column. The next phase would involve detailed exploration by a state-of-the-art flagship equipped with new-generation submersible technology and high-bandwidth, satellite communication to bring the real-time discoveries to aquaria, schools, homes, and offices. The flagship would also be set up to archive samples and distribute validated data to data repositories and from there, over the Internet. In the wake of the flagship's detailed observations, ocean observatories would be installed in key locations to continue the exploration into the time domain.

How much should the U.S. invest in ocean exploration?

The Ocean Exploration Panel recommended $75M/per year for an initial period of ten years, exclusive of capital costs. This is clearly a small investment compared with the value of the ocean to the U.S. economy. We decided on this number based on several arguments. Given that the discoveries from ocean exploration will lead to questions and specific hypotheses that will need to be followed up by research programs, an Ocean Exploration Program that is approximately 10% of the size of the total federal ocean research portfolio is reasonable. Alternatively, a bottom-up calculation for the necessary components of the program: (signature mission, auxiliary explorations, technology development, the education and public outreach, the technology transfer) leads to a similar dollar estimate. Our assumption was that contributions towards ocean exploration from state and private sources and in-kind support from existing government-funded efforts would make the total investment in ocean exploration several times the nominal $75M recommended.

Summary

I hope that Congress will support ocean exploration because the ocean is a mysterious living universe critically important to the functioning of the planet. But even if you support ocean exploration only because of its potential to increase national wealth, encourage ocean conservation, improve public health, regain U.S. technological superiority, and promote science literacy for the public, aren't these reasons good enough?

The full text of the panel report is available at:

http://oceanpanel.nos.noaa.gov/

Chairman GILCHREST. Thank you, Dr. McNutt. Dr. Ballard.

STATEMENT OF ROBERT D. BALLARD, PRESIDENT, INSTITUTE FOR EXPLORATION

Dr. BALLARD. I want to thank the Chairman and the Ranking Members of the Resources and Science Committees for convening this Hearing today and most importantly, for convening that jointly.

Many people perceive Resources and Science as separate categories, yet in my field, at least, in ocean exploration, they are closely related. It is appropriate to hold this joint Hearing as we begin to define our policy for ocean exploration so that we can move forward into the new millennium with a blueprint for the future.

For years now, we have referred to space as the last frontier. The words of Star Trek. We must go where no one has gone before. I strongly believe that America must maintain its lead in space exploration, but it is by no means the last frontier. Ironically, we have better maps of Mars on the side we can never see, than we have of Earth, itself. Most people don't realize that when Neil Armstrong took that giant leap for mankind on the surface of the moon, it occurred before earthbound explorers using deep diving submersibles entered the largest mountain ranges on our home planet.

Today, we have only explored a fraction of the world's oceans that cover more than 71 percent of the earth. This is particularly true in the Southern hemisphere where the oceans occupy 81 percent of the surface area of the planet.

Going back in time, I find it—as I have somewhat become a historian over recent years, to look at exploration in the 18th and 19th century. In the 18th and 19th century, England commonly had more survey ships in the Southern hemisphere of Earth than America now has exploring there in the 20th century.

There is virtually really no major ocean exploration program within our country. You might ask why explore? Because exploration has always preceded exploitation of the natural resources of our planet. Before we discovered the vast oil and gas and coal deposits of the West, before we had Yellowstone National Park, before there was an Anaconda Copper Mine, there was a Lewis and Clark expedition. The vast majority of our planet has never had a Lewis and Clark expedition pass through its unchartered wilderness.

I am also convinced that there is more history to be found in the deep sea than all the museums of the world combined. Yet we are only now beginning to look for that history.

I can't think of a better Nation to lead the world in a new wave of ocean exploration than our Nation. A Nation founded and explored by pioneers. I also would like to make an aside. When I was watching Dr. Colwell's videotape of the hydrothermal vents, I had to smile. Because I was co-chief scientist of the expedition that made that discovery in 1977. And we were not looking for what we found. We were looking for something else. And fundamental exploration is commonly when you are looking for something and you find something else. And, certainly, that discovery points that out.

But future explorers of Earth need to develop the technology necessary to explore the vast and remote regions that lie beneath the sea. We need a new generation of exploratory vehicles that we call AUVs, autonomous vehicles capable of accelerating our rate of exploration.

But I would also like to take the discussion a little bit further afield than what Marcia said so far and what I have said so far. Because while our exploration is underway, it—we really need to begin looking at how we can better farm the sea.

The use of the sea is still primitive, just as the farmers and ranchers came to America to plant their crops and tend their herds, significantly increasing the productivity of the Great Plains and eventually feeding the world, we need to stop being the hunter—gatherers of the sea and start to become their shepherds. To do that, we need to develop technology that—in the future for future farmers and future ranchers of the sea that will follow exploration.

Besides exploring, exploiting, farming and hurting the sea, we also need to protect it's natural beauty and cultural heritage for the enjoyment of countless generations to come. Just as we have set aside wildernesses and national parks and preserves on land, we need to do the same in the sea.

The National Marine Sanctuary is a beginning of that concept. But it is just a beginning. These newly created sanctuaries need to be expanded. And the creatures and human history within their boundaries better protected. But before the marine sanctuaries can gain the necessary public support to ensure their long-term protection, the public needs to be able to visit them, just as we visit Yellowstone Park and the Grand Canyon today. Working with NOAA, our team is—at the Institute has just made a systematic survey of the latest marine sanctuary in Thunder Bay, Michigan. There, in addition to shipwrecks, which we were mapping and discovering, we also found evidence of geological features that suggest possible Indian habitation before that area went under water.

Later this year, again, working with NOAA, we will be working in Monterey Bay at the Marine Sanctuary using the latest in telepresence technology. People visiting our facility in Connecticut will be able to do live tours in the Monterey Bay Marine Sanctuary, home of the beautiful sea otters and sea lions, all the way across the United States, building a constituency and support for the public.

I know my time is short and I wanted to submit the rest of my testimony, which has been submitted to you for the record. So I will see the red light is on and I will stop. Thank you very much.

[The prepared statement of Robert D. Ballard follows:]

PREPARED STATEMENT OF ROBERT D. BALLARD

I want to thank the Chairmen and ranking members of the Resources and Science Committees for convening this hearing today and I'd like to commend you for doing this as a joint effort.

Many people perceive Resources and Science as separate categories, yet in my field, at least—ocean exploration—they are very closely related. It is appropriate to hold this as a joint hearing, as we begin to refine our policy for ocean exploration so we move forward into the new millennium with a blueprint for the future.

For years now, we have referred to space as the last frontier and in the words of Star Trek, felt we must "go where no one has gone before". I strongly believe America must maintain its lead in space exploration but it is by no means the "last frontier".

Ironically, we now have better maps of the far side of the moon that has never faced Earth than we do of Earth itself. We have better maps of Mars and Venus than of Earth.

Most people do not know that Neil Armstrong TOOK that "giant leap for mankind" on the surface of the moon BEFORE earthbound explorers using tiny deep diving submersibles entered the largest mountain range on our own home planet. We had to wait until 1973 for that, four year after Armstrong's "giant leap".

Today we have explored only a fraction of the world's oceans, which cover more than 71% of the Earth. This is particularly true in the Southern Hemisphere, where the oceans occupy 81% of the planet's surface area.

Going back in time, you will find that, during the 18th and 19th centuries, England commonly had more survey ships in the Southern Hemisphere of Earth than America had in the 20th century.

Why explore? Because exploration has always preceded exploitation of the natural resources of our planet. Before we discovered the vast oil, gas, and coal deposits of the west, before there was Yellowstone National Park, before there was an Anaconda Copper Mine, there was a Lewis and Clark Expedition. The vast majority of our planet has never had a Lewis and Clark Expedition pass through its uncharted wilderness.

What better Nation to lead the world in a new wave of exploration than our nation, a nation founded and explored by pioneers?

But future explorers of Earth need to develop the technology necessary to explore the vast and remote regions that lie beneath the sea. We need a new class of exploratory vehicles known as AUVs: autonomous undersea vehicles that can accelerate our rate of exploration.

And while this exploration is underway, we need to begin developing how we can better farm the sea. Our use of the sea is still primitive. Just as the farmers and ranchers came to America to plant their crops and tend their herds, significantly increasing the productivity of the Great Plains and eventually feeding the world, we need to stop being hunters and gatherers of the sea and become their shepherds. To do that, we need to develop the technology future farmers and ranchers of the sea will need.

Besides exploring, exploiting, farming, and herding the sea, we also need to protect its natural beauty and cultural history for the enjoyment of countless generations to come. Just as we have set aside wildernesses and national parks and preserves on land, we need to do the same in the sea.

The National Marine Sanctuaries are a new concept that begins that task. These newly created Sanctuaries need to be expanded and the creatures and human history within their boundaries better protected. But before these Marine Sanctuaries can gain the necessary public support to insure their long-term protection, the public needs to be able to visit them just as they visit Yosemite or the Grand Canyon. Working with NOAA, my team from the Institute for Exploration just recently made the first systematic exploration of our newest Marine Sanctuary in Thunder Bay, Michigan. There, in addition to the shipwrecks that have already been identified, we found more highly preserved ones in pristine condition.

Later this year, again working with NOAA, we will conduct the first guided tours of the Monterey Bay Marine Sanctuary using the latest in telepresence technology. People visiting our facility in Mystic, CT will be able to participate in "live" guided tours of the wonderful kelp forests of Monterey Bay, home to sea otters and California sea lions.

The technology to do all this is brand new, cutting edge and very exciting. Developed in cooperation with NOAA, it was field-tested in the Black Sea last summer and is slated to go to Antarctica in the coming spring. In addition to the exploratory technology, we have to develop the technology that will be needed to live in the sea. I am not talking about living underwater in habitats but living on the surface of the sea. At this very moment NASA's International Space station is orbiting Earth and inside that space station scientists are attempting to grow plants in the simulated soil of Mars. Isn't it ironic that we are preparing for the eventual colonization of Mars, the Moon, and outer space but are not exploring how we might someday colonize the sea?

Years ago, the Office of Naval Research sponsored the development of the FLIP. A large human occupied buoy that is towed to sea and flipped vertically into position, FLIP makes it possible for a team of scientists to live for long periods of time at sea, able to survive the roughest of seas in relative comfort. The oil industry has utilized this concept to build large offshore oil and gas platforms. Now we need to do the same with an eye toward families living at sea like the pioneering families that settled the west. We need to conduct research that would enable these families to grow their own food as well as develop their own aquaculture.

To conclude, I truly believe that the next generation of explorers who are presently in elementary school will explore more of earth than all previous generations combined. But it is our job to insure this prediction comes true. First and foremost, we need to motivate and inspire the coming generation to be explorers. That is why I created the JASON Foundation for Education more than 12 years ago. When this effort first began, the dominant child in this program was a white boy.

But I am proud to say that during the short history of the JASON Project that demographic make-up has changed dramatically. Today, we have more than 1 million children in America participating in the JASON Project and their demographics reflect America's population diversity and in fact, the majority of participants are young women.

I want to thank you again for holding this joint meeting and asking me to give this short presentation. This concludes my formal statement.

PANEL II DISCUSSION

Chairman GILCHREST. Thank you very much, Dr. Ballard. Dr. Ehlers?

Mr. EHLERS. Thank you, Mr. Chairman. A few quick questions. Dr. Ballard, first of all, I am curious, where does your money come from? And I mean the Institute's, not yours, personally.

Dr. BALLARD. Well, fortunately, we are fortunate as Monterey Bay, in fact, Dr. McNutt and I have just written a joint paper together in the Journal of Marine Technology about how our institutions are rather unique to traditional oceanographic—in many cases, the vast majority of my funds come from the public visiting our facilities. We have received Federal funding. We have received support from the Office of Naval Research, from Admiral Cohen and his group behind me for the development of technology. We received support from NOAA for the use of that technology and exploration, but my salary and all of my staff's, quite honestly, come from people visiting our facility.

Mr. EHLERS. And Dr. McNutt, same question for you.

Dr. MCNUTT. Yes. I find it—and, of course, you have picked up immediately on this quite important distinction that the two institutions that are probably doing ocean exploration in its pure form right now are both privately funded. We receive small amounts of Federal grants. But basically, the mission, the technology we have developed has all been done under the auspices of the David and Lucille Packard Foundation.

Dr. BALLARD. And I would like to add just that exploration is only recently begun to join—enter the vocabulary of oceanographers. Through most of my career, you did science, you did research. You did not do exploration. And it has only been fairly recently that one can actually find a place to submit a proposal to as an explorer.

Mr. EHLERS. Thank you. I have used the—an immense amount of Hewlett-Packard equipment during my lifetime. I am pleased that some of that went to support your Institute. What new technologies should we develop or work on as a nation to enable more expansive and comprehensive ocean——

Dr. MCNUTT. Actually, it is an important issue. My own sense is that in the physical sciences area, the technology is far more mature and available off-the-shelf for measuring things like the temperature of the ocean, measuring currents, measuring its interaction with the atmosphere.

I believe that in the chemical and in the biological realms that is where the sensor technology is very much less advanced. But with the marvelous new tech—new tools—the new tools that are coming down the line thanks to the biotechnology revolution and also through MEMS technology, micro electrical mechanical devices, there are now possibilities to explore the ocean in the biological and the chemical realm that were never available before.

And as Dr. Ballard already mentioned, the importance of cost effective platforms for delivering those tools to the ocean is extremely important. We have relied on tools such as ALVIN for nearly 50 years now as a primary tool for exploring the ocean. But it is simply too expensive to use in some mass quantity. And we need autonomous underwater vehicles and remotely operated vehicles to provide more affordable access to the oceans.

Dr. BALLARD. In Dr. McNutt's testimony she talked about having an exploratory research vessel. I mean, the problem is I think what is the recipe for chicken soup. First you get the chicken, and we do not even have the chicken. We do not have a ship that is dedicated to ocean exploration. And certainly not in the Southern Hemisphere. I mean, you just have to realize how much of the Southern Hemisphere is unexplored, the vast majority of it. And we really need a ship platform. And then from that platform vehicle systems that will greatly accelerate our rate of exploration, which is very slow right now.

Mr. EHLERS. I will resist the temptation to ask you where chicken of the sea comes in.

Dr. BALLARD. It's a tuna.

Mr. EHLERS. I know, I know. I am struck by some of the things that you have said. And it reminds me when I as a youth religiously read National Geographic about their tremendous underwater explorations with very primitive vessels. And I found that really intriguing.

I wonder if what we do not need is another Jacques Cousteau to stimulate public interest.

Dr. BALLARD. It was not bad.

Mr. EHLERS. Pardon?

Dr. BALLARD. It was not bad. He did a pretty good job.

Dr. MCNUTT. He is the reason I am an oceanographer.

Mr. EHLERS. Yeah. And just—we have to stimulate more public interest in this issue. And the whole idea of exploring the ocean, which is what we did for a number of years. And now we have just gotten into the measurement and research phase.

Dr. BALLARD. We do have a JASON Project which has 1.3 million children in it right now.

Mr. EHLERS. I am well aware of that.

Dr. BALLARD. And it has been stimulating a lot of them.

Mr. EHLERS. And presumably, some of them will be Members of Congress at some point.

Dr. BALLARD. Or President.

Mr. EHLERS. Yes. I see my time has expired. I yield back.

Chairman GILCHREST. Mr. Underwood.

Mr. UNDERWOOD. Thank you, Mr. Chairman. And thank you for your testimonies. I was struck too by some of the comments, especially made by Dr. McNutt. If you would care to elaborate on some of your comparisons to what our country does in terms of oceanographic research versus some internationally. You seem to indicate that perhaps we are not giving it as much effort and attention as some other countries in a proportionate way.

Dr. MCNUTT. Yes. Compared to our GNP there are a number of countries, New Zealand, Ireland, France, Japan, that invest more in the ocean than we do. And given the very large amount of territorial waters under our jurisdiction it simply does not make sense.

My sense is that one reason why the U.S. oceanographic community has managed to maintain a premiere position is not because per capita our funding is the best, or because our tools are the latest generation, but simply we have a very, very well educated, very creative work force that is drawn globally from all over the planet that is conducting ocean research here. And we have a good system for identifying the best people and getting them funded.

It is not because we pay them the most. It is certainly not because we give them the best tools. We have a good system. And if we could build upon what are those strengths, by giving them the A-Team in terms of facilities and in terms of funding, the bottom of the ocean is the limit. The sky is the limit——

Mr. UNDERWOOD. The—what is the—what is the nexus then between the research institute and the universities, and what do you think is an appropriate relationship, I suppose, between the research institutes, the universities and government support of that? And do you—do you see that there are models in other fields of endeavor which would be conducive to the kind of enterprise we want——

Dr. BALLARD. Clearly, space exploration I think does——

Mr. UNDERWOOD. So is it——

Dr. BALLARD. Well, fine. But I think they do encourage exploration more.

Dr. MCNUTT. Yes.

Dr. BALLARD. I think there is——

Mr. UNDERWOOD. Well, how did that come to be, in your estimation? And——

Dr. BALLARD. Perhaps just the shear vastness of the problem. I think too that the unknown.

Dr. MCNUTT. Well, I think too we cannot downplay the fact that solving this problem was much easier in space because we had one government agency with the mandate for space that was created. NASA. It is easy—NASA has a very large external program that supports both technology and science and exploration in the university community, as well as, its NASA centers. They work well together. In the oceans the jurisdiction is much more diffuse. And it has been much harder to build a system like that.

I think from the standpoint, speaking as someone outside of the government, I think there is a great amount of good will out in the academic community and the research center community to all work together to these great aims. But when we look at where in the Federal Government do we plug in, we find that it is a much more diffuse system. And there is not sort of sole leadership there, we know where to go in order to all work together and to make this gel the way it has for the space community.

Mr. UNDERWOOD. Well, and you were a member of the President's panel, are you not?

Dr. MCNUTT. Right.

Mr. UNDERWOOD. And what—how was that issue addressed?

Dr. MCNUTT. The President's panel recommended that NOPP was probably the best mechanism we had right now for trying to get that to come together. In other words, the National Ocean Partnership Program which has representatives on the Leadership Committee from Navy, NOAA, NSF, NASA, USGS, that that is one place where they come together and try to coordinate. It still does not have quite the central management, if it were simply one agency. But it is certainly the closest we have yet come in my 30 years of being an oceanographer to something that works to coordinate ocean research.

Mr. UNDERWOOD. Okay. Dr. Ballard, I know you want to address that as well. But could you also address then in the context in your answer about how perhaps better we could utilize the Navy or Department of Defense assets?

Dr. BALLARD. Well, we have. I mean, the Navy has—certainly the Office of Naval Research in particular has always been a pioneer in the development of ocean exploration technology. It was the Navy that first developed manned vehicle systems, first encouraged the use of the Bathyscaph 3S. Later the Bat—developed the ALVIN vehicle system. ONR has been a pioneer in ocean exploration technology development. It is the use of that technology in exploratory manners.

You have to understand that exploration is a risky business. And scientists are—tend to be very cautious about taking great risks. You cannot come up short too many times and maintain your career. And I think scientists tend to be very cautious. And I think the agencies tend to—to somewhat encourage that cautiousness, which is part of the scientific process.

It is not the process exploration. Exploration is very risky. And that is there is no place for explorers, like myself, to go. I mean, I have to go to the National Geographic Society to do what I would do really risky exploration. Or do things and then beg forgiveness from the Navy later on. I have done that a number of times. Do not ask permission, beg forgiveness. And I have done that numerous times. Of course, the Office of Naval Research has a wonderful philosophy about that kind of thing.

Dr. MCNUTT. Forgiveness——

Dr. BALLARD. Yes. And he is sitting right behind me.

Chairman GILCHREST. Thank you. Mr. Faleomavaega.

Mr. FALEOMAVAEGA. Thank you, Mr. Chairman. And I certainly want to compliment Dr. McNutt and Dr. Ballard for their fine testimonies. I was struck by your statement, Dr. McNutt about the fact that several other nations of the world are far more advanced than us. And that is the very point that I was trying to get to in my earlier line of questions. As the saying goes, if you want to know what our national priorities are look at the budget. And I—that is where I raise the curiosity about those four areas that I was trying to seek or solicit the best opinions of our previous panel in terms of where are we really putting emphasis in terms of our national priorities. And the bottom line is how does it compare to those areas.

I—and to compliment, also Dr. Ballard mentioned, in my recent discussions with the Prime Minister of the Cook Islands, he has had to contract a Norwegian commercial oceanographic exploratory company to do the research for the Cook Islands to find out how many seabed minerals are out there in the three million square miles of ocean that is part of the jurisdiction of this little island nation. Small in numbers, but three million square miles. And to my surprise there was no American company. And that really shocked me. And I thought, man, I thought we had the best scientific situation as far as going into this kind of a situation.

Seabed minerals is a risky business, I am sure. Dr. Ballard is very familiar with the issue involved here. But when I hear the Prime Minister telling me that estimates at least, at least, well over $200 billion worth that could be harvested from the ocean of this little island nation, can you imagine what it is like in the rest of the other regions of the Pacific Ocean. And as well as the Atlantic, I suppose.

So that is where my concern comes in. I honestly believe, and in my opinion, and I have known Mr. Chairman, Mr. Gilchrest, we are not advanced in our agriculture development. We are a nation of importers of fish, which really baffles my mind. Why we—why looking at other nations where they really are far more advanced even in their fisheries programs.

You mentioned earlier about the situation that we find ourselves in the Pacific. I do not know, is there any difference between research and exploration?

Dr. BALLARD. You bet.

Mr. FALEOMAVAEGA. Okay. So the research of the pencil pushers, right. There are other ones out there looking at the dangers of——

Dr. BALLARD. No, not at all. I think that exploration is fundamental exploration. I would not think that you would characterize the Lewis and Clark Expedition as a scientific expedition. It was funded out of the pocket of the White House.

Dr. MCNUTT. Yeah, if I could add. Typically, what happens in order to conduct research, someone has a hypothesis. And they go out and they gather data that is pertinent to that hypothesis. They do not gather data that is not pertinent to the hypothesis, even though it might have been more important to gather. And that data is then used by that researcher to address that narrow aim. The data is not necessarily widely sent out to anyone to answer questions that were not—that did not occur to the researcher at the time that the study was conducted.

Mr. FALEOMAVAEGA. I think both of you had also made comment earlier about not only do we need to explore the ocean, but we also need to maintain it. No other region of the world where the people living in this region of the Pacific, and I can say that our own country detonated 66 nuclear explosions, hydrogen bombs and atomic bombs. The Bravo test that took place in 1954 was 1,000 times more powerful. The nuclear detonation in 1954 was 1,000 times more powerful than the nuclear bomb that we put on Nagasaki and Hiroshima.

The French Government, many Americans do not know this, exploded over 218 nuclear bombs——

Dr. MCNUTT. Mihara.

Mr. FALEOMAVAEGA [continuing]. In the South Pacific. And right now this little island of Mihara is called a Swiss cheese because they have had to go down 2,000 feet in exploding supposedly that is supposed to contain it. And now they find out that there are fissures, there are cracks. And I would like to see some day that maybe we will find a nuclear fissure and send it to President Chirac and see what kind of a job he has done in caring for the ocean and the problems that we face. And I say this with tremendous sensitivity. Because we live there. And I would like to think that there is a sensitivity that we do care for the environment, especially in this area of the ocean.

I just want—I am not going to get into anymore hypotheticals and my good friend, Admiral Cohen, there. I am absolutely certain that the U.S. Navy Department has got more information on exploration and observation that they would care to share with us that I just wish that maybe they could declassify it so in that way the scientific community can benefit, we can make more sense economically to compete with other nations when it comes to fisheries and the amount of things that we need to do in this area. And perhaps, Mr. Chairman, we can hold an oversight area where the Navy Department alone and maybe help us in that.

Because I honestly believe that it is true that these four basic areas are interaction and you cannot separate one from the other. But I believe that the—I should not say monster, but the good person out there with all the money and the scientific resources to do this is our—none other than the friendly U.S. Navy. And maybe they could help us a little more with the rest of our scientific community to come up to par with all the information so that we could be more economically viable in getting into the resources of the ocean.

One quick comment, Mr. Chairman, there are 14,000 varieties of algae. We have only been able to discover there is only about 1,000. And one algae product right now that is now being used by one company is for a tremendous cure for a lot of the—certain diseases. This is something that we have not even touched on.

I am sorry, Mr. Chairman, my time is up.

Chairman GILCHREST. All right, Mr. Faleomavaega, we appreciate your question. I think these people that are coming to testify before us today are encouraging us to do a lot more than we are doing of the things you are suggesting. So it is really our responsibility to appropriate the sufficient funds.

We also have a hearing scheduled with the Navy to deal with some of the things that you suggested about their research. Specifically, with sonar and marine mammals. But we certainly can add to that some of the hot-spots globally that they may be aware of. And we might find it pretty interesting.

They have rung for a vote. I think I may be the last person to ask questions before the vote. What we will do when I am done with my questions, unless there are any follow-up questions, we will recess. I believe there is just one vote. And we will back for the third panel.

Dr. McNutt, you talked about a signature mission with a flagship. Is there a ship presently in the U.S., without building one, that you could recommend do that?

Dr. MCNUTT. I am sure there is. I do not believe that it would be necessary to create a new ship. I think that it would be necessary, however, to refit substantially any existing ship. I think some of the larger class ships in the Naval Fleet could be adequate. I am sure that Navy or NOAA probably have adequate ships.

The important thing would be it must be a ship that is equipped for public outreach. And it has to be equipped, I believe, with the latest in submersible technology. Because what the public is going to want to see is not a chart recorder. They are going to want to actually be part of the exploration. They are going to want to see the high definition television cameras on the sea floor, see experiments going on, see marine creatures being observed in their environment. They are going to want to feel that they are part of that, not just see instruments writing down numbers.

It will also be important that that ship be ice-strengthened to go to polar seas. And it is going to be important that the ship be equipped with the latest in navigation and telecommunications equipment. So I believe that we could find in the current fleet——

Chairman GILCHREST. Have you discussed this at all, this particular concept signature mission with let us say, National Science Foundation or NOAA or the Navy or Dr. Ballard?

Dr. MCNUTT. Yeah. It has certainly been discussed with——

Dr. BALLARD. I was on the same commission.

Dr. MCNUTT. Yes, yes.

Chairman GILCHREST. I see.

Dr. BALLARD. I was part of that recommendation. And I would add that remember when we found hydrothermal vents we had no—we did not have the right scientists aboard. We had no biologists. And we had to wait 2 years before we could get the experts who knew something about this discovery back to that spot.

That is why we need not only public outreach for telecommunications so that the young explorers of tomorrow can participate in these expeditions, also the necessary telecommunications technology, the network scientists when you are out exploring and you are making discoveries, you are more than likely do not have all the experts aboard. And you need to be able to network them in. So the use of telecommunication technology is critical. It would certainly be nice if we could get oceanographic ships that could go faster than 15 miles an hour.

Chairman GILCHREST. Is this a concept that can be—you mentioned NOPP a number of times, National Ocean Partnership Program. Is this a concept that can work through NOPP?

Dr. MCNUTT. I believe it is. But you have to understand that this would be a great expansion of NOPP. Because NOPP is an actually pretty small pot of money that they are dealing with now. I think to do this right——

Chairman GILCHREST. When I say NOPP though, I mean, the—we could do our best to come up with the funding. And I certainly think this concept is one of those things that we can pursue to sort of enhance exploration research. But to push the public momentum toward this kind of thing.

Dr. MCNUTT. I think NOPP can do it. With my experience in being involved with NOPP, I have been impressed at the way that they have been able to do things that are larger than an individual agency's purview.

Chairman GILCHREST. As a first step though, you know the Administration recommended a budget of I think it was $14 million for ocean exploration. And I think the House to this point has put up $6. I think as a beginning it would be nice to...

Dr. BALLARD. Keep to $14.

Chairman GILCHREST. Absolutely.

Dr. BALLARD. I think the Senate may be with you on that.

Chairman GILCHREST. Well, maybe we can work that out in conference.

Last question, Dr. Ballard, you mentioned an idea of shepherds of the sea where we used to—we went into the frontier of various areas of the planet and began to harness the energy there and then began to produce food. We know a lot more now about soil in its complexity than we did just 20 years ago. And the nature of good bacteria, bad bacteria, nutrients, nitrogen, phosphorus——

Dr. BALLARD. Right.

Chairman GILCHREST [continuing]. And those kinds of things. And their impact on the local ecosystem and the watershed. If we pursue, and I am sure it will be pursued, this idea of shepherds of the sea I would assume then we would have to know a great deal more about the complexities of that marine ecosystem.

Dr. BALLARD. Absolutely.

Chairman GILCHREST. Set aside refuges on the land, marine protected areas in the sea. So do you see——

Dr. BALLARD. Yeah. I have been frustrated over the years. I have been in the field for 4 decades. And without taking a global approach to managing the oceans. I mean, certainly there are resources in the ocean. But there are certainly beautiful places that need to be preserved. I see it no different than I look at the United States. I have national parks. I have areas where farmers farm. I have places where the military operate. You know, there are so many ways that one can look at it in a much more sophisticated way. We are still very primitive.

Dr. MCNUTT. We are still open range.

Dr. BALLARD. We are no different than hunter gatherers of thousands of years ago of going out and hunting buffalo. We are out there hunting buffalo right now. We are blowing the buffalo all the way. And we are basically replicating what we did to the—in the early history of our country. We should not do that. We should really be taking a sophisticated look at management. When I say shepherds, I mean that. I mean shepherding the ocean for both—everything that we are talking about. Exportation, exploration, living.

Is it not amazing that right now you have a space station going over our head. And in that space station they have soil simulating Mars. And they are trying to grow plants. Because NASA has the mission to talk about colonization of Mars, the Moon and outer space. And nowhere in this country are we talking about the colonization of the oceans. I just find that mind-blowing.

Chairman GILCHREST. I am going to have to go for a vote. And I do appreciate, as we all do, your time, your chosen careers, and your testimony here this afternoon. Dr. Ballard, Dr. McNutt, thank you very much.

Dr. BALLARD. Thank you.

Chairman GILCHREST. We will recess for about 15 minutes.

[Recess]

PANEL III: DR. ROBERT A. WELLER, DR. J. FREDERICK GRASSLE, DR. ALFRED M. BEETON, DR. ALEXANDER MALAHOFF.

Chairman GILCHREST. The Subcommittee will come to order. I apologize for the interruption. We may have another one. Because we might have another vote within 10 minutes or within 45 minutes, so I thought it was best to come back and get started again. But thank you very much for your patience and your endurance through all of this.

The third panel is Dr. Robert Weller, Director of Cooperative Institute for Climate and Ocean Research, Woods Hole Oceanographic Institute. Welcome, Dr. Weller.

Dr. J. Frederick Grassle, Director of Institute of Marine and Coastal Sciences, Rutgers University. Welcome.

Dr. Alfred Beeton, Senior Science Advisor, National Oceanic and Atmospheric Administration. Welcome, sir. I am a little tongue-tied today.

And Dr. Alexander Malahoff, Director, Hawaii Undersea Research Laboratory, University of Hawaii. Gentlemen, thank you very much for coming.

Dr. Weller, you may begin.

STATEMENT OF ROBERT A. WELLER, SENIOR SCIENTIST AND DIRECTOR, COOPERATIVE INSTITUTE FOR CLIMATE AND OCEAN RESEARCH, WOODS HOLE OCEANOGRAPHIC INSTITUTION

Dr. WELLER. Thank you. Good afternoon, Mr. Chairman, members and staff. Thank you for the opportunity to speak. I am, as you said, Mr. Chairman, Director of the Cooperative Institute for Climate and Ocean Research. I am also a blue water oceanographer and I spend about 1 to 2 months a year at sea.

In April 1997 I sailed from Peru to deploy three moorings in the eastern tropical Pacific. One north of the equator, one at the equator and one south of the equator. When we got to the equator we found strange surface currents, strong currents to the east, not what we expected. A message to colleagues at NOAA's Pacific Marine Environmental Lab provided the answer.

What had happened is that earlier that year in February and March 1997 strong wind events in the western tropical Pacific had excited an oceanic disturbance that was moving its way across the equator. We had intercepted that disturbance. This disturbance it turned out was signaling the onset of the 1997 El Niño which became one of the strongest on record. As you know, during El Niño the presence of anomalously warm water in the eastern tropical Pacific leads to dramatic changes in weather and climate around the world.

After a strong El Niño in 1982 to 1983, NOAA, the National Science Foundation and international partners, had moved forward and begun to deploy an array of 70 moorings to measure surface winds and upper ocean temperatures in the tropical Pacific. It was data from this array that provided us the alert on the ship. It was data from this array that provided the early warnings of the 1997 El Niño and allowed people around the world to prepare.

In 1999 it was estimated that the value to consumers and producers of these early warnings, for just the U.S. and just the agriculture sector, had been $300 million. For all sectors, the estimate of the value was $1 billion a year. This is a huge payoff when you weigh it against what the U.S. puts into the El Niño observing system annually, $12 million.

There is potential to reap even greater benefits. The ocean stores 1,000 times more heat than the atmosphere. It plays a key role in weather and climate variability on time scales from days to years to decades, out to centuries. It is the climate time scale that we are concerned about.

To bring up a figure, the challenge to moving forward on an ocean observing system is the fact that the world's oceans are interconnected. Water moves from the surface to the bottom and back to the surface along pathways that are global. In the higher latitudes, as you can see in the—on the right-hand side of the North Pacific and the left-hand side in the North Atlantic, ocean water is cooled. It becomes dense, it sinks. It sinks into the interior. It flows through the interior of the world's oceans, eventually returning at and near the equator where it is warmed before it returns poleward.

This interconnectivity means that change at high latitude today in the North Pacific can in several years shows up at the equator in the Pacific and changes the character of El Niño. It also means that change today at high latitudes in the North Atlantic will eventually find its way throughout the whole globe, all the world's oceans. Change at the high latitude in the North Atlantic might in fact disrupt the whole global circulation pattern that you see in this picture.

Now this challenge is one that we are ready to take on. We know what we need to do. We have the tools. The U.S. has been leading in oceanographic research for decades. The National Science Foundation, the Office of Naval Research, the National Oceanic and Atmospheric Administration have provided the tools, the necessary foundations of instrument development, and basic research.

What is the plan? We will deploy drifting buoys, both on the surface and the ARGO profiling floats. These will give us broad special coverage. We will install moorings. These moorings will collect times series that are required to quantify air to sea exchanges of heat, fresh water, and greenhouse gasses, like CO_2. And to measure the transports of those properties within the ocean. These moorings will collect data from the sea surface down to the sea bottom.

We will make measurements repeatedly from merchant ships of both surface meteorology and ocean variability. Every five to ten years we will use research ships to collect samples over the full depth of the ocean during cruises that cross the basins and look at how man-made chemicals such as freons and CO_2 are slowly penetrating.

In summary my points are these, first, there is a huge economic benefit. Two, we must go forward globally. The oceans are interconnected. Three, we have the tools, we just need to do it.

I would like to close with a brief, very brief, video and show you some pictures of some of these elements. What you will see at first is my research group from Woods Hole Oceanographic working in the tropical Pacific deploying moorings. That is a surface buoy going over. That is what carried the meteorological instrumentation. Underneath we are attaching oceanographic instrumentation. We are going to anchor this in 4,000 meters of water. All along that mooring line we are putting instruments to measure temperature, salinity, currents. At the bottom we have hollow, glass spheres inside these hard hats as emergency buoyancy. There is an acoustic release. That is the anchor going over.

We will now steam away from that mooring and leave it for a year. A year later we return to that mooring, recover it. Come alongside, grapple that mooring, recover it, get the data out of the instruments and replace it with the new mooring to keep taking the time series.

We heard earlier about the ARGO floats. That is an ARGO float going over. A simple thing to do, we can deploy from research ships and commercial ships. Sinking down to 1,500 meters or 2,000 meters and coming to the surface telemeter.

Some of the other elements. These are the tracks of existing merchant ships. We need to make use of these tracks and make use of those ships.

These are the locations where we would deploy moorings around the world. Within the red box is the TAO Array, the only place we have instrumented so far. We need to do the rest of these sites. These are the lines of those research cruises every 5 to 10 years to sample the full depth of the ocean circulation.

Thank you very much.

[The prepared statement of Robert A. Weller follows:]

PREPARED STATEMENT OF ROBERT A. WELLER

The Benefits and Problems Facing the Development of an Integrated Ocean Observing System

Good afternoon Mr. Chairmen and members of the Subcommittees. Thank you for the opportunity to testify. I am Robert Weller, a sea-going research oceanographer at the Woods Hole Oceanographic Institution and also the Director of the Cooperative Institute for Climate and Ocean Research at the Woods Hole at Oceanographic Institution. In my testimony, I will focus on the open or blue water ocean, as you will hear other testimony on the coastal ocean.

There has been growing need for us to understand climate variability both to assess its impact on society and to guide policy decisions. This need provides a good starting point for a discussion of ocean observing systems. To understand climate variability and change in the earth system, which includes the atmosphere, the land, and the ocean, we need to make the observations necessary to track the energy balance among the components and the energy storage in each component. Critical to climate science are observations that explain the heating of the earth by shortwave radiation from the sun, the balance of that energy accumulation by longwave and reflected shortwave radiation returning to space, the impact of clouds, aerosols, and gases on the passage of longwave and shortwave through the atmosphere, and the partitioning of where energy accumulates (Fig. 1). Equally important, observations are needed to track the redistribution of freshwater and the energy associated with changes in phase of water. For this reason, it is essential to field, maintain, and sustain the land stations, sounding balloons, aircraft, and satellites needed to collect these observations (Fig. 2). Because of their importance to weather prediction, these atmospheric and terrestrial networks already exist and should be sustained and improved.

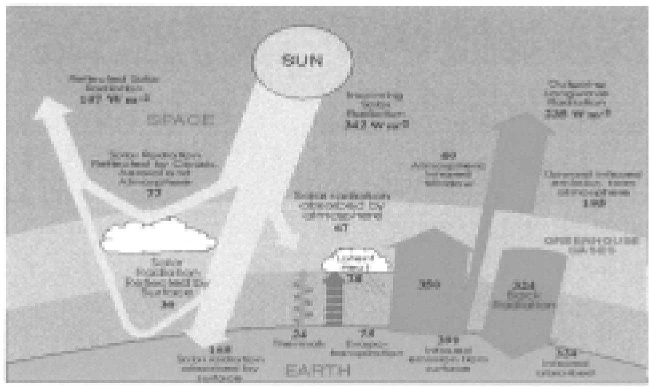

Figure 1. Schematic of the energy coming to earth as incoming sunlight (solar radiation) and being distributed in the atmosphere, to the land, and back to space as well as heating the atmosphere and earth. Incoming energy is balanced by outgoing infrared (longwave) radiation in addition to the reflected sunlight.

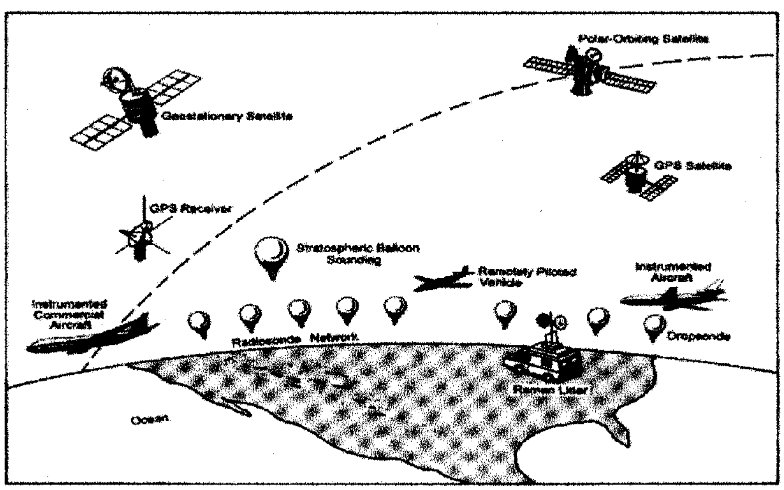

Figure 2. Existing methods for sampling the atmosphere.

However, for the ocean, there is no comparable heritage of sustained observations and no operational global ocean observing system, either for understanding the ocean's role in climate or for support of fisheries, marine transportation, defense or other purposes. An integrated global ocean observing system is needed. Consider the need from the point of view of climate. The ocean, which covers 70% of the earth, can store 1100 times more heat than the atmosphere due to the larger heat capacity and density of water. The upper 2.5 m of the ocean, when warmed 1°C, thus stores an amount of heat that would raise the entire column of air above it 1°C as well. As a consequence, an anomalously warm region of the ocean has the potential of releasing considerable energy to the atmosphere above. That heat release can alter the weather on short time scales and, if it persists, can alter climate.

The ocean has unique attributes, but these problems have been considered and a well thought out plan for the integrated ocean observing system exists. Because they dictate how to construct an integrated ocean observing system (one that is comprehensive and complete), these attributes are reviewed briefly here. Unlike the land, the ocean is not opaque to shortwave radiation and is mobile. Sunlight heats the upper ocean, and the strong solar insolation in the tropics leads to warm ocean temperatures there. There is thus often a warm surface layer that extends down to 50 to 100 m. This layer is in direct contact with the atmosphere and isolates the bulk of the ocean from direct contact with the atmosphere. Surface currents, such as the Gulf Stream, carry warm water from the tropics poleward (Fig. 3). In locations of heavy rain this surface layer is also made more buoyant by the additional

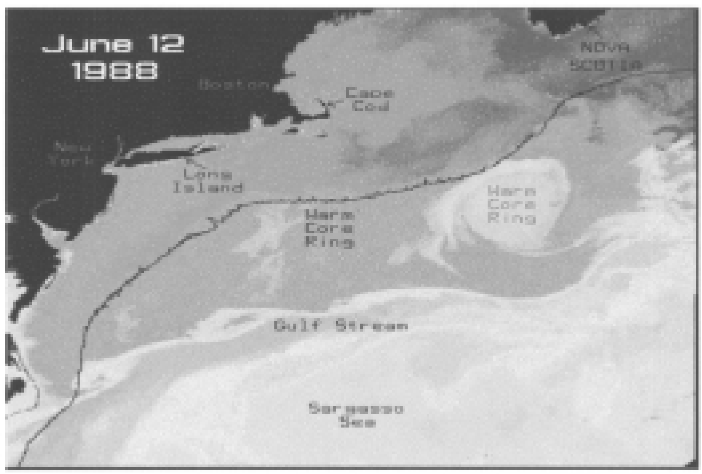

Figure 3. Satellite image of sea surface temperature, showing warm water flowing northeast in the Gulf Stream, the prominent western boundary current of the North Atlantic.

freshwater. In the western equatorial Pacific, rain and solar heating combine to make a warm pool of surface water. During El Niño that warm water is found instead in the eastern tropical Pacific, and the anomalous location of such warm water is associated with the major climate and weather impacts of ENSO. In locations outside the tropics, however, our lack of observations of air-sea exchanges and ocean pathways leaves us unable to be definitive about the mechanisms by which the oceans and atmosphere influence each other, though patterns of variability, such as the Pacific Decadal Oscillation (PDO) and the North Atlantic Oscillation (NAO) are evident.

The circulation in the ocean is not limited to the surface layer. When surface water becomes denser when cooled by the heat loss to the atmosphere and when salt is left behind during evaporation, it can sink into the interior of the ocean (Fig. 4). Convergent, wind-driven flow in the surface layer can also force water into the interior. Horizontal flow in the ocean's interior, like that in the atmosphere, is due

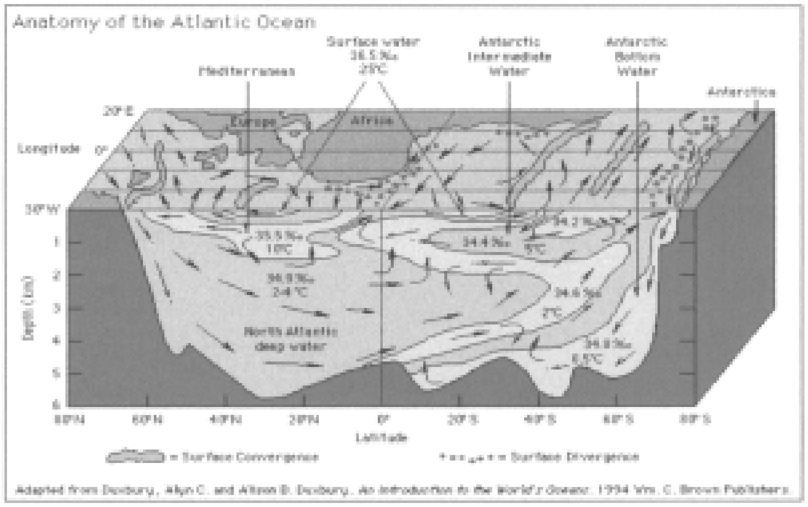

Figure 4. Schematic of the three-dimensional circulation in the Atlantic Ocean. Surface water cooled at high latitudes sinks and flows into the interior. Water at the surface is driven by the wind.

to horizontal pressure gradients resulting from spatial differences in the density of seawater. The action of the surface winds, heat and freshwater fluxes and subsequent flows in the interior of the oceans yield a fully three-dimensional flow. Particularly dense water is formed in the northern North Atlantic and along the coast of Antarctica. A much-simplified schematic of the ocean's circulation shows these water masses sinking and flowing at depth through the global ocean, rising again to the surface where they are warmed by contact with the atmosphere in the tropics and subtropics the deep ocean over the globe (Fig. 5). Note that a warmer globe could lead to melting of the polar ice caps and that the resulting freshness of the surface water at high latitudes could reduce the formation of dense water in the North Atlantic and in the Southern Ocean, thus altering the present large-scale three-dimensional flow of the world's oceans.

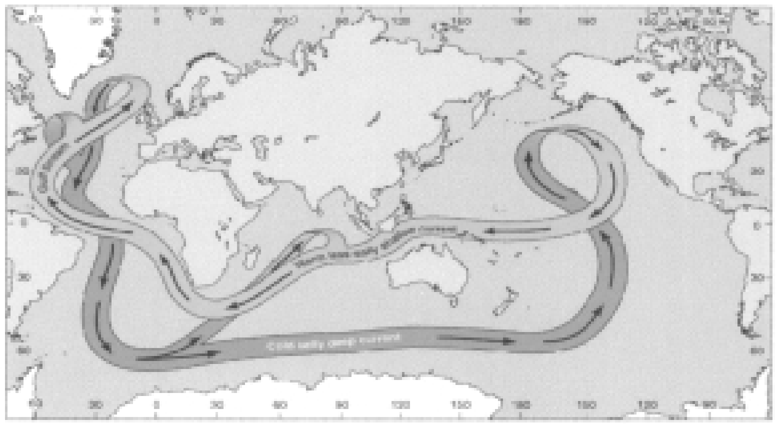

Figure 5. A greatly simplified diagram showing how the water that sinks at high latitudes flow at depth throughout the global ocean, rising to the surface to be warmed and return to the high latitude source region.

Changes in air-sea exchanges and in surface currents alter the pattern of sources and sinks for heat, freshwater, and other constituents at the base of the atmosphere and thus impact climate. The three-dimensional circulation in the ocean fully engages the very large reservoirs of the interior of ocean, over a wide range of time scales reaching to longer than decadal, in the climate system. An ocean observing system must thus observe the air-sea exchanges, the ocean pathways for transport, which lie along the boundaries of the basins as well as at the surface and in the interior, where heat, freshwater, and other properties are stored, and how the pattern of storage is evolving. This is a challenge. Changes in interior temperature and salinity will result in changes in the density-driven flow, which, in turn, may further redistribute these properties. Thus, attribution of change in temperature at a site must consider not only the possibility that additional heat is accumulating or being lost but also that changes in the three-dimensional flow has brought water of a different temperature and salinity to the site.

Measuring the air-sea exchange of heat, freshwater, momentum, CO_2, and other constituents important to climate and weather is a central goal of an ocean observing system. Numerical models and existing climatologies have large errors in the air-sea fluxes they provide, and these errors are an impediment to gauging the ocean's role in climate; and the accuracy of weather predictions at sea is limited by the lack of data from the oceans. The installation of a number (5 to 10 per ocean basin) of surface buoys is recommended to provide, at key locations, accurate time series of the surface meteorology and air-sea exchanges. These buoys would be equipped to measure surface wind, relative humidity, air temperature, sea surface temperature, barometric pressure, incoming shortwave radiation, incoming longwave radiation, and rain (Fig. 6). Sampling as fast as once per minute, these buoys are essential as the first step in an effort to obtain the air-sea fluxes over

Figure 6. Surface buoy equipped with meteorological sensors to measure all the variables (wind velocity, air and sea temperature, rain, barometric pressure, relative humidity, incoming shortwave radiation, and incoming longwave radiation) needed to compute the air-sea exchanges of heat, freshwater, and momentum.

the basins needed to quantify the ocean's role as a source and sink in the climate system, to serve as the variable and energetic forcing on the bottom of 70% of the atmosphere (and thus a major role in weather), and to be used to understand ocean response to change in surface forcing. The choice of the locations for these sites is guided by the need to observe air-sea exchange in characteristic meteorological provinces over the ocean, such as in equatorial convection, under the stratocumulus clouds found west of California and of Peru and Chile, and in the trade wind belts, and to observe air-sea exchanges in regions of strong coupling between the ocean and atmosphere.

The buoys will serve as references sites or anchors in the work of making the maps of air-sea exchanges that are needed. The spatial distribution of the air-sea exchanges around the reference sites would be obtained, in the locations that merchant ships are available, by equipping those Volunteer Observing Ships (VOS) with similar instrumentation (Fig. 7). The observations from the surface reference sites

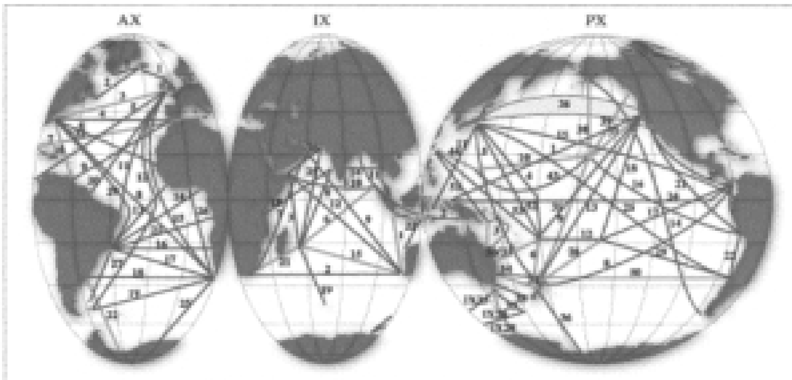

Figure 7. Routes of the Volunteer Observing Ships, merchant marine vessels used to obtain surface meteorological, ocean temperature and salinity profile, and other observations.

and VOS would be used to calibrate and drive improvements to atmospheric models and satellite remote sensing that would provide additional information about the surface meteorology and air-sea fluxes and allow production of global maps of air sea exchanges.

Observing the pathways for transport on the surface and in the interior of the ocean and the evolution of the property distribution within the ocean is also a central goal and requires broad spatial coverage of the fields, high spatial and temporal resolution to resolve pathways, and moorings. Broad coverage of the basins is to be accomplished by on an ongoing basis by a combination of the VOS, free-drifting instruments, and satellites. The VOS will drop expendable temperature probes (XBTS or expendable bathythermographs). The VOS can drop XBTS frequently enough to obtain the close spatial sampling needed to resolve the transport in boundary currents and the transport associated with ocean eddies. New, free-drifting ARGO floats that change their buoyancy and obtain vertical profiles every 10 days will be deployed globally with 100 km spacing to observe temperature and salinity in the upper 1500 to 2000 m (Fig. 8). Together with satellite observations of sea surface height and surface wind, the ARGO floats will allow the broad scale evolution of the upper 1500 m of the ocean to be tracked. Surface drifters will be deployed for calibrating remotely-sensed sea surface temperatures, and land-based tide gauges are needed to calibrate satellite altimetry.

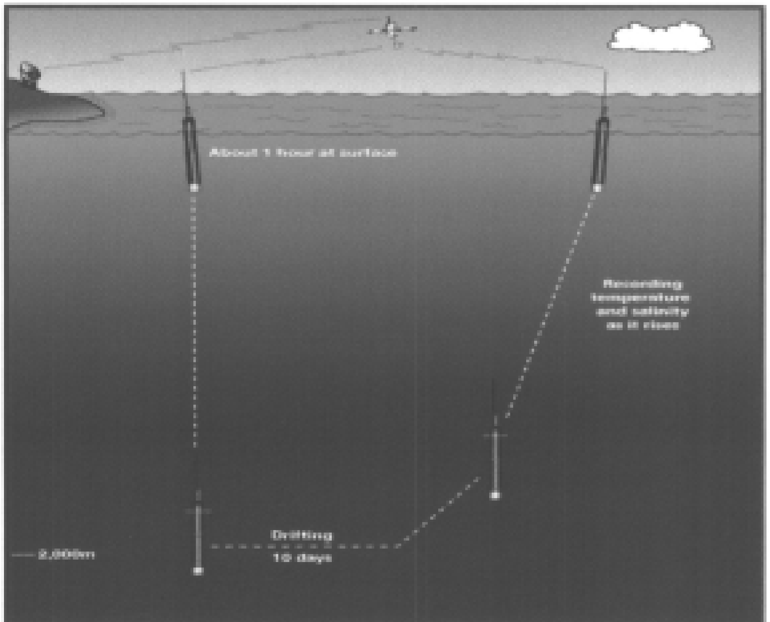

Figure 8. The ARGO profiling float changes its density to profile from the surface to 2000m, taking temperature and salinity profiles. While at the surface, it telemeters data via satellite.

Moorings, both with surface meteorological buoys and with no surface buoy (Fig. 9), will be used in key locations to quantify flow along pathways between the surface and the interior and between the warm tropics and the cooler extratropical regions. At sites where surface waters are cooled and sink and where convergent flow forces surface water into the interior, the air-sea fluxes will be quantified and the progression of water from the surface into the ocean interior will be observed. At sites where strong, narrow currents carry large volumes of water, arrays of moorings will measure the volume, heat, and salinity of these currents (Fig.10).

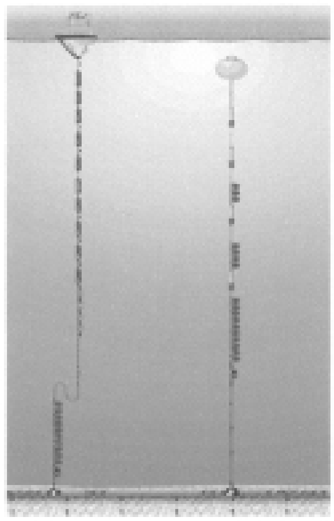

Figure 9. A surface mooring (left) and a subsurface mooring (right). The surface mooring can carry meteorological sensors; both can carry sensors along the line to measure physical, biological, geological, and chemical properties of the ocean.

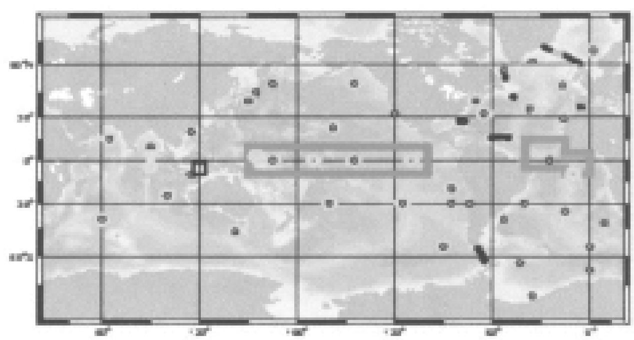

Figure 10. Planned locations for surface flux reference sites (yellow circles) and time series stations (red). Equatorial mooring arrays are located within the red and green bordered areas.

The time series collected by moorings or by frequent visitation by a ship will provide a key record of change from the surface of the ocean down to the bottom. At present, very few such observing sites exist in the ocean; and our record of change in the oceanic interior is sparse. In conjunction with plans to occupy a number of surface flux reference sites, the integrated ocean observing network would have time series sites at key locations to quantify transports and observe change.

The progression of water from the surface into the interior and to the ocean bottom is slow, estimated to take up to 100 years in some locations. Along the way, mixing processes modify the water mass, so tracking the slow overturning of the global ocean requires additional observations. Releases into the atmosphere of chemicals, such as of tritium, chlorofluorocarbons (CFCs), and CO_2, that enter into the ocean provide tracers that can be used to track the passage of chemicals through the ocean. Careful sampling, by lowering instruments from ships and obtaining water samples at depths through the water column, should be made along select north-south and east-west sections across the ocean basins. These sections (Fig. 11) would be occupied only every 5 to 10 years, and are essential to describing the slow overturning circulation of the ocean as well as change in the temperature and salinity of the deep ocean, at depths below where the ARGO profiling floats will sample. We now have few records of oceanic variability at depth. The repeat sections will build that record; and, at the same time, they will validate numerical models of the deep ocean circulation that may be used in coupled ocean-atmosphere models to investigate climate change and ocean variability.

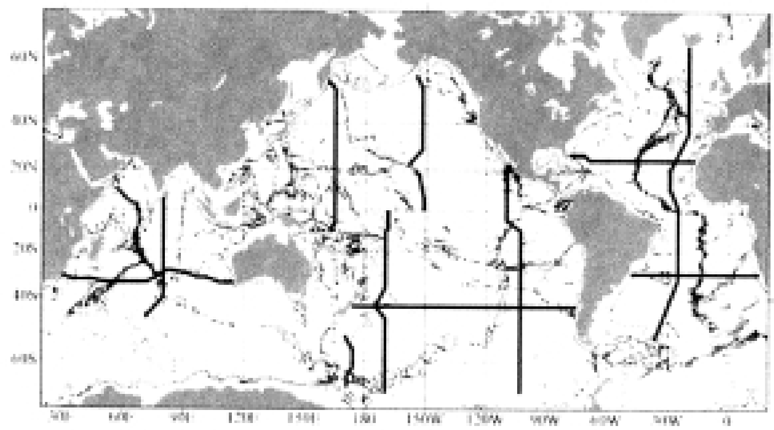

Figure 11. Location of the cross-basin lines (black) along which hydrographic (temperature, salinity) and tracer chemistry measurements would be made every 5 to 10 years.

While the focus of much of this discussion has been on physical observations, such as temperature and salinity, the required ocean observing network should make biological, chemical, and geological observations concurrently with physical observations. In the ocean, variability is often linked. For example, greater phytoplankton concentration in the upper ocean increases the absorption of sunlight and thus the heating of the water near the surface. Some platforms, such as moorings and ships, are now well equipped to carry out such multidisciplinary sampling. In addition to knowing how and where heat and freshwater are transported, the ocean observing system will provide the basis for understanding transport of nutrients, pollutants and harmful species (toxic algae, for example) and the observations needed to better predict surface waves and marine weather that impact transportation, recreation, and safety.

In contrast to the land and atmosphere, the ocean is sparsely observed. It is, however, a major part of the climate system, particularly so because of its large reservoirs and ability to move properties active in climate dynamics, such as heat, around over a wide range of time scales. An integrated ocean observing system for climate can be developed; such a system has been outlined above.

The ocean is where some of us work and many of us play. It is close to many of our homes and provides food and energy. An integrated ocean observing system will not only address climate issues; it will also provide benefits that address other societal needs, particularly if the data is available in near-real time. Knowledge of sea level change and of ocean currents, surface waves, temperatures, salinities, plant and animal populations, distribution and storage of greenhouse gases is important to weather prediction, the development of sound environmental policies and management strategies, to safety, to security, and to economic well being.

We do not have an integrated ocean observing system. Very few sustained ocean observations are now made. The plans and methods for an integrated observing system for the ocean have been developed. One region, the tropical Pacific Ocean, has been instrumented; and the return on the investment has been clear due to our increased ability to forecast El Niño and provide advanced warning of its impact on weather. In partnership with other nations, the United States should commit to completing a global ocean observing system.

The major problem facing the development of an integrated ocean observing has the lack to date of a national commitment to do so. This has resulted in the lack of key resources. These missing resources include: funding, technology, and infrastructure.

In most cases, observational priorities are agreed upon, the technology has been developed to collect the required observations, and the plan for implementing the system has been drafted. However, sustained funding has not been available. A few elements are in place, including the ENSO observing system in the tropical Pacific Ocean and the initial deployments of the Argo floats. There is no apparent source of support for the balance of a sustained, integrated ocean observing system.

In some cases, enabling technology is needed. A pressing need is increased capacity for passing data collected at sea from ships, buoys, and floats back to land. Technical advances have improved our ability to bring data to the sea surface from the ocean's interior. However, there is limited satellite capacity then available for relaying that ocean data back to the centers on land that would prepare the predictions, maps, and other products we need. This lack will limit the amount of ocean data we can acquire in near-real time. It will also prevent us from developing of an ocean observing system that resembles our present atmospheric and terrestrial systems in their ability to provide immediate coverage. Development of longer-lived and more capable observing instruments is needed to maximize the effectiveness and value of the ocean observing system.

Finally, the lack of a national commitment to sustained ocean observations has left us with have no infrastructure to support and guide such an development and maintenance of an ocean observing system. No agency has taken the lead. No person within the government is identified as a point of contact for other nations to interact with while agreeing on international commitments of support and responsibility for sectors of the ocean and contributions to the different observing elements. Progress to date has been made using the research infrastructure (funds, people, ships, labs). An integrated ocean observing system will require an investment in instrumentation and hardware, support for ships to deploy and service the system, people to quality control and process the data, communications systems to pass the data along, and the means to use the data to prepare products of use to society. This requires a commitment within the government.

In closing, thank you for allowing me to submit this testimony. The climate example was developed at length to demonstrate the readiness of the plans and methods to implement an integrated ocean observing system. Such an open ocean system links to the coastal observing systems, where it provides for them the knowledge that links those coastal regions to the open ocean and where the coastal observing systems provide key knowledge of coastal sinks and sources of carbon, freshwater, pollutants, marine life, and other quantities. The open ocean system described above is also linked to a system of operational satellites for oceanography, whose measurements would include sea surface temperature and winds, sea level from altimetry, and ocean color. I would be glad to answer questions and provide further explanation.

Chairman GILCHREST. Thank you, Dr. Weller. Dr. Grassle.

STATEMENT OF J. FREDERICK GRASSLE, DIRECTOR, INSTITUTE OF MARINE AND COASTAL SCIENCES, RUTGERS—THE STATE UNIVERSITY OF NEW JERSEY

Dr. GRASSLE. I am Fred Grassle, Director of the Institute of Marine and Coastal Sciences at Rutgers University. I thank each of the chairs for this opportunity to provide remarks on the proposed Integrated Coastal Ocean Observing System and Ocean Observatories Initiative, and the development of the Ocean Exploration Program.

My remarks focus on a need for a national network of linked and coordinated ocean observing systems and observatories and recommendations on how such a network should be established. I also support the emerging Ocean Exploration and Census of Marine Life Programs, and make suggestions for advancing these programs. I have been involved in the development of one of the world's first undersea observatories—and there are a couple graphics that illustrate the LEO–15 Observatory—participated in national efforts to construct a network of ocean observatories, serve as Principal Investigator for the inaugural expedition of the Ocean Exploration Program, and chair of the Steering Committee for the Census of Marine Life.

There are many urgent reasons for developing an integrated national network of coastal ocean observing systems. More than half of all Americans live within the coastal zone, and the ocean is our common source of enjoyment, and our responsibility. Fish stocks are being depleted and some fish habitat is being damaged. The seabed is used for oil and gas production, sand and gravel mining, and telecommunications cables. Periods of oxygen depletion are common, and the numbers and types of harmful algal blooms have increased. High levels of contaminants in coastal sediments affect bottom life and cause our ports and harbors to find means to dispose of dredged material. More than 95 percent of the nation's foreign trade moves by sea. Continuous observations are needed to ensure safe, efficient operations of the nation's congested ports.

Rutgers' Long-Term Ecosystem Observatory, LEO–15, off the coast of New Jersey, has maintained continuous measurements in the near-shore zone publicly available over the Internet for over four years. These measurements are now extended to include images of sea surface currents in the New York Bight to the edge of the continental shelf. This Sunday, scientists at Rutgers University will assimilate observations into models to produce a 3-day forecast of ocean circulation for the entire coastal shelf region from Long Island to below Delaware Bay. Reports of coastal conditions are already being carried, along with the weather, by local news stations. Through the National Ocean Partnership Program, NOPP, and direct support from NOAA, the NSF, ONR and NASA, the Rutgers LEO system and similar systems developing in every region of the country are ready to coalesce into a sustained, integrated, nationwide system. A sustained network of linked and coordinated regional ocean observing systems will provide a new way of looking at, working in, and understanding the ocean.

The extension of the LEO–15 observatory to the entire New Jersey continental shelf can serve as a model for constructing a national network of observing systems and observatories. Long-range, high-frequency radar systems should be placed along the entire coast to continuously map surface current flows for the coastal ocean. A combination of surface current information, satellite observations, subsurface measurements from buoys and autonomous gliders should be available in near real time for assimilation into model forecasts. This modeling and measurement system is needed to support the growing community of users of ocean information.

Embedded in this continuous coverage, intensive observatory facilities operated by scientists from all disciplines are needed to conduct long-term experiments, sustain long time series observations, and test new ideas. These sites will be the proving grounds for the development and validation of new technology for use by the observing system network: samples, sensors, robotic controls, data processing systems, and autonomous underwater vehicles. The National Science Foundation and the Office of Naval Research have played major roles in the development of the LEO observatory, and should continue to play the leading role in the development of intensive observatory technologies, including the deep-sea and deep-earth observatories linked to shore by underwater cables and new broad bandwidth communications. In my own area of research, the Census of Marine Life program provides many examples of the potential for new discoveries in the ocean.

With regard to administration of the national ocean observing and observatory system, I recommend that the National Ocean Research Leadership Council (NORLC) and National Oceanographic Partnership Program (NOPP) be responsible for coordinating system activities, and approving standards and protocols for administering the system. This recommendation is in accord with previous reports to Congress and the Administration. Last May the NORLC approved the NOPP Interagency Ocean Observation Office, "Ocean.US," that you have already heard about, with a charter to develop national capability for integrating and sustaining ocean observations and predictions. To provide technical assistance in the management, archiving and analysis of data, NOAA's National Ocean Service has a strong track record in linking science to management. New approaches to bridging the gap between data providers and data users are being developed at NOS' Coastal Services Center, NASA's Earth Science Applications Center, and the NOPP-sponsored Ocean Biogeographic Information System, a component of the Census of Marine Life Program.

I was a member of the panel that provided the report on Ocean Exploration. I strongly support the goals outlined in that report. And my colleagues, Marcia McNutt and Bob Ballard, have spoken about this in more detail. Incidentally, the second expedition to hydrothermal vents that included the biologists I was co-chief scientist in charge of the biologists.

In closing I would like to thank Chairman Gilchrest, Chairman Ehlers, Chairman Smith, and members of the Committees, for the opportunity to comment on ocean observing systems, observatories, and ocean exploration. These are good ideas that merit strong consideration for authorizing legislation. I will be pleased to respond to any questions the Committee may have. Thank you.

Chairman GILCHREST. Thank you, Dr. Grassle. Congressman Saxton asked me to say hi.

Dr. GRASSLE. Well, yes. I was hoping I could recognize him here today. He has certainly been a wonderful supporter of marine science.

[The prepared statement of J. Frederick Grassle follows:]

PREPARED STATEMENT OF J. FREDERICK GRASSLE

Summary of Comments

Development of Coastal and Ocean Observing Systems and Observatories

More than half of all Americans live within the coastal zone and the ocean is a common source of enjoyment and our responsibility. Fish stocks are being depleted and, in some areas, fishing gear damages bottom habitats. Uses of the seabed for oil and gas production, sand and gravel mining, and telecommunication cables are increasing. Periods of oxygen depletion are common, and the number and types of harmful algal blooms have increased. High levels of contaminants in coastal sediments affect bottom life, and cause our ports and harbors to find means to dispose of dredged material. More than 95% of the Nation's foreign trade moves by sea. Continuous observations are needed to ensure safe, efficient operations of the Nation's congested ports. A sustained, nationwide network of linked and coordinated regional ocean observing systems and observatories is needed to improve weather and ocean forecasting, predict effects of climate change on coastal populations, improve safety and efficiency of marine operations, improve public understanding of processes affecting coastal habitats and their living marine resources, provide more effective evaluations of the efficacy of environmental policies for coastal ecosystems, and foster science-based management of coastal ecosystems and their natural resources. A nationwide network of regional coastal ocean observing systems should measure common parameters using uniform methods and protocols; respond to the information needs of diverse user groups that depend on the coastal ocean for work, security, recreation, and research; be cost-effective and capitalize on existing infrastructure; provide continuous, long-term, and real-time observations and predictions of ocean phenomena in a timely and integrated way; and sustained basis, and provide a source of data and information to increase public awareness of the status and importance of the Nation's coastal oceans.

Ocean Exploration

To advance the Ocean Exploration Program, NOAA has created the Office of Ocean Exploration. In some respects, this duplicates activities of an existing program renowned for its exploratory achievements and hallmark record of safety in undersea operations—the National Undersea Research Program (NURP). NURP has developed rigorous procedures for peer review and undersea operations, and has well-established mechanisms for communicating with the ocean science community. It is important for NOAA to ensure that NURP be closely involved with the administration of the Ocean Exploration Program. Such integration will ensure safe field operations, foster exploration programs that advance quantitative science investigations, avoid duplication of effort, and reduce costs.

Introduction

Good afternoon. My name is Fred Grassle and I am the Director of the Institute of Marine and Coastal Sciences at Rutgers University. I would like to thank each of the chairs for the opportunity to provide remarks on the establishment of an Integrated Coastal Ocean Observing System, an Ocean Observatories Initiative, and the development of an Ocean Exploration Program. I would also like to recognize two New Jersey legislators who have been effective supporters of coastal and ocean research, Representative James Saxton the former Chair of the House Subcommittee on Fisheries Conservation, Wildlife and Oceans, and Representative Frank Pallone who serves on the same committee. Their continuing strong support has ensured that robust science programs are in place to support informed management of our coastal and ocean resources.

My remarks focus on the need for a national network of linked and coordinated ocean observing systems and observatories and recommendations on how such a network should be established. I will also comment on the emerging Ocean Exploration and Census Of Marine Life Programs, and make suggestions for advancing these programs. The basis of my remarks stems from my involvement in development of one of the world's first undersea observatories, participation in national efforts to construct a network of ocean observatories, and my roles as Principal Investigator for the inaugural expedition of the Ocean Exploration Program and Chair of the Steering Committee for the Census of Marine Life.

Rationale for a National Network of Coastal Ocean Observing Systems

More than half of all Americans live within the coastal zone, i.e., within 50 miles of ocean. The ocean is our common source of enjoyment and common responsibility. Fish stocks, once thought to be inexhaustible, are being depleted and, in some areas, fishing gear damages bottom habitats. Uses of the seabed for oil and gas production, sand and gravel mining, and telecommunications cables are increasing. Periods of oxygen depletion are common, and the number and types of harmful algal blooms have increased during the last 25 years. High levels of contaminants are found in coastal sediments, affecting bottom life, and causing our ports and harbors to seek expensive means of disposal of dredged material. More than 95% of the Nation's foreign trade moves by sea. Continuous observations are needed to ensure safe and efficient operations of the Nation's congested ports.

A sustained, nationwide network of linked and coordinated regional ocean observing systems is needed to:

- improve weather and ocean forecasting in coastal regions
- predict effects of climate change on coastal populations

- improve safety and efficiency of marine operations, including search and rescue, swimming, boating, fishing, transportation, and naval warfare
- improve public awareness and scientific understanding of processes affecting coastal habitats and their living marine resources
- provide more effective means for monitoring and evaluating the efficacy of environmental policies for coastal ecosystems
- foster science-based management of coastal marine ecosystems and their natural resources

Scientists, managers, and the public are often not well-equipped to make decisions about marine ecosystems, especially in environments where visibility is poor and a common sense approach literally depends on access to the latest methods for sampling and sensing the marine environment. Marine environmental issues would be less complex and easier to solve if the marine information base on ecosystems, habitats, and patterns of change were as readily available as for terrestrial environments. The ability to address complex issues and find solutions suffers from the compartmentalization of marine science disciplines and methodologies, and a lack of integration with the disciplines of resource economics and environmental management. Many marine issues, such as fisheries management, the siting of reserves, protection and restoration of habitats, human health (hazardous spill response, harmful algal blooms), safety (vessel traffic control, search and rescue, storm surge prediction), and waste disposal, require resolution through more accurate, comprehensive, and timely information.

All aspects of ocean ecosystems are presently under-sampled. Decisions are made about sampling designs for research and monitoring without an adequate spatial or temporal context. Technological advances in observation, modeling, and data assimilative methodologies enable us to enter a new era in oceanography, that of the well-sampled ocean. New remote sensing and autonomous systems now allow us to sample the ocean at time and space scales never before achieved, and parallel computing algorithms can generate forecasts of the ocean in real time. Data assimilation schemes allow us to constrain the model forecasts with observations, thereby increasing their utility in practical applications. Researchers at LEO–15, the undersea observatory located off the coast of New Jersey, have led the nation in the development of these coastal ocean observation and modeling systems.

At LEO–15 it has been possible to make many continuous measurements throughout the year for four years, but the intense sampling effort needed to achieve a well-sampled ocean can now only be achieved through intensive bursts of activity in a 30 km by 30 km research area in which real-time ocean currents are observed from shore via an existing medium-range high-frequency radar (CODAR). Regional-scale, ocean surface current data acquired through a long-range (200 km), high-frequency radar system would provide one of the most important data sets needed to improve vessel traffic safety and management of harbor activities.

Rutgers' Long-term Ecosystem Observatory (LEO–15) off the coast of New Jersey has made continuous measurements in the near-shore zone publicly available in near real time through the Internet. For the first time, these measurements have been extended to include images of sea surface currents in the New York Bight to the edge of the continental shelf. By Sunday, July 15, scientists at Rutgers University will produce a 3-day forecast of ocean circulation for the entire shelf region from Long Island to below Delaware Bay. Reports of these coastal conditions are being carried, along with the weather, by local news stations. Through the National Ocean Partnership Program (NOPP) and other federal and state sources of support, the Rutgers LEO system and similar systems developing in every region of the country are ready to coalesce into a sustained, integrated, nationwide system. A sustained network of linked and coordinated regional ocean observing systems will provide a new way of looking at, working in, and understanding the ocean.

The extension of the LEO–15 observatory to the entire New Jersey continental shelf can serve as a useful model for constructing a national network of observing systems in two ways. First, we should establish a series of shore stations equipped with new, long-range, high-frequency radar systems to continuously map surface current flows for the coastal ocean. Common standards and protocols have already been worked out by users of this equipment. Data should be made available in real-time on the World Wide Web, and when assimilated into existing hydrodynamic models, can be used to forecast the three-dimensional circulation on the continental shelf. A combination of satellite observations of sea surface temperature, surface roughness, primary productivity (at 30 m resolution when a new Navy-sponsored, hyperspectral ocean color satellite is launched), and high-resolution bathymetry and side-scan sonar will provide an enhanced context for ocean sampling. The proposed modeling and measurement system will provide regional perspectives for policy, planning, and economic analysis, and it is the rationale for development of a national network of high-frequency radars, buoys, bottom observatories, and autonomous glider vehicles. Regional-scale, real-time data will further aid search and rescue efforts by using CODAR surface currents to predict locations of vessels in distress, and inform cleanup efforts with trajectories of spills of hazardous material.

Secondly, intensive observatory facilities involving all scientific disciplines are needed where long-term experiments and sustained time series observations can be conducted and new ideas tested. New and substantial infrastructure is needed to enable exciting scientific discoveries such as those envisioned by the Census of Marine Life program. These sites will be the proving grounds for development and validation of new technology for use by the observing system network: samplers, sensors, robotic controls, data processing systems, and autonomous underwater vehicles. Scientific validation is required before information generated from new technology will be accepted by the general public. The National Science Foundation has played a major role in the development of the LEO observatory and should continue to play the leading role in the development of intensive observatory technologies, including deep-sea and deep-earth observatories linked to shore by underwater cables.

A nationwide network of regional coastal ocean observing systems should:

- measure a common set of parameters using uniform methods and protocols, which can be regionally and locally enhanced
- be based on sound science
- respond to the information needs of diverse user groups that depend on the coastal ocean for work, security, recreation, and research (e.g., facilitate safe and efficient marine operations, ensure national security, support management of living resources and marine ecosystems, ensure a sustainable food supply, mitigate natural hazards, and ensure public health)
- be cost-effective and capitalize on existing infrastructure (e.g., autonomous undersea vehicles, gliders, cabled observatories, satellite remote sensing, CODAR technology)
- provide continuous, long-term, and real-time observations and predictions of ocean events and phenomena on a timely, integrated, and sustained basis
- provide a source of data and information that increases public awareness of the status and importance of the Nation's coastal oceans

Consideration must be given to the administration of the national coastal ocean observing system and what body will be responsible for establishing standards and protocols to govern the system. Given that a variety of federal agencies will be involved in the observing network, I recommend that the National Ocean Research Leadership Council (NORLC), the organization created to implement the National Oceanographic Partnership Program (NOPP), be responsible for coordinating system activities, and approving standards and protocols for administering the system. This recommendation is in accord with the plans for implementation in "Toward a U.S. Plan for an Integrated, Sustained Ocean Observing System" submitted to Congress on 20 April, 1999, in response to a request from Representatives James Saxton and Curt Weldon, and with the subsequent NORLC Report "An Integrated Ocean Observing System: A Strategy for Implementing The First Steps of a U.S. Plan" completed December 24, 1999. On May 22, 2000 the NORLC approved the NOPP Interagency Ocean Observation Office, "Ocean.US," with a charter to develop a national capability for integrating and sustaining ocean observations and predictions.

Coastal ocean observing systems should be organized regionally. The Committee might consider establishing a federation of seven regional observing systems: Northeast, Southeast, Gulf of Mexico, West Coast, Hawaii, Alaska, and the Great Lakes. Representatives from each of these regions, drawn from academic and research institutions, and state and local governments could serve as an advisory council for the NORLC.

A single entity should be charged with providing technical assistance to the regional systems in the management, archiving, and analysis of data. One candidate is NOAA's National Ocean Service (NOS) which has a strong track record in linking science to management products and services. New approaches are developing to bridge the gap between data providers and data users at NOS' Coastal Services Center, NASA's Earth Science Applications Center, and in the NOPP-sponsored Ocean Biogeographic Information System, a component of the Census of Marine Life Program.

Ocean Exploration

As Committee members are aware, $4 million was appropriated in FY 2001 to initiate an Ocean Exploration Program at NOAA. This appropriation was provided to implement recommendations from the report on "Discovering the Earth's Final Frontier: A U.S. Strategy for Ocean Exploration," produced by a national panel convened by a Presidential Executive Order. I had the privilege of serving on this panel and am thoroughly familiar with the rationale for the report recommendations. Four challenges were highlighted as the most significant gaps in our knowledge of the oceans including: 1) mapping at new scales, 2) exploring ocean dynamics and interactions at new scales, 3) developing new technologies, and 4) reaching out in new ways to stakeholders. The report set forth a variety of exploration priorities including: Voyages of Discovery, Tools for Probing the Ocean, Data Management and Dissemination, Education and Outreach, and Capital Investment.

With the FY 2001 support, NOAA has organized expeditions to identify new species that may hold potential economic benefits, evaluate potential new energy or food resources, explore submerged cultural resources, and evaluate the effect of sound on marine resources and ecosystems. In September, I will help lead one of these expeditions known as Deep East. Deep East will feature mapping of deep sea corals in the offshore canyons and seamounts off Georges Bank, seafloor processes in the Hudson River Canyon, and biological and geochemical interactions at the Blake Ridge off Georgia. I will serve as the principal investigator for Leg 2, which is associated with the Hudson River Canyon.

Hudson Canyon extends over 400 nautical miles seaward from the New York-New Jersey Harbor across the continental margin to the deep North Atlantic ocean basin. Although it is the largest submarine canyon on the Atlantic continental margin of North America, and lies directly offshore of America's largest metropolitan area, Hudson Canyon remains to be explored with integrated high-resolution mapping and direct observations and sampling.

Submarine canyons are conduits for the transport of sediments including pollutants between land and sea, a process complicated by the interaction of down-slope movement and cross-slope flow of deep ocean currents. Low-resolution side-scan sonar (GLORIA), and medium-to high-resolution seismic reflection, echo sounding, and magnetic profiles (USGS, 1991), reveal that Hudson Canyon is susceptible to mass transport of materials down-canyon, and may thus concentrate pollutants and other materials in the canyon axis and on the continental rise. Evidence for high species abundance comes from surveys supported by the Minerals Management Service (MMS) involving quantitative analysis of box cores recovered from sediments of the continental slope and upper rise between water depths of 1,500 m and 2,500 m at 10 stations off New Jersey and Delaware. The survey also revealed remarkable biodiversity at these depths. Studies on the Hatteras slope similarly suggest that sediments of the middle to lower slope are the recipients of down-canyon transport.

A series of drill holes on the outer continental shelf, slope, and rise off New Jersey by the Deep Sea Drilling Program (Legs 11, 93, and 95) and the Ocean Drilling Program (Legs 150 and 174) established the sequence and ages of sedimentary strata, and revealed a massive bed of methane gas hydrates extending beneath the Hudson Canyon region. The presence of methane gas hydrates beneath this region opens new avenues for discoveries of processes involving the role of fluid pressure (confined gas and water) beneath the seafloor, which relate to geologic hazards (slumps and tsunamis) and climate change (methane release); the probable occurrence of chemosynthetic organisms (macrofauna and microbes) at cold seeps that relate to biodiversity and to sources of new pharmaceutical and industrial products; and to methane itself as an energy resource.

Relationship of Ocean Exploration to the National Undersea Research Program

To advance the Ocean Exploration Program, NOAA has created a new office, the Office of Ocean Exploration. In some respects, this action duplicates activities conducted by an existing program that is renowned for its exploratory achievements and hallmark record of safety with the conduct of undersea operations—the National Undersea Research Program (NURP).

NURP is organized on a regional basis with six centers serving undersea science needs in the Northeast and Great Lakes, Mid-Atlantic Bight, Southeast Atlantic and Gulf of Mexico, Caribbean, West Coast and Alaska, and Hawaii. NURP has developed rigorous procedures with respect to peer review and undersea operations, and has well-established mechanisms for communicating with the ocean science community. Existing regional infrastructure at the six NURP Centers provides local links to the science community, knowledge of advanced undersea sampling and sensing platforms, and experience with the conduct of undersea operations. I believe that it is important for NOAA to ensure that NURP be closely involved with the administration of the Ocean Exploration Program. Such integration can ensure safe field operations, foster a process wherein exploration programs can advance quantitative science investigations, avoid duplication of effort, and reduce costs.

Summary

In closing, I would like to thank Chairman Gilchrest, Chairman Ehlers, Chairman Smith, and members of the Committees for the opportunity to comment on ocean observing systems, observatories, and ocean exploration. These are good ideas that merit strong consideration for authorizing legislation. I will be pleased to respond to any questions that the Committees may have at this time. Thank you.

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Chairman GILCHREST. Yes, sir. Thank you. Dr. Beeton.

STATEMENT OF ALFRED M. BEETON, CHAIR, SCIENCE ADVISORY BOARD, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Dr. BEETON. Good afternoon. I am Al Beeton, Chair of the Science Advisory Board of the National Oceanic and Atmospheric Administration. And I appreciate the invitation of the Chairman to testify on ocean exploration and development and implementation of coastal and ocean observing systems, especially as they apply to the Great Lakes.

My research on the Great Lake started in 1955 and continues today. I have served in various ways for the International Joint Commission, the Great Lakes Commission, and Great Lakes Fishery Commission. I was Director of the Great Lakes and Marine Water Center, and the Sea Grant Program and the University of Michigan. I was Associate Director of the Great Lakes Studies Program at the University of Wisconsin, and Director of the Great Lakes Environmental Research Laboratory of NOAA in Ann Arbor.

The Science Advisory Board is the only Federal committee whose responsibility is to advise the Undersecretary of Commerce for oceans and atmosphere on long and short-term strategies for research, education, and application of science to resource management. The panel on ocean exploration was a subset of the Science Advisory Board. And the panel produced the report "Discovering Earth's Final Frontier: The Strategy for Ocean Exploration," which recommended the establishment of a program on ocean exploration. And as a consequence, NOAA followed up and established the Office of Ocean Exploration.

The coastal and ocean observations are certainly essential for predicting events that affect commerce as well as life. Water level changes, floods, storms, and harmful algal blooms are a few of the disasters that may be predicted to minimize financial and personal loss. Including and emphasizing the Great Lakes in legislation dealing with ocean exploration and coastal and ocean observing systems will benefit the nation as well as the region.

Ocean exploration activity will enhance the efforts to inventory and document the resources of the recently established Thunder Bay Marine Sanctuary in Lake Huron, as well as resources of Old Woman Creek Estuarine Research Reserve on Lake Erie. The aquatic resources of the Isle Royal National Park and other Federal recreational resources in the Great Lakes will benefit from this effort.

Ocean exploration activity should also provide for geophysical surveys to provide data to facilities for preparation of modern, updated bathymetric charts for navigation, underwater structures, fisheries, and recreation. The most recent survey of the Great Lakes was done in the 1970's and they did not include many areas of the lakes. People making charts had to use many data from the 1930's, and in some instances data from the 1800's. Certainly, it will be wise to have new and useful data for new charts.

We know a great deal about the Great Lakes, but much if not most, of our knowledge comes from sporadic surveys, individual observations, short-term studies, and some monitoring at water intakes. We need long-term monitoring to provide the kinds of data essential for detecting subtle changes in the Great Lake ecosystems. Such monitoring should be part of a Great Lakes coastal observatory system which would provide a coherent assessment of long-term data as well as detect shorter-term impacts. Monitoring of coastal water quality is essential to public health.

Recent advances in technology have made it possible to develop and implement sophisticated coastal ocean observing systems and state-of-the-art ocean exploration techniques and instrumentation. New sensors are being developed which will allow acquisition of data rapidly and accurately. In addition, we have new and better ways to manage data, transmit data, assess, and use data. Consequently, this is an appropriate time to move ahead on ocean exploration and observing systems.

And I thank you for the invitation to speak here today. And I will pleased to answer questions. Thank you.

[The prepared statement of Alfred M. Beeton follows:]

PREPARED STATEMENT OF ALFRED M. BEETON

Good afternoon, Chairman Gilchrest, Chairman Ehlers, and Chairman Smith, members of the subcommittees and staff. My name is Al Beeton, and I am the Chair of the Science Advisory Board (SAB) at the National Oceanic and Atmospheric Administration (NOAA). I would like to begin by thanking the Chairmen for inviting me to testify on the three important issues of ocean exploration, and the development and implementation of coastal and ocean observing systems, especially as they pertain to the Great Lakes.

I have many years of experience in dealing with many issues affecting the St. Lawrence Great Lakes. My research on the lakes commenced in 1955 and continues to the present. For years I served in various ways for the International Joint Commission, the Great Lakes Commission, and the Great Lakes Fisheries Commission. I was Director of the Great Lakes and Marine Waters Center and Michigan Sea Grant, University of Michigan; Associate Director of the Center for Great Lakes Studies, University of Wisconsin-Milwaukee, and Director of the Great Lakes Environmental Research Laboratory of NOAA.

The Science Advisory Board was established by a Decision Memorandum on September 25, 1997. It is the only Federal Advisory Committee with responsibility to advise the Under Secretary of Commerce for Oceans and Atmosphere on long- and short-range strategies for research, education and the application of science to resource management. The Board is composed of 15 eminent scientists, engineers, resource managers and educators that provide their expertise to ensure that NOAA science programs are of the highest quality and to provide advice and support to resource management. The latest Science Advisory Board meeting occurred two weeks ago in Santa Cruz, California, where the Board advised NOAA on fisheries science issues ranging from scientific quality of data acquisition to managing science in a regulatory environment, as well as on climate monitoring strategies.

Ocean Exploration:

The President's Panel on Ocean Exploration was a subset of the National Oceanic and Atmospheric Administration's Science Advisory Board which included six member of the Board. The Panel produced the report "Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration," recommending the establishment of a program of ocean exploration, from which the NOAA Office of Ocean Exploration was created. The Panel determined four key objectives for a national strategy in tackling ocean exploration: to map the physical, geological, biological, chemical and archaeological aspects of the ocean; to explore ocean dynamics to increase understanding of the ocean's complex interactions; to develop new sensors and systems for ocean exploration, and to communicate the new-gained knowledge effectively to stakeholders and the community.

Ocean Exploration in the United States began as early as 1807 when Thomas Jefferson authorized the Survey of the Coast, but despite of this, the ocean as well as the Great Lakes are understudied. Much benefit can be attained by furthering knowledge on ocean life, physics and chemistry, and better knowledge is translated into better advising by the Science Advisory Board. Concerning the Great Lakes specifically, the region would benefit greatly by updating bottom topography, as the area is vital to the country's shipping industry. The Great Lakes are also a very important region for maritime history and archaeology. An example is the Thunder Bay National Marine Sanctuary and Underwater Preserve in Lake Huron, where more than a hundred ships are suspected to have sunk there, but only 40 locations are presently known. Recently an expedition led by Dr. Robert Ballard in partnership with NOAA and the State of Michigan surveyed the area using a new side-scan sonar and sub-bottom profiling technology called ECHO, and found 50–70 targets, where 10–15 are verified shipwrecks, 3 of them previously unknown. I would like to add that despite the great public and scientific support behind the ocean exploration effort, the House mark failed to reflect this.

Coastal and Ocean Observations:

Coastal and Ocean observations are paramount for predicting events that affect commerce as well as human lives. Water-level change, floods, storms, and harmful algal blooms are a few of the disasters that may be predicted in the future to minimize financial and personal losses. Presently there are several independent coastal and ocean observing programs in the U.S.; the Harmful Algal Bloom monitoring program, the National Estuarine Research Reserve System, the National Water Level Observation Network (NWLON); and the National Status and Trends Program, to name a few. Because of the fluid nature of the atmosphere, lakes, and oceans they do not abide by geographical or political boundaries. Consequently, efforts in this area must be integrated regionally, nationally, as well as internationally, and the data collected made freely available to the greatest extent possible. A good example is the Integrated Global Observing Strategy Partnership (IGOS), an international partnership for co-operation in Earth observations established in 1998 by a number of international agencies concerned with environmental issues. The Ocean Theme is led by the Global Ocean Observing System (GOOS), charged with considering the full range of current and planned observations and identifying potential gaps in future observations that might compromise ocean observational records. Institutional structures are being developed to manage the total data flow, the production, distribution and quality assessment of relevant data products, and to work with end-users to ensure that the evolving system is responsive to their needs.

The Great Lakes:

Fresh water is a precious finite resource and about 68% of the fresh liquid surface water is contained in 189 large lakes of the world. About 18–20% of this water is in the Great Lakes. Consequently, about 40 million U.S. and Canadian citizens use the lakes for drinking water and many industries and other business have located in the region because of this plentiful supply. The lakes are a major source of irrigation water, as well as for use of power generation, shipping, fisheries, recreation, and waste disposal. Despite the importance of this resource, relatively little attention has been given nationally and regionally, and funding to deal with serious problems have been limited.

Including and emphasizing the Great Lakes in legislation dealing with ocean exploration, and coastal and ocean observing systems will benefit the nation as well as the region. Ocean exploration activity will enhance the efforts to inventory and document the resources of the recently established Thunder Bay Marine Sanctuary in Lake Huron as well as resources of the Old Woman Creek Estuarine Research Reserve in Lake Erie. Aquatic resources of the Isle Royal National Park and other federal recreational resources would also benefit from this effort.

Ocean exploration activity should also provide for geophysical surveys to provide data to facilitate preparation of modern updated bathymetric charts for navigation, underwater structures, fisheries, and recreation. Most of the soundings now being used to provide detailed bathymetric charts are old. The most recent surveys were done in the early 1970's and they did not include all areas of the lakes. People making these charts had to use many data from the 1930's and in some instances data from the 1800's! Certainly it would be wise to have new information to prepare updated charts, especially in view of the very low water levels now being observed and the possibility of much lower levels as a consequence of climate change.

We know a great deal about the Great Lakes, but much if not most, of our knowledge comes from sporadic surveys, individual observations, short-term studies, and some monitoring at water intakes. We need long-term monitoring to provide the kinds of data essential to detecting subtle changes in the Great Lakes ecosystem in order to support suitable management of the resources. Such monitoring should be part of a Great Lakes coastal observatory system which would provide a coherent assessment of long term data as well as detect shorter term impacts. Data are needed on trends in water levels that affect property owners, shipping, and fish and wildlife, and the relationship of these trends to climate changes. Monitoring of coastal water quality is essential for public health reasons. For example a recent editorial in the Ann Arbor News stated that more than 100 beaches in Michigan are not regularly tested for bacteria concentrations. Only 12 of 41 counties regularly monitor for E. Coli. Long-term data are needed on fish populations, fish food organisms, ice cover and climate.

A number of studies have emphasized the need for regional coastal observing systems in addition to the need observed in the Great Lakes region; the National Ocean Partnership Program; NOAA Strategic Plan; and the U.S. Coastal-Global Ocean Observing System (C–GOOS). A Great Lakes Coastal Observing System has been identified as important to the region by the International Association for Great Lakes Research and the International Joint Commission's Council of the Great Lakes Research Managers. Such an observing system will be valuable to federal agencies, for example; EPA, USGS, NOAA, as well as State agencies, academic institutions, counties, cities and towns.

Recent advances now make it possible to develop and implement sophisticated coastal ocean observing systems and state-of-the-art ocean exploration techniques and instrumentation. New sensors are being developed which will allow acquisition of data rapidly and accurately. Acquisition of data which were very difficult to obtain using older time-consuming methods. In addition we have new and better ways to manage data, transmit data, and assess and use data. New technology, such as bio-monitoring systems using bioluminescent bacteria on light sensing computer microchips to detect low levels of toxic material or harmful algal blooms, are being developed. Funding for ocean exploration and coastal ocean observing systems should be used, in part, to enhance capability.

Real-time data acquisition coupled with underwater image links connected to onshore viewing sites have a great potential to enhance public awareness and education. A coastal observing system placed at a marine sanctuary could enable visitors to observe underwater activity in a marine sanctuary and make the resources of the sanctuary a meaningful experience to a wider group of users.

I would like to thank you for the invitation to speak here today, and I will be glad to answer any questions you may have.

Chairman GILCHREST. Dr. Malahoff.

STATEMENT OF ALEXANDER MALAHOFF, DIRECTOR, HAWAII UNDERSEA RESEARCH LABORATORY, UNIVERSITY OF HAWAII

Dr. MALAHOFF. I am Alexander Malahoff, Professor of Oceanography, director of the Hawaii Undersea Research Lab, and director of the Marine Bioproducts Engineering Center, University of Hawaii at Manoa, Honolulu, Hawaii.

Ladies and gentlemen, the United States of America is surrounded by the oceans. Our country has the world's largest exclusive economic zone. We have the largest Navy, the largest research fleet, and yet, the smallest merchant marine. The oceans are an essential resource to us in our fisheries, oil, and coastal resources. This vast environment of the ocean is also our frontline against any adversary. The oceans are the source of weather and climate. The oceans are the habitats for a spectacular spectrum of life ranging in size and complexity from microorganisms to whales. The oceans are the home for the coral reefs, soft corals, and other complex organisms inhabiting the ocean floor. Submarine volcanoes and mid-ocean ridges form the habitats for exotic life assemblages around the hydrothermal vents which are homes for microorganisms known as extremophiles.

The oceans will continue to provide us with food and energy and with the resources for a range of entirely new industries. These will be specializing in marine byproducts, pharmaceuticals, and nutracueticals and other derived from exotic micro-organisms, such as extremophiles living around hydrothermal vents. We are a great and resourceful nation. Our future rests upon our competitive advantage in the world. It is based upon our out-of-the-box thinking.

These challenges in our ocean exploration program open up wide avenues for the advancement of all sectors of our society with interest and investment in the oceans. First of all, it invigorates the vision of a new presence for America and our society in the oceans. Secondly, the program offers an opportunity for a different presence in the oceans for America. With new tools, new systems, new observatories, new vehicles such as submersibles, and new sensors applied to these programs, new industries will flourish and a new ocean system industrial niche will develop. Our paucity in the international maritime transportation industry will be balanced by our leadership in the ocean exploration industry.

The National Oceanic and Atmospheric Administration has taken an effective lead by creating the Office of Ocean Exploration. This has been a bold move toward this new interdisciplinary, inter-cultural, and inter-agency arena. This is a fresh start and will be a catalyst that will enable our nation to take a lead in the holistic understanding of the world's oceans.

This broad thinking will lead to a revival of global expeditions with airplanes, ships, submersibles, satellites, robotic miniaturized underwater vehicles, autonomous observatories, and in situ labs.

Ladies and gentlemen, America must take the bold, necessary step to regain the U.S. lead on all fronts of maritime technology. The challenge of this new Ocean Exploration is monumental. In our own Hawaiian Island chain, stretching for over 1,200 miles, a home for most of America's tropical coral mass, very little is known about the nature of life of the ocean floor.

How do we begin this task in Hawaii? Much of our work to date has been accomplished in Hawaii through the use of submersibles operated by the Hawaii Undersea Research Lab, one of the six centers of NOAA's National Undersea Research Program. We have been able to do that through the use of submersibles and water labs and our own mother ship in Hawaii.

NURP has made a significant difference toward understanding the oceans and its resources. The undersea research had laid the foundations for the United States to fully explore the undersea environment. NURP has set an example in working through partnerships. For instance, in Hawaii we established a coastal zone and fisheries workshop. We took all of the interested parties from around the Pacific, including of course, all of the U.S. flag islands, and we started looking at broad problems, such as coral reefs, coastal habitats, water quality, coastal hazards and their mitigation, and fisheries. And for instance in the area of fisheries, HURL helped to understand the need for fisheries managers to look at threatened stock.

I believe that these grassroots partnerships are the key to our new out-of-the-box approach to exploration. In order to jump-start our new wave of ocean exploration and take a global lead, we must immediately expand our present capabilities, especially manned submersibles and ROVs and AUVs and ocean floor observatories. With these new metallurgy and new propulsion, and greater sensor capability will recapture our lead in the oceans and the world.

Core programs such as NOAA's NURP are essential to the accomplishment of the objectives of ocean exploration. And put in with our programs and the Defense Department, the National Science Foundation, the Environmental Protection Agency, those need to be supported. This way ocean exploration will be a cornucopia for a new wave of American knowledge and industry.

And as we say in Hawaii, mahala nue loa. Thank you very much.

[The prepared statement of Alexander Malahoff follows:]

PREPARED STATEMENT OF ALEXANDER MALAHOFF

Good afternoon Chairman Gilchrest, Chairman Ehlers, Chairman Smith, members of Congress. Members of the subcommittees and staff, ladies and gentleman, *Aloha.*

I am Alexander Malahoff, Professor of Oceanography, director of the Hawaii Undersea Research Laboratory and director of the Marine Bioproducts Engineering Center, University of Hawaii at Manoa, Honolulu, Hawaii.

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The United States of America is surrounded by the oceans. Our country has the world's largest exclusive economic zone. We have the largest Navy, the largest research fleet, and yet, the smallest merchant marine. The oceans are an essential resource to us in our fisheries, oil resources and coastal resources. Yet, this vast environment of the oceans is also our frontline defense against any adversary. Today, the oceans are much more to us than the traditional area of interest that I have just described. The oceans are the source of our weather and climate. The oceans are the habitats for a spectacular spectrum of life ranging in size and complexity from microorganisms to whales. The oceans are the homes for coral reefs, soft corals, and other complex sessile organisms inhabiting the ocean floor. Submarine volcanoes and mid-ocean ridges form the habitats for exotic life assemblages around hydrothermal vents and homes for microorganisms known as extremophiles. These environments on the ocean floor or lying just below the sea-surface represent sites where life began and then grew into the complex diverse system we know of today. This is a complex interlocking system of life, ranging from the ocean floor and the water above, to the atmosphere above that.

The oceans will continue providing us with food and energy and with the resources for a range of entirely new industries, specializing in marine bioproducts, pharmaceuticals and nutraceuticals derived from exotic micro-organisms, such as extremophiles living around hydrothermal vents on the ocean floor. We are a great and resourceful nation and our future rests upon our competitive advantage in the world based upon our out-of-the-box thinking.

In order to have a meaningful knowledge of this complex system and its potential role in the future well being of the United States and its people, a meaningful plan that has a global perspective of this earth system needed to be put in place. The plan would include a full survey and assessment of the ocean life systems, the effect of ocean chemistry and climate on these systems, and the vast array of habitats on the ocean floor, all viewed from an integrated perspective.

The plan designed to achieve our meaningful knowledge of the oceans came to us in the form of the report issued under the direction of the President entitled, "Discovering the Earth's Final Frontier: A U.S. Strategy for Ocean Exploration". The recommendations stemming from the report focus around ocean exploration—exploration with clearly identified goals, objectives and potential benefits. This is an exciting interdisciplinary, inter-cultural, inter-agency program. It lays the groundwork for understanding the whole diverse ocean system and our intimate relationship to this system. In this program, we will look at this system from human habitation on the coasts and islands of the oceans to the hydrothermal vents on the ocean floor. In order to accomplish this, we must systematically map the complete environment. We must establish multi-sensor observatories that will read all environmental data from the coastline to the deep ocean floor. This includes the biology, geology, physical oceanography, and water chemistry of the oceans. We must understand the role, history and impact of humans upon the ocean from pollution to historic wrecks and structures on the ocean floor. We must make this information readily available to educators and environmental, political, industrial and research leaders, so that effective plans for new aquaculture, new ocean industries, and new ocean conservation initiatives can be laid.

These challenges in our Ocean Exploration Program open up wide, avenues for advancement to all sectors of our society with interest and investment in the oceans. First of all, it invigorates the vision of a new presence for the American society in the oceans. Secondly, the program offers an opportunity for a different presence in the oceans for America. With new tools, systems, observatories, vehicles, and sensors applied to these programs, new industries will flourish and a new ocean systems industrial niche will develop. Our paucity in the international maritime transportation industry will be balanced by our leadership in the ocean exploration industry. The exciting aspect of the Ocean Exploration Initiative will be the challenge of partnerships that would envelope the diverse interests described.

The National Oceanic and Atmospheric Administration has taken an effective lead by creating the Office of Ocean Exploration. This has been a bold move towards this new interdisciplinary, inter-cultural and inter-agency arena. This is a fresh start and a catalyst that will enable our nation to take a lead in the wholistic understanding of our oceans. This is a critical step for our nation to take and everyone should be behind it.

It is and exciting step because it challenges us to think along a broad intellectual front, yet focus on frontier problems. These could be the survival of coral reefs, or the range in the diversity of microorganisms, or the challenge of open ocean pelagic fishery aquaculture, or the extraction of new pharmaceuticals from organisms living in the hydrothermal vents, or the impact of human presence on our coastlines. This broad thinking will lead to a revival of global expeditions with airplanes, ships, submersibles, satellites, robotic miniaturized underwater vehicles, autonomous observatories, and *in situ* robotic laboratories. This U.S.-led Ocean Exploration Program will also attract international partners with a dazzling array of ocean observational systems spanning the globe.

Ladies and gentlemen, America must take the bold, necessary step to regain the U.S. lead on all fronts of maritime technology. The challenge of this new Ocean Exploration is monumental. In our own Hawaiian Island chain, stretching the length of over 1,200 miles, a home for most of America's tropical coral mass, very little is known about the nature and life of the ocean floor north of the inhabited windward islands. The Hawaiian Islands are strategically located in the middle of the Pacific Ocean, a physical and cultural presence of the United States in the middle of the world's largest ocean.

How do we begin this task in our Hawaii? Much of the work to date has been accomplished in Hawaii through the use of submersibles operated by the Hawaii Undersea Research Laboratory, one of six Centers of NOAA's National Undersea Research Program (NURP). NURP is a is a comprehensive underwater research program that places scientists underwater, directly through the use of submersibles, underwater laboratories, and wet diving, or indirectly by using remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), and observatories.

NURP is primarily a grant program with most of its funding going to the research community, primarily academia. In this program, research quality is ensured by competitive and high standards of peer review. Highest priority is given to proposals for studies in the large lakes, territorial seas, and adjacent waters of the United States. Responsibility for soliciting and supporting the research is assigned to regional Centers: North Atlantic and Great Lakes; Mid-Atlantic; Southeastern U.S. and Gulf of Mexico; Caribbean; West Coast and Polar; and Hawaii and Western Pacific.

The National Undersea Research Program is one that has made a significant difference towards understanding of the oceans and its resources. The undersea research has laid the foundation for the United States to fully explore of the undersea environment. NURP sets an example in working through partnerships. For instance, the Hawaii Undersea Research Laboratory conducted a workshop of our constituents and Pacific partners in 1997. The Hawaii and American Flag Pacific Islands Coastal Zone and Fisheries Workshop was a resounding success because it effectively addressed the key concerns of the this large region related to: 1) coral reefs, coastal habitats and water quality, 2) coastal hazards and mitigation, and 3) fisheries. In the area of fisheries, for example, it helped HURL to understand the needs of fisheries managers (e.g., NOAA's National Marine Fisheries Service) and it aided in the development of partnerships and the leveraging of funding sources to solve such problems as:

- Examine of the effectiveness of 'no-take' marine protected areas.
- Evaluate the extent and status of exploited fish resources and the discovery of new resources.
- Understand the functional role of habitat in survivorship, growth, and reproduction of managed marine species.
- Quantify rates of recovery for habitats impacted by chronic and pulsed fishing activities.
- Map and characterize the habitat and biological integrity of benthic communities and reefs at selected continental shelf sites (e.g., marine protected areas) that are inaccessible to usual diving techniques (deeper than 50 meters).

Because of the infrastructure and presence of unique equipment, such as the 220-foot mothership, the R/V *Ka'imikai-o-Kanaloa* and the 6,800-foot depth capable *Pisces IV* and *Pisces V* and ROVs at the Hawaii Undersea Research Laboratory, discoveries of unique and diverse populations of extremophiles in hydrothermal vents of the pit craters of the submarine volcano, Loihi, were made possible. The extremophiles discovered barely 20 years ago in vents and seeps surrounded by mineral deposits and unique life that exists without sunlight and oxygen, have revolutionized modern scientific theory about the origin and sustenance of life on Earth. Extremophiles are known for their ability to flourish in the world's most harsh environments. These are the organisms whose unique biology holds great potential in biomedical and commercial applications.

We will need a larger number of ROVs, with better sensor capability, that are suited for a variety of tasks, from the small ones that can explore smaller crevices to large ones that better equipped to do larger tasks and that have the payload capacity to return a variety of samples to the scientists operating from the surface. However, as with the exploration of the farther reaches of space, a greater dependence will begin to be put on AUVs and fixed seafloor observatories. AUVs need to become more reliable, capable of doing a variety of tasks, and capable of larger range. Fixed, or multi-deployable, seafloor observatories of the *Aquarius* and LEO–15 type also need to be expanded in capability and number to examine, *in situ,* the processes of such phenomena as deep-sea processes. Such processes include the volcanic evolution of new islands, e.g., Loihi in the Hawaiian-chain, or the dynamics of spreading ridges. These result in the injection of mass and energy into the ocean, and the evolution of new species and resources.

There is an immediate need for an expansion of our present capabilities—manned submersibles, ROVs, AUVs, and seafloor observatories. The key to this expansion will be the development of a new generation of submersibles, such as those capable of going efficiently and safely to the depths of the ocean. No new deep ocean submersibles have been built in the United States during the past 30 years. With new metallurgy, new propulsion and greater sensor capability, the development of better and smaller electrical, acoustical, and optical sensors, and a new generation of deep ocean exploration vehicles should be developed by the United States. Twenty million dollars per vehicle would provide the U.S. with leadership in this field.

The new Ocean Exploration Initiative is an exciting and challenging program for the United States. It will build new industries, educate the citizenry, preserve the environment and open new collaborative partnerships.

In the technology arena, partnerships between academia, the U.S. Navy, NASA, NOAA, EPA and industry will be forged. A new ocean knowledge base will be established, providing critical ocean information to the U.S. government for defense, resource management, environmental protection and policy and law. The ocean knowledge base will also provide information to coastal developers, states and municipalities, fisheries, oil and ocean mineral industries, and provide the knowledge base for oceanographers and educators.

It is essential that this new venture be fully supported by Congress, that the fledgling Office of Ocean Exploration be fully funded, and that a fleet of new age submersibles be constructed for the exploration of the Pacific, Atlantic and Arctic oceans, and the Gulf of Mexico.

Core programs essential to accomplishing the objectives of Ocean Exploration, such as NOAA's NURP should be fully funded and ocean exploration programs in the Defense Department, the National Science Foundation, the Environmental Protection Agency be supported. States bordering and surrounded by the oceans should be encouraged to join the partnership and U.S. industry should be encourages by government to take a lead in the development and manufacture of instruments, vehicles, systems, observatories, data processing and information technology. This way, Ocean Exploration will be a cornucopia for a new wave of American knowledge and industry.

PANEL III DISCUSSION

Chairman GILCHREST. Thank you, Dr. Malahoff. I do not speak any Hawaiian so I can say aloha when you leave. Thank you very much, gentlemen. Mr. Ehlers.

Mr. EHLERS. Thank you, Mr. Chairman. A few questions. First of all, Dr. Beeton, I just wanted to express my appreciation to you for the great work you did in Michigan for so many years on the Great Lakes system, which I think is a very important aquatic system. And you served well and long and we really appreciate the work.

Dr. BEETON. Thank you. I——

Chairman GILCHREST. Would the gentleman yield just for a quick comment. Dr. Beeton came to my office when I was first elected to Congress to start helping me understand NOAA. So, Dr. Beeton, good to see you and thank you for all of the work that you do.

Dr. BEETON. Thank you.

Mr. EHLERS. I think you educated a lot of Members of Congress. I have a question. In your testimony you mentioned the Great Lakes could benefit from a NOAA exploration initiative to help chart and map the lakes. I am just in a sense asking an administrative question. Would it not work better for that to happen through NOAA's national ocean service which is responsible for charting and mapping coastal areas or——

Dr. BEETON. Well, the way I look at it, the ocean exploration activity is something that should—NOAA should be key player in. And the—NOS, National Ocean Service, that has charting capability and so on will be part of that. So I——

Mr. EHLERS. So you are assuming they would both work together——

Dr. BEETON. Yes.

Mr. EHLERS. Okay.

Dr. BEETON. So I think that is where the activity should be.

Mr. EHLERS. Okay. Dr. Weller, I am a physicist and I do not understand the ocean current chart you displayed. I have seen it before. What mechanism is there that keeps it going more or less uniformly in the same place? What behavior in a liquid with the current that is in between would make it so stable, relatively stable?

Dr. WELLER. Well, it is the distribution of the density. And the density is set by temperature and salinity. In the high North Atlantic we have a unique condition in which we expose the sea water there to extreme, strong cooling. And the sea water starts out fairly salty normally. So as it cools, it gets more dense and it sinks. Now as the water moves down through the interior of the ocean, mixing rates are slow and the flow is driven by the pressure gradient set up by the spatial differences in density. And those are fairly stable. Those evolve, you know, down away from the surface of the ocean where the atmosphere mixes it. Things evolve slowly. So down even 1,000 feet, change year to year is very slow. And that penetration, and we can track it by looking at freons and things, that takes many years for that water to move down.

But the key is that it starts with that getting denser. And the key is that the atmosphere creates these spatial differences in density and drives the flow.

Mr. EHLERS. I understand that. But what I do not understand is how you—it goes down, curls, circulates all up into the Pacific, turns around and comes back. That is a rather intricate pattern of motion. Obviously, there are forces changing direction of the motion—movement of the currents.

Dr. WELLER. Well, you know, it would be—if in your bathtub, say, at home you took two immiscible fluids, you know, a blue one and clear one, different densities. Now let us find the fluid that is at a density in-between those two.

Mr. EHLERS. Which is a lava vent.

Dr. WELLER. Right. And so down by the drain of your bathtub you pour that fluid in. It will sink initially to the density, you know, in-between——

Mr. EHLERS. I am not worried about the sinking——

Dr. WELLER [continuing]. Spread out.

Mr. EHLERS [continuing]. Working—I am worried about working all the way across.

Dr. WELLER. Sure. Once it sinks, you know, it has more fluid coming behind it, there is a pressure head, it will then spread out at its normal density. The ocean is stratified from top to bottom with light to heavy. So water sinks to where it finds its own density and then it can't move up or down because it will move against density. It moves sideways.

Mr. EHLERS. Yeah. Why does it not go out in all directions rather than circulating——

Dr. WELLER. Well, then the physics of the earth's rotation come into effect.

Mr. EHLERS. So is it a Coriolis force?

Dr. WELLER. It is. It is Coriolis. It is what as an oceanographer we call geostrophic. It is a balance between the density created pressure gradient and the Coriolis Force due to the earth's rotation.

Mr. EHLERS. Okay. Still hard for me to understand how it would—you know, I am used to dealing with one or two particle systems. It is hard for me to understand how that flow is so uniform. Okay. Another question, Dr. Weller. It was one I asked earlier of Mr. Gudes. And that was the role of polar orbiting satellites program in ocean observation. And was that—was the decision to go ahead with this made in cooperation with the various members of the research community interested in this? And is it an optimum program, is it going to provide you the data that you need and want for your work?

Dr. WELLER. You know, it is a landmark decision. NASA flies research satellites. They have proven that they can be a great value to oceanography. We do not yet have an operational oceanographic satellite program. This marks the transition. To be honest, not all oceanographers believe that the optimum sensors have been chosen. But this is moving forward. Operationalizing satellite observations for oceanography. It is forward progress. We need to maintain a dialogue now to optimize it.

Mr. EHLERS. I see. And do you see it meshing well with the ARGO program?

Dr. WELLER. Oh, it fits extremely well with the ARGO program. One of the key measurements is altimetry which is measuring the height of the ocean as the density of the temperature and salinity patterns vary and the height of the ocean varies. ARGO gives you the information about temperature and salinity, its profiles. Take it together with this height measurement, and you can infer this geostrophic flow that we were just talking about. So satellites plus ARGO, you get the global circulation.

Mr. EHLERS. And just another quick one. I am not sure if you are the one who mentioned about putting measuring instruments on ships?

Dr. WELLER. Yes.

Mr. EHLERS. Are we doing any of that now and is there any reason we cannot do it on all ships?

Dr. WELLER. We are just—we have a standard program under the weather service with a too small investment. Very simple instrumentation. NOAA Office of Global Programs has pilot projects in the Atlantic and the Pacific to test the value of improved meteorological measurements. Other countries are doing it. We are proving the value. We should move forward. And since those ships are routinely out there for their own purpose, we should instrument them.

Mr. EHLERS. And is there any possibility of trying to fill in the gaps by contracting with commercial airliners to simply have a device on them that would drop meteorological instruments every hundred miles as they are flying across the ocean? We have a vast network of air traffic, too. That could be——

Dr. WELLER. That—it is probably going to be difficult to work out the airplanes dropping. But there is a plan from one of the NOAA research labs to have globally orbiting balloons. You know, several people have tried——

Mr. EHLERS. Yeah.

Dr. WELLER [continuing]. To fly around the world in these balloons. The plan is to have large balloons that circumnavigate. And they drop ocean probes as they pass over the oceans.

Mr. EHLERS. All right. I yield back.

Chairman GILCHREST. Thank you, Mr. Ehlers. Mr. Barcia.

Mr. BARCIA. Thank you, Mr. Chairman. I, like my colleagues from Michigan, want to thank Dr. Beeton for his fine work in Ann Arbor, Michigan. Not only in terms of the research you have done as it relates to the Great Lakes Basin, but of course your expertise in the issues effecting our ocean systems throughout the world.

Dr. Beeton, I just have one question for you. And I would just like to say that I am interested in learning more about your proposal for a Great Lakes Coastal Observatory System. You recommend including and emphasizing the Great Lakes in legislation dealing with ocean exploration and ocean observing systems. Could you gives some examples of what is needed? Also, could you give some benefits to the region and the nation from a Great Lakes Coastal Observatory System? And finally, how would you structure such a system and how much funding do you think would be required to support it? I know it is a lot of questions but if you could—in a general——

Dr. BEETON. Well, fortunately, just recently I was in Ann Arbor talking to the people at the Great Lakes Environmental Research Laboratory. And they have been thinking about a system that could be actually a mobile observing system that could be put in place, for example, in the Thunder Bay Marine Sanctuary. That not only would provide observations insight to the sonar and TV camera networks and so on. So it would provide—and other kinds of sensors, biological and chemical that would provide data to people in universities. But also to Federal agencies like EPA, NOAA, U.S. Geological Survey and so on. But it would have a link to the shore so that visitors to the marine sanctuary could actually then see something of the marine sanctuary.

I mean, the marine sanctuaries are great but for a lot of people that might want to come and visit, what are they going to see. The shore and some water. And so if we have an underwater observation system that would greatly enhance their learning and the outreach activity to educate them. And so this is one of the things that has been proposed. In fact, this proposal ought just been sent forward to NOAA headquarters as a possible thing to be funded.

So those are some of the things that we are thinking about.

Mr. BARCIA. Any idea what the cost involved might be, a ballpark figure?

Dr. BEETON. No. Because I think this is really at the concept stage. And, you know, I think it might be inappropriate to try to put some kind of a figure on it until people really sat down and looked at it and got some hard data.

Mr. BARCIA. Thank you.

Chairman GILCHREST. Thank you, Mr. Barcia. Mr. Abercrombie.

Mr. ABERCROMBIE. Thank you very much, Mr. Chairman. I regret that I could not get here earlier. But I want to commend you for just working on this joint hearing.

I want to in particular, I think you know, welcome Dr. Malahoff who is a good and dear friend. And I want to say a valued colleague in the sense of our interest in what I call innerspace. We have devoted a good portion of the national budget, Mr. Chairman, for some period of time now to outer space. And we have not managed to put the same kind of emphasis, in my judgment, on inner space on our own planet. Inner space taking up, if I—if Dr. Malahoff's instructions to me are correct, about ¾ of the surface of the planet.

Now in that regard, if I could be granted an opportunity to ask Dr. Malahoff about his testimony, and some of this may have been covered. But I hope I can provide some emphasis. If you look at page four of your testimony, Dr. Malahoff, you talk about—in the second paragraph about the immediate need for expansion of our present capabilities. Manned submersibles, ROVs, AUVs and sea floor observatories. And there is a picture over here of the LEO–15, that kind of thing. There is a whole spectrum operating here. You indicate as well, and I am reading this just in case you were not able to read all of it during the portion of your testimony. No new deep ocean submersibles have been built in the United States for the past 30 years. And then you go on to recount new metallurgy, new propulsion, greater sensor capability has allowed for the development of better and smaller electrical acoustical and optical sensors. And a new generation of deep ocean vehicles should be developed.

My question to you is, in relation then to the last sentence of that paragraph, $20 million per vehicle would provide the U.S. with leadership in this field. Is that $20 million a figure that is drawn from some hard research with respect to specifications, et cetera? And $20 million, does that mean ROVs, AUVs, sea floor laboratories? Just exactly what does the $20 million refer to and how hard is the data that comes up with that figure?

Dr. MALAHOFF. Yes, sir, Congressman. It is submersibles. It is based upon the cost of building the Mire's that are now in Russian hands. And it is based upon my current estimate of building similar submersibles here in the United States.

And I envision perhaps five of these vehicles being distributed throughout the areas of interest in the United States. Including, of course, one based in Hawaii so we could cover the central and tropical Pacific Ocean.

Mr. ABERCROMBIE. Dr. Weller has provided, and I expect that you must have before you, have you seen this particular publication——

Dr. MALAHOFF. Yes.

Mr. ABERCROMBIE [continuing]. I expect entered in the record. Is it not, Mr. Chairman?

Chairman GILCHREST. We will enter it into the record right now.

Mr. ABERCROMBIE. If you will. It is Volume 42, number 1.

Chairman GILCHREST. Without objection, so ordered.[2]

Mr. ABERCROMBIE. Thank you. The reason I bring it up is that, and maybe I can ask Dr. Weller to comment, the picture on the front is a rendering. This is obviously not a photograph. Is that right, Dr. Weller?

Dr. WELLER. That is correct.

Mr. ABERCROMBIE. And it is a rendering because this vehicle has not been built yet?

Dr. WELLER. That is correct.

Mr. ABERCROMBIE. And it—I have it here at either the ABE2 or the ABE2.

Dr. WELLER. Early versions of ABE, an autonomous vehicle, have been built.

Mr. ABERCROMBIE. Okay. When you say they have been built, are they presently able to be utilized or are they models?

Dr. WELLER. No. They have started to do scientific research.

Mr. ABERCROMBIE. And how would this vehicle relate to what Dr. Malahoff has in his testimony? What would be the relationship in his testimony about the immediate need for these new ocean submersibles, ROVs, AUVs, sea floor laboratory—observatories?

Dr. WELLER. One of the things that is difficult for oceanographers to do is to do the equivalent of a mapping mission, say,

[2] See "Oceanus" in Appendix 4.

from a plane. How do you go down and get a—essentially, a snap shot, synoptic picture of features or processes. It would be very difficult to do. If we took a ship out and we dropped, say, core profilers or instruments at spots. And moving the ship as we heard earlier, they move very slowly. But if you could go out with the ship and lower a vehicle like that and send it on its mission to fly a radiator pattern, it could accomplish those sort of mapping missions very effectively.

Mr. ABERCROMBIE. Would that not be useful for the security interest of this nation as well?

Dr. WELLER. Well, in my judgment, mapping things like routes along which submarines transit would be very valuable.

Mr. ABERCROMBIE. So would it not be a useful procedure for us to meld in this instance Department of Defense research capabilities and funding, and the scientific side of it, a kind of dual technology, if you will, or a dual purpose technology?

Dr. WELLER. I agree completely. A lot of the observational tools we are talking about have many applications. Mapping features on the bottom for geological studies is not that much different than trying to find and detect buried mines on the bottom.

Mr. ABERCROMBIE. Would there be in your—or any of the members of the panel, are there now presently institutional repositories in the Department of Defense with which you could usefully connect?

Dr. GRASSLE. Yes. As Bob Ballard mentioned, a lot of the new technology has come from the Navy. I might mention though specifically with regard to ABE, the—that came out of a group that—the group that first discovered hydrothermal vents. And thinking about how we were going to explore the mid-ocean ridge system. And the concern was that it is 40,000 miles long. And we needed to explore it on a number of different scales.

And the idea for ABE was that we could not afford to be there with a ship and a submarine to go and look more than a few sites along the ridge on any one trip. And so the idea was to have an autonomous vehicle go out and go back and forth continuously and mobile one, as Bob refers to it, and get a continuous coverage that is not only the geological features but the—but the life on the sea floor.

And there is another such vehicle which also was developed at Woods Holes called REMUS, which you will see in the LEO picture. It was actually developed as a coastal vehicle, REMUS. But it is being used by the Navy to have continuous coverage of a kilometer square in shallow water. And it is now being adapted for deep sea use with Navy support.

Mr. ABERCROMBIE. Mr. Chairman, thank you for your indulgence in the questions. Would it be useful, or I would like to suggest in conclusion that perhaps under auspices of even the joint committee to include—joint committee auspices rather, to include perhaps the Armed Services Committee.

Chairman GILCHREST. We were—we attempted to do that for this hearing. But scheduling did not——

Mr. ABERCROMBIE. The schedule——

Chairman GILCHREST [continuing]. Future hearings.

Mr. ABERCROMBIE. Well, whether hearings or not, I certainly hope that perhaps we could work together to try and see if we could not come up with a proposal for the scientific community, particularly the under—Dr. Beeton's—or perhaps with Dr. Beeton's assistance to empower the National Oceanic and Atmospheric Administration to work with the Department of Defense and other appropriate research entities in academia to come up with a comprehensive proposal for undersea research, or what I would—again, I am going to prefer to call inner space research. That would involve the various resources of the United States Government to back up the academic side that is obviously well represented and incredibly professional and prepared right now. Do we have a proposal?

Chairman GILCHREST. I think one of the purposes of this hearing today, we had Admiral Cohen from the Navy here earlier along with Curt Weldon. Is to—and that is an excellent idea. And that is what we are pursuing.

Mr. ABERCROMBIE. Wonderful. Well, I appreciate that, Mr. Chairman. I am sure under your vigorous leadership we will be able to accomplish that.

Chairman GILCHREST. And Mr. Ehlers and yours.

Mr. ABERCROMBIE. Yes, of course.

Chairman GILCHREST. Thank you, Mr. Abercrombie. We will finish up with just—I have just a few questions for the panel.

I would like to go back to an earlier question Dr. Ehlers raised about ocean currents, Dr. Weller. I found your explanation fascinating. This living organism seems to sustain itself by a pretty complex, interesting mechanical structure, I guess if you take the parts apart. What would you say it would take for the ocean currents to stop or change or be reversed? Would it be a traumatic event, would it be a slow cyclical event, period of cyclical changes, would it be global warming. What would it take? Or have the ocean currents been different in the past and, therefore, the climate been different?

Dr. WELLER. In the paleo-oceanographic record looking at, say, pollen or tree rings and things coral, we do know that in the past the ocean circulation, that conveyor belt picture that I showed, has stopped. That is what we call the shutdown of the thermal-haline circulation. The sort of change you can expect is—can be a rapid change. The temperature in Western Europe could change 20 degrees Fahrenheit in ten years. In fact——

Chairman GILCHREST. Colder or warmer?

Dr. WELLER. Colder. Europe, because of this poleward heat transport of heat in the North Atlantic is anomalously warm for the latitudes it is at, so in ten years it could be much cooler.

Chairman GILCHREST. Would the equatorial regions be a lot warmer then?

Dr. WELLER. They would—yes. There would be a rebalancing. And in fact, as you worry about global warming I hope you would consider that we have now started on an oceanographic experiment. We are heating the earth's surface. We are heating the ocean. We are melting the ice caps. We are doing two things at the poles that will shut down that sinking process. We are letting loose very light fresh water at the poles.

Chairman GILCHREST. You say it has been that way in the past?

Dr. WELLER. It has, yes.

Chairman GILCHREST. The current has shut——

Dr. WELLER. Yes.

Chairman GILCHREST. What would cause it to shut down, a shift in climate?

Dr. WELLER. A shift in climate, yes.

Chairman GILCHREST. I guess in the past that shift in climate has been a natural shift that occurred over a longer period of time than the potential change we are seeing now?

Dr. WELLER. No. In the paleo-climate record there are times when the climate has changed almost as rapidly. If you go back and you recreate the temperatures, say, in the Atlantic Ocean, say, in the Younger Dryas—there were times when temperature changed within a decade, say, ten degrees. The changes——

Chairman GILCHREST. Now that change in temperature occurred within ten years rapidly.

Dr. WELLER. Yes.

Chairman GILCHREST. But the reason that the ocean currents stopped, was that just as rapid or was that a slow process?

Dr. WELLER. It is a slow process in the sense that I showed you the conveyor belt and the water moves down slowly. But what you could have, say, you could have a series of years where the winters in the North Atlantic are milder. It is not cold, ice is melting. Each winter for a succession of winters, perhaps five winters, you have successively each winter pushed down into that intermediate layer less of that water. And that——

Chairman GILCHREST. So the ocean, the current, the flow actually stops?

Dr. WELLER. Yes.

Chairman GILCHREST. So does that mean that the ocean bottom current stops? Does that mean the Gulf Stream, for example, would not be moving?

Dr. WELLER. You know, we can go to models to answer your question. And then you have to ask if—how faithful the models are. I mean, the simple answer to your question is yes. If we change that temperature and salinity distribution at the source, we then change all the currents that depend upon the dynamics of being driven by density differences.

Chairman GILCHREST. Is there some idea about what that temperature would have to be in order for that to happen? Some of the predictions by the IPCC are as much as four or five degrees, six degrees or more Fahrenheit over the course of a century? Would that be enough to cause this current to stop? And then I guess if it stops the Northern Hemisphere gets colder, the equatorial regions get warmer?

Dr. WELLER. There is the potential that the pathway we have embarked upon as indicated by the IPCC can cause this. The United Kingdom just put 20 million pounds into research and observations to study the possibility that there will be an abrupt shutdown of the circulation.

Chairman GILCHREST. Mr. Ehlers?

Mr. EHLERS. If the gentleman would yield. But is not there a positive feedback loop if it gets colder in the Northern Hemisphere then once again the water will start sinking and become more dense and start this all over again?

Dr. WELLER. You are right.

Chairman GILCHREST. How fast does that happen?

Mr. EHLERS. So you could get an oscillatory——

Dr. WELLER. You could get an oscillatory behavior. The remarkable thing is that the past 10,000 years of climate have been very stable. I think of concern is can we push it out of being stable and enter one of these oscillatory patterns.

Chairman GILCHREST. But if it oscillates, what is the time frame for that? We move into a period where the ocean stops, the current.

Dr. WELLER. Right.

Chairman GILCHREST. Then like Vern said, it gets real cold in the Northern Hemisphere. And then that could start it back again. You said the change in climate could happen within 10 years. Does reversing that happen within 10 years?

Dr. WELLER. I can't answer that. You know, what I should do is I should look at the papers that use the paleo-oceanographic record to recreate sea surface temperatures. And I should send you a figure, say, that contrasts many thousands of years of temperature, Bermuda versus Greenland, and write you a little note about the answer.

Chairman GILCHREST. Thank you. I guess that was not part of the description of what we wanted you to testify on when you came. Just briefly, I know it has been a long day for everybody. But, Dr. Grassle, can you comment on the mid-Atlantic Long-Term Ecosystem Observatory Program you are now involved in just 15 meters of water? Is that just along the New Jersey coast?

Dr. GRASSLE. Yes.

Chairman GILCHREST. Does that extend beyond New Jersey?

Dr. GRASSLE. I do not know whether you can see the two graphics, but the one is for the middle part of the Jersey coast, which is a 30x30-kilometer area served by bottom cables buried in the sediments that provide profiling systems to get the vertical measurements, salinity, temperature, depth, chlorophyll, light, backscatter of particles. Also, we have autonomous vehicles that go out and make measurements. The REMUS vehicle I referred to before. But the new instruments that we are using more frequently are the gliders, which are like ARGO floats but they can be redirected by radio.

Chairman GILCHREST. Is part of the reason you are doing this type of observation to see the impact on the ocean of coastal activity?

Dr. GRASSLE. Yes. But it is to understand the relationships among organisms in the ocean to calibrate satellite information on chlorophyll and other pigments. And for the coastal ocean so that we will get that information from the coastal environment all around the country.

Chairman GILCHREST. Do you know of anybody else that is doing something similar to that?

Dr. GRASSLE. There is nothing quite this intensive. But there are similar efforts in a number of places. The State of Maine has embarked on a system like that. I think Al mentioned that there is interest in that sort of system in the Great Lakes. There is work with high-frequency radar, long-range high-frequency radar which is very important. And we are the first to have continuous measurements on that, but there are also systems at Oregon State and at the Navy Post-Graduate School——

Chairman GILCHREST. Is the data collected from those systems compatible?

Dr. GRASSLE. Yes. We have made an effort to go around and talk with one another and come up with uniform standards and protocols because that is so important for developing the National Ocean Observing System.

Chairman GILCHREST. In the areas where these—where you placed these monitors or where they are being studied, how did you choose other than 15 meters the places to collect the data?

Dr. GRASSLE. We started because we had a laboratory that was situated in an inlet.

Chairman GILCHREST. Oh.

Dr. GRASSLE. It is a Coast Guard lifeboat station. And when the Institute of Marine Coastal Sciences was started we wanted to make long-term measurements in our coastal region. And these need to be interdisciplinary measurements involving all the scientists, and the starting point is to get the circulation in the coastal ocean through time.

And we find, for instance, the primary productivity, the shape of it in the ocean varies. But there are discrete bodies of primary productivity that had not been seen before. There are coastal jets of water which are chock-full of chlorophyll. There is a circulation driven by small-scale upwelling that also are places where there are hot spots of primary production.

These features were known before we had an observing system that was continuous in time and this fine scale spacially.

Chairman GILCHREST. Sounds fascinating. Mr. Abercrombie, any other questions? Mr. Ehlers? For the sake of time——

Mr. ABERCROMBIE. Excuse me, Mr. Chairman. I probably—a question to both chairmen. I realize what you said was difficult to put something together logistically with Armed Services. But might we—might I inquire as to what your intentions are with respect to perhaps coming up with a recommendation on these areas in the time frame? Maybe we could do some kind of study to put this together even in this budget, if it is possible. I would certainly be—volunteer to work with you to try and accomplish that task. I guess that is what I am trying to put forward.

Mr. EHLERS. Well, let me just repeat something I said earlier in the meeting. Through hearing Congressman Weldon's testimony, I sent him a short note suggesting a way in which we could engage in this activity in this Congress. And he sent back a shorter saying, good idea. Let us work on it. So we will talk to you about that and——

Mr. ABERCROMBIE. I have great admiration for Congressman Weldon's commitment in this area. And I would certainly try to work with him and with you to accomplish that.

Mr. EHLERS. Yeah. It is both his energy and his intensity in working on it is very good. So we will try and see what we can do.

Chairman GILCHREST. But we were hoping an increase in the military budget, about 80 percent of it would go to ocean research——

Mr. EHLERS. Yes.

Chairman GILCHREST [continuing]. And exploration.

Mr. ABERCROMBIE. I am for that.

Chairman GILCHREST. We are going to make that recommendation. We will keep the record open for members to submit follow-up questions to any of the witnesses for, I guess, a period of as long as we want, I supposed. But we could do it for five days. But I want to thank the witnesses again for your testimony. It has been very helpful. The topic is fascinating. And we hope to continue this dialogue for some time to come. The hearing is adjourned.

[Whereupon, at 4:45 p.m., the Subcommittee was adjourned.]

Appendix 1:

Panel I Biographies, Financial Disclosures, and Answers to Post-Hearing Questions

Scott B. Gudes

Scott B. Gudes
Acting Under Secretary for Oceans and Atmosphere and NOAA Administrator/Deputy Under Secretary for Oceans and Atmosphere

In June 1998, Scott B. Gudes was named deputy under secretary for Oceans and Atmosphere for the Department of Commerce's National Oceanic and Atmospheric Administration. As NOAA's third highest ranking official, the deputy under secretary oversees the management of NOAA's seven line offices: the National Weather Service, the National Marine Fisheries Service, the National Ocean Service, NOAA Research, the National Environmental Satellite, Information and Data Service, the Office of Finance and Administration and the Office of Marine and Aviation Operations, as well as NOAA's Staff Offices. With employees in every U.S. state, at sea, and at many overseas locations, NOAA employs nearly 12,700 people with a FY2001 Budget of more than $3.2 billion. In addition to his duties as DUS, Mr. Gudes has served as the assistant secretary/chief financial officer for the Department of Commerce from July to October 1999, as acting assistant secretary/deputy administrator of NOAA from November 1999 to June 2000, and since January 2001, is serving as the acting under secretary for oceans and atmosphere/acting NOAA administrator.

NOAA is responsible for all U.S. weather and climate forecasting, monitoring and archiving of ocean and atmospheric data, management of marine fisheries and mammals, mapping and charting of all U.S. waters, coastal zone management, and research and development in all of these areas. NOAA is the largest part of the Department of Commerce and manages the U.S. operational weather and environmental satellites, a fleet of ships and aircraft for oceanographic, surveying, fisheries, coastal, and atmospheric studies, twelve environmental research laboratories, and several large supercomputers.

Mr. Gudes' background and experience have kept him involved in NOAA issues for the past 17 years. He served as NOAA's budget examiner beginning in 1983 at the U.S. Office of Management and Budget until 1986 when he began a career as a Professional Staff Member for the U.S. Senate's Committee on Appropriations. While at Senate Appropriations, he worked for both political parties thus gaining a reputation for bipartisanship.

In 1990 Mr. Gudes became the staff director for the Commerce, Justice and State, the Judiciary and Related Agencies Subcommittee, under whose auspices the NOAA Budget is supported. His background in Appropriations has made him an integral part and a key figure in the way NOAA presents its budget to Congress, and he is frequently called upon to brief Congressional committees and members on a great variety of NOAA science and management issues. At NOAA he is known for a focus on employees, human resource issues and a commitment to rebuilding the agency's infrastructure.

Mr. Gudes was born and raised in California and studied at the University of Liverpool, United

Kingdom, and in California, where he graduated from San Diego State University in 1976. He earned his Masters of Public Administration from California State University at Fullerton two years later. He served as a Presidential Management Intern after graduate school, working in the Office of the Secretary of Defense.

An avid recreational fisherman, golfer and SCUBA diver, Mr. Gudes highly values marine and coastal conservation and is a champion of NOAA's critical role as the nation's ocean resource steward.

Publication of the National Oceanic & Atmospheric Administration (NOAA)
Last Updated: 5/24/01

Dr. Rita Rossi Colwell
Director
National Science Foundation

Dr. Rita Colwell became the 11th Director of the National Science Foundation on August 4, 1998.

Since taking office, Dr. Colwell has spearheaded the agency's emphases in K-12 science and mathematics education, graduate science and engineering education/training and the increased participation of women and minorities in science and engineering.

Her policy approach has enabled the agency to strengthen its core activities, as well as establish support for major initiatives, including Nanotechnology, Biocomplexity, Information Technology, and the 21st Century Workforce. In her capacity as NSF Director, she serves as Co-chair of the Committee on Science of the National Science and Technology Council.

Under her leadership, the Foundation has received significant budget increases, and its funding recently reached a level of more than $4.5 billion.

Before coming to NSF, Dr. Colwell was President of the University of Maryland Biotechnology Institute, 1991-1998, and she remains Professor of Microbiology and Biotechnology (on leave) at the University Maryland. She was also a member of the National Science Board (NSF's governing body) from 1984 to 1990.

Dr. Colwell has held many advisory positions in the U.S. Government, non-profit science policy organizations, and private foundations, as well as in the international scientific research community. She is a nationally respected scientist and educator, and has authored or co-authored 16 books and more than 600 scientific publications. She produced the award-winning film, *Invisible Seas*, and has served on editorial boards of numerous scientific journals.

She is the recipient of numerous awards, including the Medal of Distinction from Columbia University, the Gold Medal of Charles University, Prague, and the University of California, Los Angeles, and the Alumna Summa Laude Dignata from the University of Washington, Seattle.

Dr. Colwell has also been awarded 18 honorary degrees from institutions of higher education, including her Alma Mater, Purdue University. Dr. Colwell is an honorary member of the microbiological societies of the UK, France, Israel, Bangladesh, and the U.S. and has held several honorary professorships, including the University of Queensland, Australia. A geological site in Antarctica, Colwell Massif, has been named in recognition of her work in the polar regions.

Dr. Colwell has previously served as Chairman of the Board of Governors of the American Academy of Microbiology and also as President of the American Association for the Advancement of Science, the Washington Academy of Sciences, the American Society for Microbiology, the Sigma Xi National Science Honorary Society, and the International Union of Microbiological Societies. Dr. Colwell is a member of the National Academy of Sciences.

Born in Beverly, Massachusetts, Dr. Colwell holds a B.S. in Bacteriology and an M.S. in Genetics, from Purdue University, and a Ph.D. in Oceanography from the University of Washington.

-NSF-

DISCLOSURE REQUIREMENT
Required by House Rule XI, clause 2(g)
and Rules of the Committee on Resources

A. This part is to be completed by all witnesses:

1. Name: Dr. Rita R. Colwell

2. Business Address: National Science Foundation, 4201 Wilson Blvd., Arlington, VA 22230

3. Business Phone Number: 703-292-8000

4. Organization you are representing: National Science Foundation

5. Any training or educational certificates, diplomas or degrees or other educational experiences which add to your qualifications to testify on or knowledge of the subject matter of the hearing:

Ph.D. Oceanography, University of Washington, Seattle (cv attached)

6. Any professional licenses, certifications, or affiliations held which are relevant to your qualifications to testify on or knowledge of the subject matter of the hearing:

NO

7. Any employment, occupation, ownership in a firm or business, or work-related experiences which relate to your qualifications to testify on or knowledge of the subject matter of the hearing:

NO

8. Any offices, elected positions, or representational capacity held in the organization on whose behalf you are testifying:

NO

B. To be completed by nongovernmental witnesses only:

1. Any federal grants or contracts (including subgrants or subcontracts) which you have received since October 1, 1998, from the _________*, the source and the amount of each grant or contract:

2. Any federal grants or contracts (including subgrants or subcontracts) which were received since October 1, 1998, from the ___________* by the organization(s) which you represent at this hearing, including the source and amount of each grant or contract:

3. Any other information you wish to convey which might aid the members of the Committee to better understand the context of your testimony:

*Note: When the witness letter is sent out, complete the blank to identify the federal agency or agencies overseeing the program or law which is the subject of the hearing.

ANSWERS TO POST-HEARING QUESTIONS

Responses by the National Science Foundation

1. *Great promise has been demonstrated in living marine resources for pharmaceuticals, but the track record of human exploitation shows it has not been done in the most sensitive or sustainable manner. What are the risks of exploring for marine resources without a framework to guide actions?*

As a science agency, NSF's involvement in identifying living marine resources is done within a research context. The kind of exploration and research activities supported by NSF are unlikely to threaten a species or ecosystem. On the contrary, these activities promote understanding of them and better enable conservation. Activities that may occur subsequent to exploration, such as exploitation for commercial purposes, clearly could produce adverse impacts if not done in a sustainable manner. Agencies with resource management responsibilities can better speak to the "exploitation" issue.

2. *How successful has the NOPP been?*

The National Ocean Partnership Program (NOPP), enacted in 1997, has been successful in a variety of areas. Primarily, it fosters the exchange of information and facilitates cooperation between key players in ocean research and education on an ongoing basis, and helps to identify areas of mutual interest and to create common solutions. In addition to encompassing relevant federal agencies with ocean responsibilities, NOPP activities include members of the academic community, industry, and other members of the ocean science community.

In its first few years, NOPP funding has enabled significant headway in technology development (ocean environmental sensors and their platforms). Under the auspices of NOPP, agencies and the ocean community have laid out plans for a U.S. ocean observation system and established a coordination office (OCEAN.US). Also, funding was provided for a data assimilation and modeling consortia to enable societally relevant modeling of key oceanographic parameters. NOPP activities have provided an excellent start for expanded interagency coordination and collaboration; NOPP is developing a virtual ocean data system that will encourage uniform data handling and dissemination, a vital activity requiring participation by multiple partners. In the area of education, NOPP partners have seen tremendous success with its support of the National Ocean Sciences Bowl competition for high schools, and with other community-based K–12 educational activities.

3. *What would be the role of the UNOLS fleet in this new program for exploration and observation?*

Well-equipped and capable research vessels will be needed in any effort to explore and observe the oceans. The research vessel fleet, which offers some of the most advanced capabilities presently available, will continue to enable the exploration of our oceans. In addition to the vessels themselves, UNOLS ships are able to deploy Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs) and the ALVIN, one of the foremost manned submersible in the world and the U.S. workhorse for exploring the deep ocean floor and hydrothermal vent systems.

A planned new system of seafloor observatories and sensor packages attached to mobile floats and gliders moving through the ocean waters would greatly facilitate the exploration of our oceans. The UNOLS fleet has a key and long-term role to play in servicing these autonomous systems. With the ALVIN and many of the research vessels approaching the end of their design lifetimes, the Federal Oceanographic Facilities Committee of NOPP is preparing a long-term plan for fleet renewal.

4. *You highlight the relatively long-running Ocean Drilling Program, which provided extensive information on sedimentary strata and the earth's crust. In light of other priorities mentioned by the President's Ocean Exploration Panel and the other witnesses today, should this program be maintained, or the resources applied to other priorities? Could we find out just as much about the earth's crust from the private sector through cooperative agreements or other means?*

The fundamental operations of the Ocean Drilling Program (ODP) should be maintained. Scientific ocean drilling continues to provide the sole means for sampling the 70% of the Earth that lies beneath the ocean. Research efforts include:

- Integrated studies of global geochemical cycling, from creation of new ocean crust at mid-ocean ridges to consumption back into the mantle. A new emphasis in future years will be to penetrate the seismic zone beneath island arcs to study the processes responsible for large, destructive earthquakes.

- Acquiring a global array of drill holes to examine the evolution of the global environment, particularly changes in ocean and atmospheric circulation and chemistry that have controlled biologic evolution and global climate change.
- The deployment of new instrumentation in boreholes to quantify the magnitude and role of fluid circulation through sediments and crust, measure its impact on the extent of the deep biosphere, and determine its roles in the formation of gas hydrates and hydrocarbons.

A future phase of scientific drilling, the proposed Scientific Ocean Drilling Program (SODP), envisions an expansion of exploration beneath the oceans made possible by increasing drilling capability, from the single-ship operation currently in use to a multiple-drilling platform operation of the future. The new drilling, sampling and observing capabilities would allow scientists to conduct experiments and collect samples in environments and at depths never before attempted.

The fundamental research and exploration questions examined by scientific ocean drilling are much broader in scope than those addressed by offshore drilling for the private sector oil, gas and mineral industries. The focus of these industries is on specific sites where economic returns can be obtained rather than scientific advancement. The ODP and IODP scientific, technical, planning and management groups actively include industrial liaison members to ensure industry interests and capabilities are included in program operations.

5. *Should there be a specific capitalized program to develop new technologies for ocean exploration and observation, providing incentives and seed money to encourage the public and private sector to get involved in development? Such a program would be similar to the Hybrid Automobile Partnership and the Advanced Technology Program at the Department of Commerce.*

Continued and enhanced investments are required to implement the technologies needed for cutting-edge ocean exploration and observation activities. A variety of models exist that would encourage private sector involvement in technology development efforts. At NSF, we have extensive experience with preparing program announcements or requests for proposals that announce basic requirements and encourage private sector participation.

NSF has not been significantly involved with either the Hybrid Automobile Partnership or the Advanced Technology Program. However, in the Hybrid Automobile Partnership, the requirements of the desired product are known at the outset. In an ocean observing system, technology development and the conduct of research must go hand-in-hand. History shows that activities carried out at the frontiers of knowledge evolve in unexpected ways. Development of the technology exclusively at the start of an activity almost guarantees the construction of instrumental dinosaurs. Technology development must proceed in parallel with the activity and be driven by the continuously changing needs of the activity.

6. *The observation system you all talk about is primarily for the physical environment. What are the practical applications of applying this new stream of data to the management of biological species? How would this information ultimately support the management of resources through an understanding of such things as primary productivity, fish stocks and marine pollution?*

The observation system discussed would gather data on physical, chemical, geological and biological characteristics of ocean and coastal waters. While physical sensors are currently more advanced than their chemical and biological counterparts, NSF and NOPP are funding numerous efforts to develop appropriate chemical and biological sensors for the future observation system. This extended suite of sensing capabilities will provide a comprehensive and interdisciplinary view of dynamic processes occurring in the ocean to better support sustainable management of resources. NSF strongly endorses the concept that all the characteristics of the ocean must be studied and evaluated simultaneously to eventually predict biological production, including fish stock variability.

7. *The Western Pacific is a huge area. What are the critical monitoring projects or observations that should occur in the Western Pacific, particularly with the importance climate change and sea level rise has to the region?*

Enhanced regional measurements, such as those in the Western Pacific, are important but must be done in the context of global measurements. Key monitoring projects or observations important to the understanding of climate change and sea level rise in the region include:

- a repeat global hydrographic survey following up on the one initiated under WOCE (World Ocean Circulation Experiment) and JGOFS (Joint Global Ocean Flux Study) to tie down the multi-decade trend;
- maintenance of the ENSO (El Niño Southern Oscillation) observing system including NOAA's tide gauge network, the TAO (Tropical Atmosphere Ocean) array, and surface drifters;
- continuation of high precision altimetry measurements conducted by NASA as well as GRACE (NASA's Gravity mission), which is critical to determining absolute sea surface height; and
- distribution of profiling floats (e.g., ARGO) and high resolution XBT (Expendable Bathythermograph) lines to provide measurements of temperature and salinity structure in the upper kilometer.

A global data assimilation system is necessary to capitalize on the data produced by increased observations. Estimating Circulation and Climate of the Ocean (ECCO), a NOPP-funded project supported by ONR, NSF, and NASA, assimilates data on ocean circulation and climate on global and basin scales. In addition, NSF, under the Information Technology Research priority area, is supporting a project to develop a modular ocean data assimilation system with application in coastal and tidal models.

Office of
Naval Research
800 N. Quincy Street, Arlington, VA 22217-5660

Rear Admiral Jay M. Cohen

Chief of Naval Research

Rear Admiral Jay M. Cohen became the 20th Chief of Naval Research, commanding the Office of Naval Research (ONR), on June 7, 2000. As the Chief of Naval Research, RADM Cohen manages the science and technology programs of the Navy and Marine Corps from basic research through manufacturing technologies.

In addition to his position as Chief of Naval Research, RADM Cohen also assumed the duties of Director, Test and Evaluation and Technology Requirements in the office of the Chief of Naval Operations, and Assistant Deputy Commandant (Science and Technology), Headquarters, U.S. Marine Corps.

Rear Admiral Jay M. Cohen received his commission as an Ensign upon graduation from the United States Naval Academy in 1968, where he was a Trident Scholar. After graduation, he qualified as a Navy diver with the SEALAB Group in San Diego, CA. Following training at Submarine School, New London, CT, he reported to USS DIODON (SS 349) in San Diego for duty as Supply and Weapons Officer during an extended WESTPAC deployment. He next studied at the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution under the Navy's Burke Scholarship Program. He received a joint Ocean Engineering degree and Master of Science in Marine Engineering and Naval Architecture from MIT. Following Nuclear Power Training, he was assigned to the Engineering Department aboard USS NATHANAEL GREENE (SSBN 636) (BLUE) in New London. He was next ordered to duty as Engineer Officer aboard USS NATHAN HALE (SSBN 623) (BLUE) in overhaul at Bremerton, WA, subsequently changing homeport to Charleston, SC. Upon completion of that tour, he served on the staff of the Commander Submarine Force, U.S. Atlantic Fleet, from which he reported to USS GEORGE WASHINGTON CARVER (SSBN 656) (GOLD) in New London as Executive Officer.

Rear Admiral Cohen commanded USS HYMAN G. RICKOVER (SSN 709) from January 1985 to January 1988. Under his command, RICKOVER completed a Post New Construction Shakedown availability in New London, changed homeport to Norfolk, VA and completed three deployments. RICKOVER was awarded a Navy Unit Commendation, a Meritorious Unit Commendation, the SIXTHFLT "Hook'em" Award for ASW excellence, CINCLANTFLT Golden Anchor Award for retention excellence, the COMSUBRON 8 Battle Efficiency "E" Award, and was designated the best Atlantic Fleet Attack Submarine for the BATTENBURG CUP.

Following command, Rear Admiral Cohen served on the staff of Commander in Chief, U.S. Atlantic Fleet, as senior member of the Nuclear Propulsion Examining Board, and the staff of the Director of Naval Intelligence at the Pentagon as Director of Operational Support.

Rear Admiral Cohen commanded USS L.Y. SPEAR (AS 36) and her crew of 800 men and 400 women from March 1991 to April 1993. During his tour, SPEAR was awarded the Submarine Force Atlantic Fleet Battle Efficiency "E" Award and conducted an unscheduled five-month deployment to the Persian Gulf in support of Operation DESERT STORM that included repairs to over 48 U.S. and allied ships, recovery of an F/A-18 Hornet sitting in 190 feet of water off the coast of Iran and humanitarian projects in Kuwait City. SPEAR received a Meritorious Unit Commendation for the deployment which was the ship's first in eleven years. Additionally, SPEAR was the CINCLANTFLT 1991 Secretary of Defense Maintenance Award nominee and the only Atlantic Fleet tender recognized in two consecutive Golden Anchor competitions.

In April 1993, Rear Admiral Cohen reported to SECNAV staff for duty as Deputy Chief of Navy Legislative Affairs. In October 1997 he was promoted to the rank of Rear Admiral and reported to the Joint Staff for duty as Deputy Director for Operations. In June 1999 he assumed duties as Director Navy Y2K Project Office. In May 2000 he was ordered to duty as Chief of Naval Research.

Rear Admiral Cohen is authorized to wear the Defense Superior Service Medal and multiple awards of the Legion of Merit and Meritorious Service Medal. He is submarine and surface warfare qualified.

Vice Admiral Conrad C. Lautenbacher, Jr., USN (Ret.)

A native of Philadelphia, Pennsylvania, and a graduate of the U.S. Naval Academy (Class of '64), Vice Admiral Lautenbacher has served in a broad range of operational, command and staff billets.

Operational tours include Division Officer in USS WASP (CVS-18), and USS HENRY B. WILSON (DDG-7), a second tour on the USS HENRY B. WILSON (DDG-7) as Department Head, and Executive Officer of USS BENJAMIN STODDERT (DDG-22). Areas of expertise include Anti-submarine Warfare, Anti-air Warfare, and Naval Surface Fire Support, with expertise gained during a number of deployments to the Western Pacific and Southeast Asia during the Vietnam War.

Command experience includes tours as Commanding Officer of USS HEWITT (DD-966), Commander Naval Station Norfolk, Commander of Cruiser-Destroyer Group Five with additional duties as Commander, U.S. Naval Forces Central Command Riyadh, during Operations Desert Shield and Desert Storm, where he was in charge of Navy planning and participation in the air campaign. As Commander U.S. Third Fleet, he introduced Joint training to the Pacific with the initiation of the first West Coast Joint Task Force Training Exercises (JTFEXs). A leader in the introduction of cutting edge information technology, he pioneered the use of information technology to mount large-scale operations using sea based command and control. He was the architect of the USS CORONADO transformation to a prototype Joint Command and Control ship (JCC), a founding father of the current Fleet Battle Experiment program, and originator of the Sea Based Battle Laboratory concept for significantly reducing the time to move technology to the fleet.

Staff duties include higher education as well as significant assignments in senior management. Vice Admiral Lautenbacher attended Harvard University receiving MS and Ph.D. degrees in Applied Mathematics. He was selected as a Federal Executive Fellow and served at the Brookings Institution. He served as a guest lecturer on numerous occasions at the Naval War College, the Army War College, the Air War College, The Fletcher School of Diplomacy, and the components of the National Defense University

As a Cost Analyst in OSD Systems Analysis, he became an expert in building cost estimating models for major acquisition programs with specialization in aircraft R&D and procurement. He was one of the original members of the Cost Analysis Improvement Group (CAIG) independent cost estimating effort. As Assistant for Strategy with the CNO Executive Panel, and Program Planning Branch Head in the Navy Program Planning Directorate, he continued to hone his analytic skills resulting in designation as a specialist both in Operations Analysis and Financial Management.

As a Flag Officer he served as Deputy Chief of Staff for Management/Inspector General on the staff of Commander in Chief U.S. Pacific Fleet; and Director of Force Structure, Resources, and Assessments (J-8) on the Joint Staff, where he contributed to the development of the Base Force and was a prime architect of the Bottom Up Review military force structure. He also served as Director, Office of Program Appraisal, on the Staff of the Secretary of the Navy and his last assignment on active duty was Deputy Chief of Naval Operations (Resources, Warfare Requirements and Assessments) personally responsible for developing the Navy Future (five) Years Program and $80B annual budget. These positions resulted in the development of significant expertise in federal government processes within both the Executive and Legislative branches.

After transitioning to the civilian sector, he formed his own management consultant business, and worked principally for Technology, Strategies & Alliances Inc. He is currently the President and CEO of the Consortium for Oceanographic Research and Education (CORE). This not-for-profit organization has a membership of 65 institutions of higher learning, and a mission to increase basic knowledge and public support across the spectrum of ocean sciences.

DISCLOSURE REQUIREMENT
Required by House Rule XI, clause 2(g)
and the Rules of the Committee on Resources

A. This part is to be completed by all witnesses:

1. Name: Vice Admiral Conrad C. Lautenbacher, Jr. USN (Retired)

2. Business Address: 1755 Massachusetts Avenue, NW Suite 800
Washington, D.C. 20036-2102

3. Business Phone Number: (202) 332-0063 ext. 260

4. Organization you are representing: Consortium for Oceanographic Research and Education (CORE)

5. Any training or educational certificates, diplomas or degrees, or other educational experiences which add to your qualifications to testify on or knowledge of the subject matter of the hearing:

   Ph.D. in Applied Mathematics, Harvard University, Thesis: Gravity Wave Refraction by Islands

6. Any professional licenses, certifications, or affiliations held which are relevant to your qualifications to testify on or knowledge of the subject matter of the hearing:

   36 years as a commissioned officer in the U.S. Navy, expert user of the world's oceans

7. Any employment, occupation, ownership in a firm or business, or work-related experiences which relate to your qualifications to testify on or knowledge of the subject matter of the hearing:

   16 years government experience in planning and executing research, acquisition and operating budgets
   President, Consortium for Oceanographic Research and Education (CORE), 3/01 - Present

8. Any offices, elected positions, or representational capacity held in the organization on whose behalf you are testifying:

   President, Consortium for Oceanographic Research and Education (CORE), 3/01 - Present

B. This part to be completed by non-governmental witnesses only:

1. Any Federal grants or contracts (including subgrants or subcontracts) which you have received since October 1, 1998, from the National Science Foundation and Department of Defense*, the source, and the amount of each grant or contract:
   NSF: $ 787,191
   NRL: $4,304,133
   ONR: $5,633,596

2. Any Federal grants or contracts (including subgrants or subcontracts) which were received since October 1, 1998, from the National Science Foundation and Department of Defense* by the organization(s) which you represent at this hearing, including the source, and the amount of each grant or contract: **N/A**

3. Any other information you wish to convey to the Committee which might aid the members of the Committee to better understand the context of your testimony: **N/A**

*Note: When the witness letter is sent out, complete the blank to identify the federal agency or agencies overseeing the program or law which is the subject of the hearing.

ANSWERS TO POST-HEARING QUESTIONS

Responses to Questions from the Honorable Robert Underwood

Vice Admiral Conrad C. Lautenbacher, U.S. Navy, (Retired); President, Consortium for Oceanographic Research

1. *What would be the role of the UNOLS fleet in this new program for exploration and observation?*

The UNOLS fleet will have a key role in the implementation of any ocean exploration or ocean observation program. The UNOLS fleet has excellent capacity and capability to support such endeavors. If an observation system is funded, UNOLS ships will be involved in deploying and maintaining system assets, as well as supporting expanded research efforts tied to the new system. UNOLS currently is working on a recapitalization plan because several mid-sized vessels are reaching the end of their planned service lives. The Federal Oceanographic Facilities Committee (FOFC), a subcommittee of the National Ocean Research Leadership Council (NORLC), is in the process of finalizing this plan and CORE members have provided information and comments. The plan (which is now in draft form) will include an assessment and analysis of UNOLS vessel support for current operational observation systems and discuss how UNOLS could support a larger, integrated coastal and ocean observing system.

2. *What Federal assets are available through the Department of Defense to support ocean observation and exploration? Sharing what has been done with the military and civilian satellite program and the opening of access to SOSUS array data, are there any other areas where science might benefit from former and current defensive technologies to achieve cost savings in building a civilian ocean observing capability?*

Examples of Department of Defense (DOD) assets that could contribute to ocean observation and exploration include the following:

- Underwater SOSUS arrays can be used for some observational purposes and over the horizon radar has been used to look at sea surface currents off the coast of Maine. While such systems provide useful information, they are expensive assets that will require sustained investments.
- In the past, DOD submarines were used for Arctic research because they are capable of surfacing under the Arctic icepack, however, the last of these have been taken out of service.
- Navy survey vessels currently contribute unclassified data to NOAA for weather and hurricane prediction and that data can be used to complement data collected by an integrated coastal and ocean observing system. In general, data collected by the Navy for both atmospheric and ocean forecasting is being made available to a wide range of federal and private sector users.
- Supercomputer facilities, such as the Navy's Fleet Numerical Meteorology and Oceanography Center, host sophisticated operational coupled air-sea models and could provide a key framework for assimilation of information from an ocean observing system.
- The Office of Naval Research (ONR), through the National Oceanographic Partnership Program (NOPP), has provided funding for pilot observing systems and development of technology for systems such as Argo and autonomous underwater vehicles.

3. *You mention the wide variety of benefits we might get from the oceans based on exploration and observation. How do you foresee moving the information gathered and analyzed to actual utilization?*

The NORLC established OCEAN.US in May of 2000 to serve as the integrator of ocean data. OCEAN.US is charged with the integration of long-term, routine, consistent observing systems for research and operations in the following areas:

- Detecting and Forecasting Oceanic Components of Climate Variability
- Facilitating Safe and Efficient Marine Operations
- Ensuring National Security
- Managing Marine Resources
- Preserving and Restoring Healthy Marine Ecosystems
- Mitigating Natural Hazards
- Ensuring Public Health

OCEAN.US currently is working to define the architecture for an integrated ocean observing system and the NOPP agencies are working on developing a virtual data hub so that observations can be cataloged and dispersed to agencies and organizations that need the information in real time. With proper funding and support, the initial systems architecture will be completed in the coming year. We envision the operational control of the observing system will require some form of virtual operations center joining all of the current agency operational authorities in a combined data net with a small central coordinating office.

4. How successful do you feel NOPP has been?

NOPP has an outstanding record of achievement for a program that is barely four years old. NOPP efforts have resulted in $57 million being invested in national priority areas in the ocean sciences. This research investment is based upon the pooled NOPP expertise and provides a 'super-agency' capability to integrate agencies to ensure funding for the most pressing research in the most coordinated and efficient manner. ONR currently provides the largest annual NOPP contribution, followed by the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). NOPP issues an annual report to Congress detailing program activities. The latest report for FY 2001 is located on the CORE website at: *http://www.COREocean.org/NOPP01report.html*. CORE provides administrative support for NOPP.

5. Please explain OCEAN.US.

OCEAN.US is essentially a joint program office under the direction of the NORLC. It will integrate requirements and serve as system architect for a national ocean and coastal observing system. OCEAN.US is supervised by a subcommittee of the NORLC and is charged with overseeing the implementation of long-term, routine, consistent observing systems for research and operations in the areas listed above. The office's primary goal is to develop the initial framework for an integrated system that is efficient and cost-effective and includes common data standards and protocols for all users. The strong interagency commitment to its success is demonstrated by the interagency Memorandum of Agreement signed by the following eight agencies: NOAA, ONR, Oceanographer of the Navy, NSF, NASA, Minerals Management Service, United States Geological Survey, Department of Energy, and United States Coast Guard.

6. Should there be a specific capitalized program to develop new technologies for ocean exploration and observation, providing incentives and seed money to encourage the public and private sector to get involved in development? Such a program would be similar to the Hybrid Automobile Partnership and the Advanced Technology Program at the Department of Commerce.

There is a fairly robust market for small firms to make specialized equipment for ocean exploration and observation, however, most instruments for such activities are currently built in university and federal labs and these companies are 'spin-offs' from these institutions. Large-scale deployment of an observing system should lure private sector capital into the ocean technology market and result in private sector competition to build the instruments needed for a large-scale observing system. As an example, Japan is currently the world leader in the deployment of such systems and most of the state-of-the-art instrumentation for ocean observing systems is being developed by Japanese companies as a result of the Japanese government making an ocean observing system a national policy priority.

NOPP provides one successful federal process to encourage development of technologies for both ocean exploration and observation. For example, the current ARGO buoy program is the result of a NOPP demonstration grant. However, the oceanographic community has expressed two concerns with the NOPP process. First, the federal investment in NOPP must be increased substantially in order to ensure adequate progress in the areas of technology development, testing pilot observing systems, and data management. Second, the NOPP program must be broadened to provide for the transition of successful pilot programs and experimental technologies into operational applications.

7. The observation system you talk about is primarily for the physical environment. What are the practical applications of applying this new stream of data to the management of biological species? How would this information ultimately support the management of resources through an understanding of such things as primary productivity, fish stocks, and marine pollution?

Sea surface and ocean water column temperatures as well as physical chemistry have profound effects on fish stocks and primary productivity so there is an immediate benefit from the improved understanding of the oceans physical processes. El Niño and La Niña events have demonstrated that physical changes in the ocean climate (in the case of an El Niño, the warming of the eastern equatorial waters) result in some fish stocks such as anchovies disappearing as well as smaller salmon populations in the Pacific Northwest. We are just starting to recognize that changes and shifts in regional climate regimes can have profound effects on fisheries management issues and in the future we will need to incorporate climate events into fisheries management decisions. Thus, an ocean observing system that can assess and identify subtle changes in climate can be a useful tool in the management of biological data.

It also is important to recognize that an ocean observation system is a platform that can be used to deploy many different advanced biological sensors as they become available. Just as the Department of Defense has many weapons platforms that can deploy different weapons for different missions, so too can an ocean observing system deploy different sensors to examine and address more regionally specific issues with regards to biological species. Sensors that are aimed specifically at productivity issues can be deployed in regions of the system where productivity is a key issue and similarly, sensors that applicability to specific fish stocks can be located where they are most needed. A similar argument applies to monitoring and managing the effects of marine pollution.

8. *The Western Pacific is a huge area. What are the critical monitoring projects or observations that should occur in the Western Pacific, particularly with the importance climate change and sea level rise has to the region?*

As a former commander of the 3rd Fleet with responsibility for the defense of the Pacific sea approaches to the United States, I understand and appreciate this question more than most. Observational priorities must be established with international partners and clearly the Tropical Ocean-Global Atmosphere Tropical Ocean Atmosphere (TOGA–TAO) array is an example of scientists from many nations working together to address critical observational gaps. While the TOGA–TAO array has been an enormous success in helping to predict El Niño events, we must recognize that there are vast areas of the Western Pacific that are never sampled *in situ.* Satellites can aid significantly in improving our understanding of the Western Pacific by making observations over a wider area, however they are severely limited in their ability to 'peer' into the ocean. It is for this reason that an *in situ* ocean observing system is crucial for the Western Pacific. Such a system is absolutely essential to determine the heat content and physical circulation, as well as the chemical and biologic processes of the ocean. Additionally, satellite ocean surface data requires in situ monitoring sites for calibration.

Clearly, we should remain committed to maintaining and expanding the TOGA–TAO array, as well as extending our monitoring to both northern and southern midlatitudes. Such deployment would allow us to broaden our understanding beyond El Niño and study other decadal ocean cycles that determine both our short-term and long-term climates. We should also consider seriously the deployment of observing systems into the Arctic and Antarctic regions of the Western Pacific as these regions are the 'tripwires' for the most sensitive climatic changes. Many believe that changes in climate will most likely be apparent first in the more sensitive regions of the world. The logical priority in deploying an ocean observing capability would be first to populate those areas that can readily determine the precursors to changes in climate.

Appendix 2:

Panel II Biographies, Financial Disclosures, and Answers to Post-Hearing Questions

Biography for Marcia K. McNutt

President, Monterey Bay Aquarium Research Institute, 7700 Sandholdt Road, Moss Landing, CA 95039–0628; (831) 775–1814 (office); (831) 775–1647 (fax); mcnutt@mbari.org

Biographical Information

2/19/52	Born, Minneapolis, Minnesota
6/70	Graduated from high school, Northrop Collegiate School, Minneapolis, Minnesota.
5/73	B.A. in Physics from Colorado College, Colorado Springs, Colorado.
1/78	Ph.D. in Earth Sciences from Scripps Institution of Oceanography, La Jolla, California. Dissertation title: Continental and Oceanic Isostasy.
Awards and Fellowships	
1970	Class valedictorian, recipient of awards for mathematics, science and French.
1970–1971	National Merit Scholarship
1973	Phi Beta Kappa, summa cum laude
1973–1976	National Science Foundation Graduate Fellowship
1977–1978	University of California Dissertation Fellowship
1984, 1993	*Journal of Geophysical Research* Editor's Citation for Excellence in Refereeing
1985	Graduate Student Council Award for Teaching
1985–1986	Mary Ingraham Bunting Fellow, Radcliffe College
1988	Macelwane Award, American Geophysical Union
1988	Fellowship, American Geophysical Union
1988	Doctor of Science, *honoris causa,* Colorado College
1989–1990	NSF Visiting Professorship for Women, Lamont-Doherty Geological Observatory of Columbia University
1991–	Griswold Professor of Geophysics
1993	Outstanding Alumni Award, The Blake Schools, Minneapolis
1995	Capital Science Lecturer, Carnegie Institution
1996–7	Phi Beta Kappa Visiting Scholar
1996	MIT School of Science Graduate Teaching Prize
1998	Fellowship, Geological Society of America
1998	Fellowship, American Association for the Advancement of Science
1999	Member, American Academy of Arts and Sciences
1999	Sanctuary Reflections Award, Special Recognition Category, Monterey Bay National Marine Sanctuary
Post-graduate Employment	
1/78–6/78	Postdoctoral Research Associate, Scripps Institution of Oceanography
6/78–7/79	Visiting Assistant Professor, University of Minnesota, Minneapolis
6/79–6/82	Geophysicist, Branch of Tectonophysics, Office of Earthquake Studies, U.S. Geological Survey, Menlo Park, California
7/82–7/86	Assistant Professor of Geophysics, Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology
7/86	Associate Professor of Geophysics, EAPS, MIT

Biographical Information—Continued

7/89–3/98	Professor of Geophysics, EAPS, MIT
7/93–7/95	Associate Director, MIT SeaGrant College Program
7/95–8/97	Director, MIT/WHOI Joint Program in Oceanography and Applied Ocean Science and Engineering
9/97	President/CEO Monterey Bay Aquarium Research Institute
6/98	Professor, Department of Earth Science, UC Santa Cruz (on leave)
10/98	Professor of Geophysics, Stanford University
Special Training	
8/74	Completed U.S. Navy UDT and Seal Team training course in underwater demolition and explosives handling. Also, NAUI certified SCUBA diver and Red Cross Water Safety Instructor.

Sea Experience

Participant on 14 oceanographic expeditions on ships from Scripps, Woods Hole, Oregon State University, and Columbia University.
Co-chief scientist on *Crossgrain 2* marine geophysical expedition to the Marquesas Islands, April 1987.
Co-chief scientist on the *R/V Ewing EW9103* multichannel seismic expedition to French Polynesia, May, 1991
Chief scientist on the *R/V Ewing EW9106* marine geophysical survey of the Marquesas Fracture Zone, September-October, 1991
Chief scientist on the *R/V Ewing EW9204* ocean bottom seismometer experiment in the Marquesas Islands, May, 1992
Co-chief scientist on BARGE, a multichannel seismic survey on Lake Mead of the Colorado Plateau—Basin and Range breakaway zone, March, 1994
Chief scientist on EW9602, multichannel seismic survey of the Austral Islands, March-May, 1996
Chief scientist on *R/V Roger Revelle* expedition to measure hydrothermal heat flux in the Hawaiian Islands, August-September, 1997

Professional Societies

American Geophysical Union (Fellow)
American Association for the Advancement of Science (Fellow)
Geological Society of America (Fellow)

Relevant Activities

Member, NSF panel for graduate fellowships in Earth Sciences, 1985, 1986, 1987 (Chairman 1988, 1989, 1990)
NSF Ocean Sciences, Panelist, 1986–1988, 1990
NSF Science and Technology Centers Panelist 1989
Member, Lithosphere Panel, Ocean Drilling Program, 1986–1988
Chairman, Joint Committee for Marine Geology and Geophysics, MIT/WHOI Joint Program, 1984–1988, 1991–1995
Member, Atolls and Guyots Detailed Planning Group, Ocean Drilling Program, 1991
Member, Performance Evaluation Committee, Ocean Drilling Program, 1991
Member, Organizing Committee for the Frontiers of Science Symposium, National Academy of Sciences, 1991–2, 1994
Member, Advisory Committee for Earth Sciences, National Science Foundation, 1990–1993
Member, NASA Earth Science and Applications Division Advisory Subcommittee, 1990–1993
Member, Advisory Structure Review Committee, Ocean Drilling Program, 1992–1993
Chairman, Organizing Committee for the Frontiers of Science Symposium, National Academy of Sciences, 1993
Chairman, Visiting Committee, Scripps Institution of Oceanography, 1993
Member, Board on Earth Sciences and Resources, National Research Council, 1994
Member, Committee on Geophysical and Environmental Data, National Research Council, 1994

Member, National Academy of Sciences Television Advisory Committee, 1994
Member, Committee to Study the Criteria for Federal Support for Research and Development (Press Committee), 1995
Member, Organizing Committee for the German-American Frontiers of Science Symposium, 1995, 1996
Member, National Medal of Science Committee, 1995–1997
Member, New England Aquarium Advisory Board, 1995–1997
Co-Chair, NSF-OCE Workshop on the Future of Marine Geosciences, 1995–1998
Vice-Chair, Advisory Committee for Geosciences, National Science Foundation 1996–1998
Co-Chair, Chinese-American Frontiers of Science Symposium, August, 1998
Member, Government-University-Industry-Research-Roundtable Committee on Stress in Universities, 1995–1998
Member, NRC Committee on 50 Years of Ocean Sciences at NSF, 1998
Member, ODP Executive Committee for Drilling Opportunities in the 21st Century, 1998–9
Member, German-American Academic Council, 1994–1999
President, American Geophysical Union 2000–2002
Member, Ocean Science Synthesis Committee, NSF 1998-present
Member, Board of Directors, Monterey Bay Aquarium, 1998-present
Member, Schlumberger Technical Advisory Committee, 2000-present
Chair, Ocean Research Advisory Panel, National Ocean Partnership Program, 2001-present
Chair, President's Panel on Ocean Exploration, 2000-present
Chair, Monterey Bay Crescent Ocean Research Consortium, 2000-present

Author of more than 80 peer reviewed publications in Ocean and Earth Sciences

DISCLOSURE REQUIREMENT
Required by House Rule XI, clause 2(g)
and Rules of the Committee on Resources

A. This part is to be completed by all witnesses:

1. Name: Marcia Kemper McNutt

2. Business Address: 7700 Sandholdt Road, Moss Landing, CA 95039

3. Business Phone Number: (831) 775-1814

4. Organization you are representing: President's Panel on Ocean Exploration and The Monterey Bay Aquarium Research Institute

5. Any training or educational certificates, diplomas or degrees or other educational experiences which add to your qualifications to testify on or knowledge of the subject matter of the hearing:
BA, Colorado College, Physics
PhD, Scripps Institution of Oceanography
NAUI certified scuba diver
Explosives training in underwater demolitions, US Navy Seals

6. Any professional licenses, certifications, or affiliations held which are relevant to your qualifications to testify on or knowledge of the subject matter of the hearing:
President, American Geophysical Union

7. Any employment, occupation, ownership in a firm or business, or work-related experiences which relate to your qualifications to testify on or knowledge of the subject matter of the hearing:
Professor at MIT for 15 years
MIT Director of the Joint Program in Oceanography with Woods Hole Oceanographic Institution

8. Any offices, elected positions, or representational capacity held in the organization on whose behalf you are testifying: Chair, President's Panel on Ocean Exploration (convened by NOAA)

B. To be completed by nongovernmental witnesses only:

1. Any federal grants or contracts (including subgrants or subcontracts) which you have received since October 1, 1998, from the NOAA(?)*, the source and the amount of each grant or contract:
none

2. Any federal grants or contracts (including subgrants or subcontracts) which were received since October 1, 1998, from the NOAA (?)* by the organization(s) which you represent at this hearing, including the source and amount of each grant or contract: none

3. Any other information you wish to convey which might aid the members of the Committee to better understand the context of your testimony:

*Note: When the witness letter is sent out, complete the blank to identify the federal agency or agencies overseeing the program or law which is the subject of the hearing.

ANSWERS TO POST-HEARING QUESTIONS

Response to Questions from the Honorable Robert Underwood with Regard to the Hearing on Ocean Exploration and Observations
Submitted by Marcia McNutt, Monterey Bay Aquarium Research Institute

1. *In light of pressing scientific question such as climate change, ocean interactions, ocean circulation and heat exchange, why hasn't the National Science Foundation or the university community devoted more of its own resources to doing work on their own? Why is the U.S. in general lagging behind devoting resources to answering these questions?*

I think it is best if the Director of NSF responds to the question of why NSF is not investing more in this area. I will only point out that the National Science Board has ranked Ocean Observing Systems for understanding ocean health and climate very highly for its Major Research Equipment fund, but that the fund has been cut by the White House and Congress in the past few fiscal years.

The university community, in my opinion, is doing what it can to address the pressing issues concerning climate, but universities have few sources of revenue to fund this work other than the federal government. Such initiatives are consistently highly rated for university and state matching funds whenever federal funds are available, showing the high regard for the relevancy of such work within the university systems.

During the years that I was on the faculty at MIT, I came to understand the university budgeting process quite well. Basically, universities have 3 main sources of income: tuition, gifts, and sponsored research. MIT, probably like most other universities, runs its research programs on a "cost minus" basis. By the time the university adds up all of the costs it incurs in order to be a research university as opposed to merely a teaching institution, it loses money on its grants and contracts. That money lost must come from gifts and endowment income. Each dollar taken from such funds to further subsidize the research means one dollar less to provide scholarship assistance for students. MIT practices "need blind" admissions. If a student meets the admission criteria, MIT ensures that student that he or she will be offered a financial assistance package that will allow that student to attend MIT regardless of family finances. Further subsidy of research, such as a major university investment in oceans and climate, would jeopardize MIT's need blind admissions. MIT is the place where a smart kid from the barrio can still go to get a first class education no matter who her daddy is or the size of the family bank account one of the most pure meritocracies. We should keep it that way.

Certainly this is not to say that MIT would be better off without a research program. The dollars and cents analysis fails to recognize that MIT would not be MIT if it were not a world-class research university, thanks to government funding. But nevertheless I hope I have made the point that there are not extra pots of money being wasted on useless enterprises that could better be devoted to the oceans.

2. *Should there be a specific capitalized program to develop new technologies for ocean exploration and observation, providing incentives and seed money to encourage the public and private sector to get involved in development? Such a program would be similar to the Hybrid Automobile Partnership and the Advanced Technology Program at the Department of Commerce.*

My own view is that a capital program to develop new technologies for ocean exploration and observation is best undertaken hand-in-hand with the scientific research programs that will use those tools. I see no other way to ensure that the technology actually meets the needs for measuring, sampling, and experimenting in the ocean. Allow me to provide an example.

When I was on the faculty at MIT, most of ocean science was undertaken in the Department of Earth, Atmospheric, and Planetary Sciences within the School of Science. Most of the development of new ocean technology took place within the Department of Ocean Engineering within the School of Engineering. The natural barriers that arise between departments and schools at any large institution made it very difficult for those two groups of researchers to work together. Often they didn't even know each other. The problem was confounded by the fact that NSF funds research and instrumentation programs separately under different program managers. The MIT scientists continued to solve the problems they COULD solve, rather than the problems they SHOULD solve, because they used whatever technology they already had. On the other hand, the engineers built nifty new devices to deploy in the ocean that caused the scientists to scratch their heads and say, "That is cute, but what is it good for?"

Since arriving at MBARI, I have been impressed by how much more progress can be made with less effort when all barriers (organizational and financial) to collaboration are removed. Here the scientists discuss with the engineers an entire suite of worthwhile problems that cannot currently be addressed due to lack of appropriate technology. The engineers then help them select which ones are most ripe for a great leap forward because the necessary technology is just now on the horizon. Often this is technology that has matured on account of great investment by other sectors (defense, biomedical, communications, information technology), but the other drivers will not put in the extra 5% needed to adapt the technology to work autonomously underwater. So MBARI fills that niche, reaping great rewards for the ocean science community from modest investment.

To set up a separate government program for ocean technology development divorced from the research programs (such as Ocean Exploration or Ocean Observing Systems) would be a step in the wrong direction, in my view. I am greatly in favor of providing incentives, but they should be done within the context of a long-term and forward-thinking research and development program.

3. The observation system you all talk about is primarily for the physical environment. What are the practical applications of applying this new stream of data to the management of biological species? How would this information ultimately support the management of resources through an understanding of such things as primary productivity, fish stocks and marine pollution?

I don't believe that I spoke about an observing system for the physical environment, but certainly other presenters did. The Ocean Exploration panel report stresses the importance of characterizing the ocean in all disciplines: biological, chemical, geological, as well as physical. In the questioning after my presentation, I made the point that the current emphasis needs to be on the development of *in situ* biological and chemical sensors for the ocean. Thanks largely to substantial investment by the Navy, an organization with a very special need to understand the ocean's physical environment, physical and geophysical sensors for the ocean are relatively mature and commercially available at reasonable cost. The same cannot be said for biological and chemical sensors. In my personal view, the current generation of plans for ocean observing systems are incomplete in that they are not sufficiently investing in the development of chemical and biological sensors that can operate unattended on autonomous platforms for long periods of time. My own institution, MBARI, is currently investing heavily in chemical sensors that work at low power and require no expendable reagents to detect chemical species of interest. We have also developed a device (the ESP, or Environmental Sample Processor) that can identify micro-organisms in the ocean *in situ,* autonomously, using their genetic code, and beam the results back to shore labs. Both of these devices currently work on moorings and are quite adaptable to use on autonomous underwater vehicles.

We have already successfully used the ESP to predict the occurrence of the red tide and other harmful algal blooms by detecting the first onset of growth of toxic marine organisms in the ocean before they make their way up the food chain to poison shellfish, marine mammals, and humans. It is our belief that the current standards for what organisms are being monitored is grossly inadequate. A far larger number of micro-organisms harmful to human health are present in the environment, but prior to the development of the MBARI ESP there was no way to determine what organisms are actually making people sick. The potential for tools such as this to improve public health, track pollution, and better understand the marine food web is enormous. Clearly much more investment in these sorts of devices is needed.

DR. ROBERT BALLARD BIOGRAPHY

Education

Dr. Ballard received his undergraduate degree in Geology and Chemistry from the University of California. He attended graduate school at the University of Southern California, the University of Hawaii's Graduate School of Oceanography and received his Ph.D. in Marine Geology and Geophysics from the University of Rhode Island.

Military Service

Dr. Ballard was graduated from the University of California as a distinguished military graduate with a commission in Army Intelligence. Later his commission was transferred to the U.S. Navy and during the Vietnam War he served on active duty as an Ensign, Lt. J.G. and finally as a Lieutenant. Dr. Ballard has rejoined the U.S. Naval Reserve as a Commander.

Television Projects

Dr. Ballard is recognized as one of the premier spokesmen for marine research. For the past twenty years he has participated in numerous educational programs with PBS Television, National Geographic Society, NOVA, the BBC in Great Britain, Nippon Television in Japan, ZRF Television in Germany, and the major television networks in the United States. From 1989 to 1991, he hosted National Geographic's EXPLORER, shown on Turner Broadcasting Station.

Associations and Memberships

Dr. Ballard is a member of Sigma Xi, Oceanography Society, Geological Society of America, Marine Technology Society, American Association for the Advancement of Science, American Geophysical Union and The Bohemian Club. He holds Honorary Degrees from the University of Rhode Island, Clark University, Southeastern Massachusetts University, Long Island University, Southampton, the University of Bath, England, Lehigh University, Skidmore College, Worcester Polytechnic Institute, Bridgewater State College, Tufts University, Lenoir-Rhyne College, Maine Maritime Academy and Massachusetts Maritime Academy.

Achievement Awards and Honorariums

- 1976 Underwater Society of America Science Award
- 1977 Marine Technology Society, Compass Distinguished Achievement Award
- 1981 American Association for the Advancement of Science Newcomb Cleveland Prize
- 1982 Cutty Sark Science Award and Science Digest
- 1985-1986 Navy Chair Award, presented by Secretary of the Navy, John Lehman
- 1985 University of California-Santa Barbara Distinguished Alumni Award
- 1986 Underwater Society of America, Northeast Region Diver of the Year Award
- 1986 American Society of Magazine Photographers Innovations in Photography Award
- 1986 Sigma Alpha Epsilon, Highest Effort Award
- 1987 Boston Museum of Science Washburn Award

- 1987 Explorers Club Lowell Thomas Award
- 1987 Discover Magazine Scientist of the Year
- 1988 American Defense Preparedness Association Undersea Warfare Div. David Bushnell Award
- 1988 National Geographic Society Centennial Award
- 1990 Westinghouse American Association for the Advancement of Science Award
- 1990 American Academy of Achievement Golden Plate Award
- 1990 Sigma Xi William Proctor Award for Scientific Achievement
- 1990-1991 Texas Bluebonnet Award
- 1990 American Geological Institute Award
- 1990 Computerworld Smithsonian Institution Award
- 1991 Harvey Mudd College Wright Prize
- 1992 Valley Forge Military Academy Order of Anthony Wayne Citation
- 1992 University of Rhode Island Alumni Association Distinguished Science Award
- 1992 United States Navy Robert Dexter Award for Scientific Achievement
- 1976 Underwater Society of America Science Award
- 1977 Marine Technology Society, Compass Distinguished Achievement Award
- 1981 American Association for the Advancement of Science Newcomb Cleveland Prize
- 1982 Cutty Sark Science Award and Science Digest
- 1985-1989 Navy Chair Award, presented by Secretary of the Navy, John Lehman
- 1985 University of California-Santa Barbara Distinguished Alumni Award
- 1986 Underwater Society of America, Northeast Region Diver of the Year Award
- 1986 American Society of Magazine Photographers Innovations in Photography Award
- 1986 Sigma Alpha Epsilon, Highest Effort Award
- 1987 Boston Museum of Science Washburn Award

- 1987 Explorers Club Lowell Thomas Award
- 1987 Discover Magazine Scientist of the Year
- 1988 American Defense Preparedness Association Undersea Warfare Div. David Bushnell Award
- 1988 National Geographic Society Centennial Award
- 1990 Westinghouse American Association for the Advancement of Science Award
- 1990 American Academy of Achievement Golden Plate Award
- 1990 Sigma Xi William Proctor Award for Scientific Achievement
- 1990-1991 Texas Bluebonnet Award
- 1990 American Geological Institute Award
- 1990 Computerworld Smithsonian Institution Award
- 1991 Harvey Mudd College Wright Prize
- 1992 Valley Forge Military Academy Order of Anthony Wayne Citation

- 1992 University of Rhode Island Alumni Association Distinguished Science Award
- 1992 United States Navy Robert Dexter Award for Scientific Achievement
- 1994 The Kilby Award
- 1994 Association for Unmanned Vehicle Systems Pioneer Award
- 1996 The Hubbard Medal, National Geographic's Highest Honor
- 1994 The Kilby Award
- 1994 Association for Unmanned Vehicle Systems Pioneer Award
- 1996 The Hubbard Medal, National Geographic's Highest Honor

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Disclosure Information for House

1994 Association for Unmanned Vehicle Systems Pioneer Award
1994 Order of Magellan, Circumnavigators Club
1995 Explorer's Club Medal
1998 Lockheed-Martin MTS Award for Ocean Science and Engineering

Born: June 30, 1942, Wichita, Kansas
Married to: Barbara Earle Ballard
Two sons: Douglas Matthew and William Benjamin
One Daughter: Emily Rose

Robert D. Ballard, Ph.D.
President of
Institute for Exploration
List of Federal Grants, Contracts, and Subcontracts
October 1998 - Present

Agency Year Amount

Subcontract from
National Oceanic and Atmospheric Administration
Through JASON Foundation for Education
October, 1998 $875,000
October, 1999 $914,000
October, 2000 $1,250,000

Office of Naval Research October, 1998 $381,000
October, 1999 $391,500
October, 2000 $402,000

ANSWERS TO POST-HEARING QUESTIONS

Questions submitted by the Honorable Robert Underwood, Subcommittee on Resources

Responses submitted by Robert D. Ballard, President, Institute for Exploration

1. What Federal assets are available through the Department of Defense to support ocean observation and exploration? Sharing what has been done with the military and civilian satellite program and the opening of access to SOSUS array data, are there other areas where science might benefit from former and current defensive technologies to achieve cost savings in building a civilian ocean observing capability?

As far as I am concerned, the greatest contribution the U.S. Navy could make to ocean exploration—or any ocean observatory program—would be for them to declassify their multi-narrow beam bathymetric data base. One can defend to some degree their reluctance to declassify some of their data base that was collected near U.S. harbors, but there is no reason whatsoever to protect data collected in deep water. There is no military threat to the U.S. in deep water, particularly far from home. The U.S. Navy also has modified various nuclear submarines that might be highly useful to ocean exploration as well as the unmanned vehicles deployed by those submarines.

2. You discuss ocean farming and ocean colonization as the future of the ocean. But considering the lack of information we currently possess about the oceans, how far in the future do you foresee these events occurring?

The fact that we lack information regarding ocean farming and eventual colonization is the point I wanted to make. We are doing nothing in these two areas of potential ocean utilization. I would like to see at least some amount of funding directed toward these areas. In particular, I would like to see a research program built around using the FLIP ship from the Scripps Institution of Oceanography as a proto-type for living at sea for long periods of time. Clearly, without a Federal research program in open ocean farming or what is needed to colonize the open sea, their futures are very far away but need not be.

3. As the Explorer-In-Residence at the National Geographic, I'm sure you are familiar with the Sustainable Seas Expeditions. Could you please describe for us what tangible research has been accomplished as part of these expeditions? Should ocean exploration in general be focused on the U.S. EEZ initially, or a broader approach taken from the beginning?

Although I am an Explorer-in-Residence for the National Geographic Society, I am not familiar with the science program associated with the Sustainable Seas Program. If I were asked to evaluate its scientific accomplishments, I would seek a list of papers published in refereed journals resulting from data collected during that program since that is the traditional measure of the science being done. The exploration of America's EEZ clearly needs to be done. This is especially so in the western Pacific where the geology of those territories is extremely complex resulting in a highly varied world which may contain many new discoveries. I do, however, believe that the greatest potential for discovery is in the southern hemisphere and polar regions simply because they are so vast and unexplored.

4. Should there be a specific capitalized program to develop new technologies for ocean exploration and observation, providing incentives and seed money to encourage the public and private sector to get involved in development? Such a program would be similar to the Hybrid Automobile Partnership and the Advanced Technology Program at the Department of Commerce.

I agree! We need to support the development of AUVs (autonomous underwater vehicles) that can traverse long stretches of the seafloor—on the order of hundreds of kilometers—before needing to return to the surface for new power packages.

5. The observation system you all talk about is primarily for the physical environment. What are the practical applications of applying this new stream of data to the management of biological species? How would this information ultimately support the management of resources through an understanding of such things as primary productivity, fish stocks and marine pollution?

Clearly, the major costs of any ocean observation system is the physical installation of a large network or array of cables and instrumentation nodes within that network. I think it is critical that as those arrays are being designed, every effort be made to maximize their utilization for the very reasons you mention. If one uses the past as a way of predicting the future, however, you need to know that the biological community has seldom been the pioneer in the development of advanced technologies. It has always been the geological/geophysical, physical, and engineering communities to be the leaders in the development of advanced ocean technologies with the biological communities then taking advantage of these technologists once developed and then modifying them for their particular research uses.

I hope these answers are helpful. If you need further clarification I would be delighted to elaborate.

Appendix 3:

Panel III Biographies, Financial Disclosures, and Answers to Post-Hearing Questions

Woods Hole Oceanographic Institution

Scientific and Technical Staff Directory

Robert A. Weller

Senior Scientist
Physical Oceanography

Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Mailstop: 29
Phone: (508) 289-2508
Fax: (508)
rweller@whoi.edu

Education
A.B. Harvard University, 1972, Engineering and Applied Physics
Ph.D. Scripps Institution of Oceanography, 1978, Physical Oceanography

Research Interests
Wind-forced motion in the upper ocean; mixed layer dynamics; upper ocean velocity structure studies; air-sea interaction; development of current meters and surface meteorological instrumentation for air/sea experiments; air-sea fluxes; implementation of the global ocean observing system.

Back to WHOI Scientific and Technical Staff Directory

Back to PO page

Disclosure Requirement

Required by House Rule XL, clause 2(g) and Rules of the Committee on Resources

A. This part to be completed by all witnesses:

1. *Name:* Robert A. Weller
2. *Business Address:* Clark 204a, MS 29, Woods Hole Oceanographic Institution, Woods Hole, MA 02543
3. *Business Phone Number:* (508) 289–2508
4. *Organization you are representing:* Woods Hole Oceanographic Institution
5. *Any training or educational certificates, diplomas, degrees or educational experiences which add to your qualifications to testify on or knowledge of the subject matter of the hearing:* B.A., 1972, magna cum laude, Harvard University (Engineering and applied physics); Ph.D., 1978, Scripps Institution of Oceanography, University of California, San Diego (Oceanography).
6. *Any professional licenses, certifications, or affiliations held which are relevant to your qualifications to testify on or knowledge of the subject of the hearing:* PATENT: U.S. Patent No. 4,152,934, "Vector Measuring Current Meter" (with R. Davis, assigned to the Secretary of the Navy). AWARDS: James B. Macelwane Award, 1986, American Geophysical Union; Fellow, American Geophysical Union, 1986; NASA Certificate of Recognition, 1991; Henry B. Bigelow Chair for Excellence in Oceanography, Woods Hole Oceanographic Institution, 1993–1997; Secretary of the Navy Chair in Oceanography, 1998–. MEMBERSHIPS: American Geophysical Union, American Meteorological Society, American Association for the Advancement of Science, The Oceanography Society, U.S. Naval Institute.
7. *Any employment, occupation, ownership in a firm or business, or work-related experiences which relate to your qualifications to testify on or knowledge of the subject matter of the hearing:*

Employment:

Scripps Institution of Oceanography
Research Assistant, 1972–1978;
Postgraduate Research Oceanographer, 1978–1979

Woods Hole Oceanographic Institution
Postdoctoral Scholar, 1979–1980;
Postdoctoral Investigator, 1980;
Assistant Scientist, 1980–1984;
Associate Scientist, 1984–1994;
Associate Scientist with Tenure, 1988
Senior Scientist, 1994
Director, Cooperative Institute for Climate and Ocean Research, 1998

Sea duty (research cruises):

U.S.C.G. *Evergreen,* Site D, February 1972;
R.V. *Thomas Washington,* Kuroshio Current survey, off Japan, August 1973;
R.V. *Thomas Washington,* NORPAX (North Pacific Experiment) Pole Experiment, January-February 1974;
R.V. *Alexander Agassiz*-7603, TWATE III, current meter test, February-March 1976;
R.P. *FLIP* (FLoating Instrument Platform), thesis experiment, January 1977;
R.P. *FLIP,* upper ocean response study, North Pacific, May 1980;
R.V. *Oceanus*-85, Long Term Upper Ocean Study (LOTUS), North Atlantic, August 1980;
R.V. *Knorr*-85, Gulf Stream Extension and LOTUS, November 1980;
R.V. *Knorr*-87, LOTUS, February 1981, Chief Scientist;
R.V. *Oceanus*-103, LOTUS, September 1981, Chief Scientist;
R.V. *Oceanus*-119, LOTUS, May 1982;
R.P. *FLIP,* upper ocean studies, North Pacific, December 1982, Chief Scientist;
R.P. *FLIP,* upper ocean studies, North Pacific, May 1983, Co-Chief Scientist;
R.P. *FLIP,* October-November 1983, 35-day Mixed Layer Dynamics Experiment (MILDEX), North Pacific, Co-Chief Scientist;
R.V. *Oceanus*-145, LOTUS, North Atlantic, January 1984;
R.V. *Oceanus,* LOTUS, North Atlantic, May 1984;

R.V. *Knorr*-119, FASINEX (Frontal Air-Sea Interaction Experiment), co-Chief Scientist, North Atlantic, mooring deployment, January-February 1986;
R.V. *Oceanus*-175, FASINEX, Chief Scientist, February-March 1986;
R.V. *Knorr*-123, FASINEX, Chief Scientist, mooring recovery, June 1986;
R.V. *Endeavor,* Buoy Farm, North Atlantic, test buoy deployment, January 1989;
R.P. *FLIP,* surface wave and mixed layer study (SWAPP) trial cruise, North Pacific, July-August 1989;
R.P. *FLIP,* SWAPP (Surface Wave Processes Program), Co-Chief Scientist, February-March 1990;
R.V. *Oceanus*-240, leg 3, Subduction mooring deployment, North Atlantic, Chief Scientist, June-July, 1991;
R.V. *Oceanus*-250, Subduction experiment, North Atlantic, Chief Scientist, January-February, 1992;
R.V. *Wecoma,* Chief Scientist, TOGA COARE mooring recovery cruise in the western equatorial Pacific, March 1993;
R.V. *Thomas Thompson*-TN040, mooring deployment cruise in Arabian Sea, October 1994;
R.V. *Endeavor*-260, Chief Scientist, mooring deployment cruise on Georges Bank, January, 1995;
R.V. *Thomas Thompson*-TN046, Arabian Sea, Chief Scientist; mooring recovery and deployment cruise in Arabian Sea, April 1995;
R.V. *Thomas Thompson*-TN052, mooring recovery cruise in Arabian Sea, October 1995;
R.V. *Roger Revelle,* Chief Scientist, Lima, Peru to San Diego, mooring deployments in equatorial eastern Pacific, April 1997;
R.V. *Thomas Thompson,* Chief Scientist, eastern Pacific mooring recovery and deployment cruise, eastern equatorial Pacific, November-December 1997;
R.V. *Argo Maine,* Massachusetts Bay, mooring recovery cruise, Sept. 1998;
R.V. *Gyre,* Gulf of Mexico, U.S. Navy mine counter-measures field experiment, GOMEX99, Gulf of Mexico, September 1999;
R.V. *Melville,* Cook 02, Chief Scientist, mooring deployment in South American stratus cloud deck west of northern Chile, September-October 2000.

Service:

American Geophysical Union

President-elect Ocean Sciences Section, 1998–2000;
President Ocean Sciences Section, 2000–

National Research Council/National Academy of Sciences

Computer Science and Telecommunications Board, Committee Toward A National Collaboratory, 1991–1993;
GOALS (Global Ocean Atmosphere Land System) Panel, 1995–1997;
GEWEX (Global Energy and Water Cycle Experiment) Panel, 1995–1997;
Panel on the Global Ocean Observing System, 1996–1997;
TOGA Panel on Near-Term Development of Operational Ocean Observations, 1991–1993;
Committee on Radio Frequencies, 1990–1996;
Guidance Group for formation of a Committee to consider 'On Being A Scholar in a Digital Age', 1998–;
Board on Atmospheric Sciences and Climate, 1999–.

International science panels

CCCO–JSC Ocean Observing System Development Panel (OOSDP), 1990–1995;
JSTC/WCRP Ocean Observations for Climate Panel, 1995–present;
International CLIVAR (Climate Variability Program) Scientific Steering Group, 1999–;
Chair, CLIVAR Pacific Implementation Workshop Organizing Committee, 1999–;
WOCE International Indian Ocean Special Studies working group, 1991–1992;
TOGA (Tropical Ocean-Global Atmosphere) Program
- TOGA Coupled Ocean Atmosphere Response Experiment (COARE) Science Working Group, 1990–1994;
- TOGA COARE International Scientific Oversight Team, 1992–1993;

VEPIC (VAMOS (Variability of the American Monsoon System)—EPIC (Eastern Pacific Investigation of Climate) Science steering group), 1999–;

IOC (International Oceanographic Commission) Data Exchange Policy Group, 2000–;
GOOS Capacity Building Panel, 2000–.

National science panels

W.O.C.E. (World Ocean Circulation Experiment)
- Working Group on the Surface Layer;
- Working Group on Technology Development;
- Process Studies Implementation Panel (chairman);
- Working Group for In-Situ Measurements for Fluxes;
- Organizing Committee for the Workshop on Atmospheric Forcing of Ocean Circulation (January, 1988; sponsored by Institute for Naval Oceanography, W.O.C.E., and T.O.G.A.);

U.S. CLIVAR (Climate Variability)
- Scientific Steering Committee, 1998–;
- Co-Chair, Pacific Implementation Group, 1998–.

American Meteorological Society

Program Committee, Seventh Conference on Ocean-Atmosphere Interaction, 1988;
Associate Editor, *Journal of Atmospheric and Oceanic Technology,* 1993–1998.

U.S. Navy, Office of Naval Research

Coordinator for the Frontal Air-Sea Interaction Experiment (FASINEX), 1984–1988;
Coordinator for the Surface Wave Processes Program (SWAPP), 1989–1995;
Executive Committee for Marine Luminescence in the Mixed Layer (MLML), 1988–1991;
Executive Committee for Subduction program, 1990–1995;
Planning Committee for the Atlantic Stratocumulus Transition Experiment (ASTER), 1990–1992;
Secretary of the Navy Chair in Oceanography, 1998–;
Deputy Undersecretary of Defense Technology Area Review and Assessment (TARA) panel for Battlespace Environments, 1998–;
Chair, ONR Code 32/Battlespace Environments Board of Visitors, 2000;
WHOI-Surface Warfare Development Group Workshop, 2000;
Co-coordinator (with Jim Edson) ONR CBLAST–LOW, (Coupled Boundary Layer Air-Sea Interaction—Low wind), 2000–.

National Science Foundation

National Center for Atmospheric Research, Atmospheric Technology Division Review Panel, 1993–1996;
HIAPER Review Panel, 1998.

NOAA

Chairman, science team and later science advisory group for the Surface and Upper Ocean Observations Project of the NOAA Climate and Global Change Program, 1990–1994;
NOAA NODC/Joint Oceanographic Institutions, Sea Surface Temperature Working Group, 1991–1992;
Science Working Group, Pan American Climate Studies (PACS), 1997–2000;
Chair, EPIC (Eastern Pacific Investigation of Climate) Science Steering Group, 1997–present;
Director, WHOI–NOAA Cooperative Institute for Climate and Ocean Research (CICOR), 1998–present;
NOAA Climate Council, 1999–present;
NOAA Climate Observing Systems Council, 1999–present;
NEOOS (Northeast Ocean Observing System) Steering Group, 1999–2000.

Consortium for Oceanographic Research and Educatlon (CORE)

Ocean Observatories Steering Committee, 2000–;
ORAP subcommittee to review the Integrated Ocean Observing Plan, 2000.

Other

NASA Working Group on Science Requirements for Low Frequency Passive Microwave Observations of the Earth, 1990–1991;
GOMOOS (Gulf of Maine Ocean Observing System), CEO Search Committee, 2000;
Encyclopedia of Oceanography, Editorial Advisory Board;

SEAFLUX Organizing Committee, a project to look at producing turbulent air-sea fluxes from satellite data, 1998–.

Publications:

75 papers in reviewed journals
43 non-refereed publications, technical reports, chapters

8. *Any offices, elected positions, or representational capacity held in the organization on whose behalf you are testifying:*

Director, WHOI–NOAA Cooperative Institute for Climate and Ocean Research (CICOR), 1998–;
Partnership for Ocean Global Observations (POGO), WHOI representative, 1999–;
WHOI Physical Oceanographic Observing Laboratory (POOL) steering committee, 1999–.

B. To be completed by nongovernmental witnesses only:

1. *Any federal grants or contracts (including subgrants or subcontracts) which you have received since October 1, 1998 from the agencies funding ocean exploration and/or observing systems, including the source and amount and amount or each grant or contract:*

Federal Grants or Contracts for Robert A. Weller

Number of Awarded Records Found for PI: 23

WHOI Proposal #	Title	Agency	Project Dates	PIs/Co-PIs	Anticipated Total Award
P001090.01	Vector Measuring Current Meter (VMCM) Upgrade Replacement	NSF	01-Oct-1996–30-Sep-1999	Weller, Hosom, Trask	$156,040
P001508.01	An Innovative Platform for Upper Ocean Research	ONR	01-Jan-1997–31-Dec-2000	Weller, Trask	$648,297
P001514.01	Mixed Layer Response to Monsoonal Surface Forcing in the Arabian Sea	ONR	01-Jan-1997–31-Dec-1999	Weller, Trask	$497,499
P001609.00	Observations of Air-Sea Fluxes and the Surface of the Ocean	U. Calif., Scripps	01-Jan-1997–31-Dec-1998	Weller	$69,667
P001615.00	Observations of Air-Sea Fluxes and the Surface of the Ocean	U. Calif., Scripps	01-Jan-1997–31-Dec-1998	Weller	$89,190
P002025.00	Ocean Buoy Shortwave Dataset: Programmer Support and Maintenance	State Univ. NY	30-Sep-1998–31-May-1999	Weller	$7,716
P002030.01	Observations of Air-Sea Fluxes and the Surface of the Ocean	U. Calif., Scripps	01-Jan-1998–31-Dec-2001	Weller	$293,046
P002515.00	Improved VOS Measurements as Part of GCOS/GOOS (CILER)	Univ. of Michigan	01-Aug-1998–30-Jun-2002	Weller, Hosom	$375,000

Federal Grants or Contracts for Robert A. Weller—Continued

Number of Awarded Records Found for PI: 23

WHOI Proposal #	Title	Agency	Project Dates	PIs/Co-PIs	Anticipated Total Award
P010206.01	Air-Sea Interaction in the Eastern Tropical Pacific ITCZ/Cold Tongue Complex	NOAA	01-Sep-1999–31-Aug-2001	Weller, Anderson	$150,106
P010206.02	Air-Sea Interaction in the Eastern Tropical Pacific ITCZ/Cold Tongue Complex	NOAA CICOR	01-Sep-2000–30-Jun-2001	Weller, Anderson	$146,994
P010236.01	Long-Term Evolution and Coupling of the Boundary Layers in the Stratus Deck Regions of the Eastern Pacific	NOAA	01-Sep-1999–31-Aug-2001	Weller, Anderson	$650,508
P010236.02	The Long-Term Evolution and Coupling of the Boundary Layers in the Stratus Deck Regions of the Eastern Pacific	NOAA CICOR	01-Sep-2000–30-Jun-2002	Weller, Anderson	$733,500
P010338.01	Establishment of Prototype NOAA Regional GOOS Centers for the United States	NOAA CICOR	01-Apr-1999–30-Jun-2002	Weller	$33,000
P010692.00	IMET Flux Instrument Suite Upgrade	NOAA CICOR	01-Sep-2000–30-Jun-2002	Weller, Hosom	$50,000
P010842.00	UNESCO/IOC: Time Series Working Group Meeting	UNESCO IOC	30-Apr-2001–15-Aug-2001	Weller	$11,000
OE10606.01	The Coupled Boundary Layers, Air-Sea Transfer Experiment in Low to Moderate Winds (CBLAST–LOW)	ONR	01-Oct-2000–31-Dec-2004	Edson et al.	$3,845,054
P010501.00	Developing Gridded Surface Flux Fields through Synthesizing Data from in situ Measurements, Satellite Remote Sensing, and Numerical Weather Prediction Models—A Pilot Study in the Atlantic Ocean	NOAA	01-Aug-2000–31-Jul-2003	Yu, Weller	$624,104

2. *Any federal grants or contracts (including subgrants or subcontracts) which were received since October 1, 1998, from the agencies funding ocean exploration and/*

or observing systems, by the organization(s) which you represent at this hearing, including the source and amount or each grant or contract:

The Woods Hole Oceanographic Institution is a private, not-for-profit research institution whose scientists are funded largely by the federal government, including grants or contracts from the National Science Foundation, the Office of Naval Research, and the National Oceanic and Atmospheric Administration. The federal funding is approximately $75M per year.

3. *Any other information you wish to convey which might aid the members of the Committee to better understand the context of your testimony:*

The witness is an oceanographer interested in ocean dynamics, the physics of atmosphere-ocean coupling, and the role of the ocean in climate variability. He has been involved in the development of the instrumentation and technology that now makes it possible to deploy surface moorings in the open ocean to collect observations of surface meteorology and oceanographic variability. These observations are essential to the determination of how much heat, freshwater, and other properties are exchanged between the ocean and the atmosphere, how the ocean responds to the surface winds and the heat exchange with the atmosphere, and how the atmosphere in turn responds to the ocean.

ANSWERS TO POST-HEARING QUESTIONS

Questions submitted by the Honorable Robert Underwood, Subcommittee on Resources

Answers submitted by Robert A. Weller, Director, Cooperative Institute for Climate and Ocean Research, Woods Hole Oceanographic Institution

1. What would be the absolute priorities in a world of limited resources to be able to put in place a real-time observation system?

In order of priority, with highest priority number 1:

1) A global array of surface moorings observing and reporting a) surface meteorology and atmosphere-ocean exchanges of heat, freshwater, and momentum; b) physical properties (temperature, salinity, and ocean currents) through the water column from surface to bottom, and c) key biological, chemical, and geological observables (nutrients, chlorophyll, carbon dioxide, seismic information, for example).
2) The global deployment of the ARGO profiling floats, which would collect temperature and salinity profiles from the surface to 2000 meter depth, every 10 days, at a spacing of roughly 300 km.
3) Upgraded instrumentation on the Volunteer Observing Ship fleet (merchant ships that routinely repeat the same tracks across the ocean basins), to measure surface meteorology and atmosphere-ocean exchanges of heat, freshwater, and momentum and to make observations at the sea surface and in the upper ocean of physical (temperature, salinity, currents), chemical (carbon dioxide), and biological (chlorophyll, nutrients) properties.

2. Aside from the initial outlays for equipment, how would the equipment be maintained in perpetuity, who would pay for this responsibility, and who would maintain it?

The global ocean observing system will be an international partnership, like the global system for observing and reporting weather. The different nations would have, by agreement, different contributions and the responsibility for supporting and maintaining them.

This points to the allocation in the U.S. of federal funding for operational ocean measurements that would be realistic in coping with inflation and to the establishment of the necessary infrastructure. That infrastructure would include: a) a lead agency or entity that would be the U.S. point of contact for other nations, that could negotiate and monitor international agreements on responsibilities for elements of the ocean observing system, and that would focus and coordinate funding of the U.S. contributions, b) the people and ships needed to deploy and maintain the U.S. contributions, c) the people and hardware needed for the transmission, collection, and processing of data, and d) the ability to engage in capacity building and technology exchange to help other nations and thus ensure that quality and uniformity of the observing system. The maintenance would be done be a partnership of government, academic, and private laboratories. These labs now have the capability to work globally and the experience and knowledge to go forward. Additional ship time and people would be needed.

3. Should there be a specific capitalized program to develop new technologies for ocean exploration and observation, providing incentives and seed money to encourage the public and private sector to get involved in development? Such a program would be similar to the Hybrid Automobile Partnership and the Advanced Technology Program at the Department of Commerce.

Yes. Ocean observation and exploration, exclusive of satellite remote sensing, is at present a small enterprise in the U.S. and the resulting lack of incentives, foci, and opportunities limit participation and in turn our ability to conduct both.

For example, there is a lack of capacity for relaying in real-time data from the ocean's surface back to laboratories in the U.S. It was hoped that the new generation of telecommunications systems using low earth orbiting satellites (such as Iridium) would solve this problem. However, present market forces are not driving the private sector to provide upgraded communication over the global ocean. As a result we lack capacity to relay ocean data in real time.

A key requirement for such a program will be the ability to sustain support over a number if years. The cycle for testing new technologies that would address long-term ocean observations and exploration is one that takes many years. Not all new hardware deployed in the ocean is recovered, and a number of field trials are required to confirm success. It is not uncommon for new ocean instrumentation to take 10 years to reach operational status.

4. *The observation system you all talk about is primarily for the physical environment. What are the practical applications of applying this new information to the management of biological species? How would this information ultimately support the management of resources through the understanding of such things as primary productivity, fish stocks and marine pollution?*

Observing and understanding the physical environment (temperature, salinity, currents) provides an essential foundation. Population variability can be driven by a number of causes, one of which is change in the environment. Environmental change has several year (El Niño), decadal (Pacific Decadal Oscillation, North Atlantic Oscillation), and longer periods of variability and may alone drive change in species' populations and distributions of populations among different year classes. The impact of fishing pressure cannot be understood unless the variability driven by change in the environment is also understood. Management of the pollock fishery in the northeast Pacific is now done making use of observations of the physical environment. In the northwest Atlantic Ocean, there is decadal variability in the flow patterns of water down along Canada into the Gulf of Maine and to Georges Bank. This must be observed and understood as an integral part of developing an understanding and management plan for the fish populations there.

Nutrients and pollutants are distributed both horizontally, into different parts of the ocean, and vertically, through the water column, by physical processes (currents, mixing). Understanding of these processes is needed for developing understanding of the biological, chemical and geological variability in the oceans. Currents, for example, carry spilled oil, the algae in toxic algal blooms, and larvae. The exchange of nutrients between the buoyant surface layer of the ocean, where nutrients are often depleted, and the nutrient-rich water below is understood only if the physical processes of mixing are taken into account. Currents and waves are needed by the oil and shipping industries, who are working to place drilling platforms in deeper water and to improve the cost-effectiveness and safety of marine transportation.

Dr. J. Frederick Grassle.

grassle@imcs.rutgers.edu

Education

B.S. Yale University

Ph.D. Duke University

Areas of Expertise

Relationship of sediment transport processes to benthic community s
biodiversity especially in the deep sea; Interdisciplinary studies of be

IMCS Home

Research

Dredging and Remediation

The institute has been working with the Port Authority of New York/N federal government agencies, and environmental groups to assess r make contaminated dredged material cleaner and safer.

Faculty/Staff

•

Waste Disposal in the Ocean

Investigations have been conducted prior to, during and after the dis site 106 miles off the coast of New Jersey. This major, interdisciplina the fate and effects of this material in the deep sea environment.

Long-term Ecosystem Observatories

The Institute has established three Long-term Ecosystem Observato corridor off the New Jersey coast. Each of these observatories will us sensing tools to measure marine processes not detectable with conv techniques. Remotely operated vehicles, autonomous explorers and used to investigate marine processes important to fish survival, sedir involved in sand ridge formation and nearshore sediment dynamics,

Disclosure Requirement
Required by House Rule XI, clause 2(g)
and Rules of the Committee on Resources

A. This part is to be completed by all witness:
1. Name: J. Frederick Grassle

2. Business Address: Institute of Marine & Coastal Sciences, Rutgers, the State University of New Jersey, 71 Dudley Rd, New Brunswick, NJ 08901

3. Business Phone Number: 732 932-6555 x509

4. Organization you are representing: Institute of Marine & Coastal Sciences Rutgers, the State University of New Jersey

5. Any training or educational certificates, diplomas or degrees or other educational experiences which add to your qualifications to testify on or knowledge of the subject matter of the hearing:
B.S. Yale University 1961
Ph.D. Duke University 1967

6. Any professional licenses, certifications, or affiliations held which are relevant to your qualifications to testify on or knowledge of the subject matter of the hearing:
See attached CV.

7. Any employment, occupation, ownership in a firm or business, or work-related experiences which relate to your qualifications to testify on or knowledge of the subject matter of the hearing:
Scientist at Woods Hole Oceanographic Institution, 1969-1989
Professor and Director, Institute of Marine and Coastal Sciences, Rutgers, the State University of New Jersey 1989 - present

8. Any offices, elected positions or representational capacity held in the organization on whose behalf you are testifying:

B. To be completed by nongovernmental witnesses only:
1. Any federal grants or contracts (including subgrants or subcontracts) which you have received since October 1, 1998, from ________*, the source and the amount of each grant or contract:
See attached list.

2. Any federal grants or contracts (including subgrants or subcontracts) which were received since October 1, 1998, from the ________* by the organization(s) which you represent at this hearing, including the source and amount of each grant or contract:

3. Any other information you wish to convey which might aid the members of the Committee to better understand the context of your testimony:

*Note: When the witness letter is sent out, complete the blank to identify the federal agency or agencies overseeing the program or law which is the subject of the hearing.

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IMCS Grants - July 1, 1998 to June 30, 1999

	Title	Funding Agency	Start Date	End Date	Total Amount	99 Amount
	NY Bight Center: long term observation sites off the coast of New Jersey.	NOAA	03/01/99	02/29/00	1,620,000	$540,000
Frederick Grassle	Installation of seafloor cable	NSF	02/15/94	07/31/99	1,781,897	$356,379
Frederick Grassle	EPA graduate fellowship	EPA	09/03/96	09/02/99	29,801	$9,934
Frederick Grassle Michael DeLuca	Establishment of the aquaculture technology transfer center.	NOAA - Aquaculture	09/01/95	08/31/99	4,625,000	
Frederick Grassle	NY Bight Center: long term observation sites off the coast of New Jersey.	NOAA	03/01/97	03/31/99	3,091,998	$1,159,499
Frederick Grassle Scott Glenn	Multi-scale model-driven sampling with autonomous systems at a national littoral laboratory.	ONR	08/15/97	09/30/99	775,000	$387,500
Frederick Grassle	Global benthic census	Alfred P. Sloan Found.	03/01/98	03/31/99	30,000	$22,500
Grassle, Frederick	Coordinating studies of estuarine flushing & fluxes of larvae of estuarine & coastal bivalves	NJMSC/Sea Grant	03/01/98	02/28/00	$49,498	$24,749
Oscar Schofield Frederick Grassle	Hyperspectial remote sensing of the coastal ocean	ONR	01/01/99	12/31/01	533,301	$88,884

IMCS Grants - July 1, 1999 to June 30, 2000

PI	Title	Funding Agency	Start Date	End Date	Total Amount	00 Amount
Frederick Grassle	Fishery Resource Analysis and Monitoring of Pacific Groundfish	National Marine Fisheries Service	01/03/00	01/03/01	$52,920	$26,460
Frederick Grassle	Installation of seafloor cable	NSF	02/15/94	07/31/99	1,781,897	$29,698
Frederick Grassle	EPA graduate fellowship	EPA	09/03/96	09/02/99	29,801	$1,656
Frederick Grassle Michael DeLuca	Establishment of the aquaculture technology transfer center	NOAA - Aquaculture	09/01/95	08/31/01	4,625,000	$1,000,000
Frederick Grassle Scott Glenn	Multi-scale model-driven sampling with autonomous systems at a national littoral laboratory	ONR	08/15/97	09/30/99	775,000	$96,875
Oscar Schofield Frederick Grassle	Hyperspectrial remote sensing of the coastal ocean	ONR	01/01/99	12/31/01	328,419	$109,473

ANSWERS TO POST-HEARING QUESTIONS

Questions submitted by the Honorable Robert Underwood, Committee on Resources

Responses by J. Frederick Grassle, Director, Institute of Marine and Coastal Sciences, Rutgers University

1. The Physical Ocean Real-Time System (PORTS), run by NOAA, has a similar purpose to that of the innovative LEO–15 System you described. Is it envisioned that additional LEO–15 installations would link with existing and future PORTS installations? How do the two systems currently interact? Should they be integrated as they expand? What about cost savings through integration?

Establishment of observing systems must be integrated with existing marine observation systems such as PORTS. Presently, PORTS installations are centered at a number of ports throughout the country where they primarily support navigation needs of ships entering and departing harbors. In the NY/NJ Harbor for example, PORTS consists of five sites, a current meter at Bergen Point and four sites with tide gauges (two of these have salinity and temperature sensors as well). Three sites provide weather information. The addition of information from an observatory like LEO would complement and make more useful the data collected and disseminated through PORTS. For example, we have proposed providing real time surface current information from high frequency radar (CODAR) units and subsurface salinity and temperature data. These additional data will allow us to forecast the three-dimensional circulation for the entire New York Bight. Currently, the PORTS system and LEO–15 do not interact. However, Rutgers University has advanced a proposal to establish a NY/NJ Harbor Observing System that would certainly capitalize on and incorporate PORTS data. Current efforts to install a CODAR system in the NY/NJ Harbor will be integrated with PORTS and jointly made available to the public over the Internet.

As observing systems evolve regionally throughout the nation, they should integrate PORTS systems. Integration of existing data collection systems such as PORTS, satellite-based imaging capabilities, aircraft, autonomous undersea vehicles, and shore-based remote sensing systems should be included. With government, the academic community, and industry working together, the operational capabilities of these observing systems will develop at minimal cost, providing more efficient use of coastal waters and major savings to port and shipping interests.

2. Please expand on your comments on how the Ocean Exploration Program and Office of Ocean Exploration are duplicative of the NURP, and provide examples.

Research supported by NURP is broad-based, high-quality, peer-reviewed science that responds to the mission needs of NOAA. Frequently however, NURP research leads to discoveries that fall into the exploration category. Regardless of whether a NURP project is classified as exploration or research, a common set of procedures has been used to evaluate the scientific integrity of the proposed work, ensure the safety of the mission, and to select the most appropriate sampling and sensing tools and platforms. One recent example is the Deep East exploration cruise developed by three NURP Centers on the east coast (Rutgers U., U. Connecticut, U. North Carolina–Wilmington). These centers relied on the existing rigors of their peer review procedures and cruise planning expertise to assemble the inaugural ocean exploration mission on the east coast. The cruise was efficiently organized by experienced ocean explorers, benefits from existing science and operations expertise, and relies on regional and local mechanisms to interact with educators, the science community, and the undersea technology community. The Ocean Exploration program should capitalize on this proven experience in conducting safe, efficient, high-quality programs rather than recreate the capabilities available through the NURP program. NOAA should ensure that NURP provides a major part of the science and operational support services required by the Ocean Exploration program.

3. You highlight the relatively long-running Ocean Drilling Program, which provided extensive information on sedimentary strata and the earth's crust. In light of other priorities mentioned by the President's Ocean Exploration Panel and other witnesses today, should this program be maintained, or the resources applied to other priorities? Could we find out just as much about the earth's crust from the private sector through cooperative agreements or other means?

The Ocean Drilling Program (ODP) has been a leader in ocean exploration since it began in 1985 and cost sharing by the international partners makes it an exceptional bargain for the United States.

Scientific ocean drilling has produced data relevant to understanding many important issues affecting society today, including climate change, energy resources, metal exploration, and geologic hazards, such as volcanoes and earthquakes. The 1998 National Research Council paper, *Opportunities in Ocean Sciences: Challenges on the Horizon* states, "Ocean drilling has produced sediment cores that provide our best long-term records of natural climate fluctuations." Through these cores, scientists have gained new understanding of the range of climatic conditions that have occurred on our planet, discovered that the Earth undergoes very rapid climate changes, and documented evidence of climate extremes. The program discovered how massive sulfide ore deposits rich in iron, copper, and zinc form, which has changed the exploration strategy of mineral resource companies. ODP has revolutionized our understanding of geologic hazards, such as tsunamis and great earthquakes in subduction zones. ODP has documented living organisms as deep as 3000 feet below the sea floor—illustrating that the deep subsurface biosphere plays a fundamental role in life on Earth.

ODP has been a leader in developing ocean observing systems. The program has established several permanent subseafloor observatories containing seismometers that will provide tsunami warnings, monitor earthquake activity, and verify underground nuclear testing. Through these observatories, we have begun to understand how water circulation through ocean crust affects systems as diverse as ocean chemistry, atmospheric composition, metallic ore deposits, and earthquakes. Simply put, without an Ocean Drilling Program, there can be no comprehensive ocean observing system.

Deep water oil and gas is a bright frontier for conventional energy supplies. Because ODP has a wealth of experience in drilling in several thousand meters of water, the program has also developed tools and technology that have paved the way for technology and knowledge transfer to industry for deep water oil and gas exploration. Current exploration by industry heavily uses knowledge and experience developed and transferred by ODP over the last twenty years. ODP has also contributed to the discovery of methane hydrates, a potentially huge energy source buried within ocean sediments. Future ODP research is scheduled to better evaluate the future economic potential of gas hydrates.

Furthermore, ODP is perhaps the most successful example of an international science partnership. The contributions of more than 20 nations are combined to fund this program. In addition, the program works in partnership with the private sector in many areas of research and technology development. By leading the international efforts of the Ocean Drilling Program, the United States has been at the forefront of the oceanic discoveries. The United States has contributed 60% of the funding over the life of the program, yet it has benefited greatly from 100% of the program's research and educational efforts.

The active drilling phase of the Ocean Drilling Program will draw to a close in September 2003, but a great deal of work has been expended in developing a successor program, the Integrated Ocean Drilling Program (IODP). IODP will bring together the resources of many countries to fund new ships and new technology to greatly extend the reach of the program and the value to U.S. taxpayers. Japan will be a partner with the U.S. and will provide a state-of-the-art riser drilling vessel at a cost of nearly a half a billion U.S. dollars. Through its anticipated contribution of no more than 40% of the total costs of this new international program, the United States stands to benefit handsomely. Research on climate and environmental changes on the Earth, the deep biosphere, mineral and energy resources, geologic hazards and the installation of new and more capable ocean observatories will yield information highly relevant to the Nation's national policies and international relations.

So in summary, the answer to your first question, *"In light of other priorities mentioned by the President's Ocean Exploration Panel and the other witnesses today, should this program be maintained, or the resources applied to other priorities?,"* the ODP and its successor, the IODP, are essential to the goals of mapping the ocean floor, exploring ocean dynamics, developing sensor and other technologies, and providing educational opportunities such as those outlined by the President's Panel for Ocean Exploration. The ODP has a history of demonstrated success in these areas and the new technology used in IODP will continue to contribute exciting new discoveries.

In response to your second question, *"Could we find out just as much about the earth's crust from the private sector through cooperative agreements or other means?,"* I believe the answer is a resounding no. ODP has demonstrated through its many successes the benefits of a close cooperation among international partners, both public and private. This collaboration has proven to be a winning combination from all aspects—societally relevant research, education, technology development and transfer, and cost efficiency, all guided by a comprehensive international peer-review advisory system. It seems inconceivable to me that private concerns alone could organize and execute such a far-reaching and complicated program with anything approaching the cost efficiency and research excellence of ODP.

ODP is a superb example of international cooperation that has led to very significant discoveries of relevance to policy makers around the globe. The Integrated Ocean Drilling Program, for which funding is needed to begin in FY 2004, is of highest priority for continuing this research, and I hope scientific ocean drilling will receive full support from the Congress.

4. Should there be a specific capitalized program to develop new technologies for ocean exploration and observation, providing incentives and seed money to encourage the public and private sector to get involved in development? Such a program would be similar to the Hybrid Automobile Partnership and the Advanced Technology Program at the Department of Commerce.

The major impediment to ocean exploration is the lack of suitable undersea systems to provide regular access to the deep ocean. Existing assets (DSV ALVIN and the ROV JASON) are oversubscribed, and are best suited for small-scale, high-resolution sampling and sensing missions. Incentives to develop new exploration tools including ocean observatory systems can benefit from public-private partnerships where scientific demand for specific sampling, sensing, and exploration capabilities can be addressed by private sector capabilities. Incentives and seed money, like that available through the two programs noted above plus the Small Business Innovation and Research Program provide a means to foster this partnership. The SBIR program in particular has been successful in stimulating development of undersea samplers that have improved the capabilities of the DSV ALVIN. More funding for ocean technology via the SBIR infrastructure would greatly enhance development of new ocean exploration and observation technology.

The National Ocean Partnership Program has played an effective role in developing public and private sector partnerships for ocean exploration and observation through a peer review process that encourages creative partnerships among universities, government, and the private sector. I strongly recommend that an integrated ocean and coastal observing system be funded as part of the National Ocean Partnership Program under the auspices of the National Ocean Leadership Council (section 7902(a) of title 10 United States Code). Economic incentives to promote private partnerships with academically-based observing systems will assist technology development and lead to new markets for value-added data products and services.

5. The observation system you all talk about is primarily for the physical environment. What are the practical applications of applying this new stream of data to the management of biological species? How would this information ultimately support the management of resources through an understanding of such things as primary productivity, fish stocks and marine pollution?

The physical measuring system allows prediction of patterns of ocean currents, sediment movements, river plumes, and passive dispersal of most marine organisms. Physical processes do affect the distribution, abundance, and health of biological resources. Thus, it is important to understand how changes in these processes govern the distribution and dynamics of biological species. The Census of Marine Life (CoML) program with support from the Alfred P. Sloan Foundation and federal agencies through the National Ocean Partnership Program has developed several pilot projects to demonstrate new technologies that are deployed with regard to the physical predictions provided by ocean observing systems. These technologies and new approaches to biological sampling of the ocean will be integrated into future observing systems and used to predict fluctuations in fish stocks, changes in the distribution patterns of economically important fish and shellfish, toxic algal blooms, and changes in essential fish habitat.

The measurement and prediction capabilities of both the LEO–15 observatory and the proposed network of regional ocean observing systems are designed to address issues concerning a broad range of user needs including management of biological resources. For example, ocean color imagery provides a suite of derived products including plant biomass, colored dissolved organic matter, sediments, primary productivity and, potentially, phytoplankton community classification. Emerging acoustic imaging and tagging methods are expected to be incorporated in observing systems to understand the population dynamics of species throughout their range, especially coastal migratory species. Real-time measurements, data assimilation, and physical modeling used to understand the distribution of organisms are the same measurements needed to: enhance the safety and efficiency of marine transportation, measure movements of contaminated sediments in storms, improve weather forecasts, and encourage greater public safety and enjoyment of the ocean.

DISCLOSURE REQUIREMENT
Required by House Rule XI, clause 2(g)
and Rules of the Committee on Resources

A. This part is to be completed by all witnesses:

1. Name: Alfred M. Beeton

2. Business Address: 2761 Oakcleft Ct.
Ann Arbor, MI 48103

3. Business Phone Number: 734-769-3348

4. Organization you are representing: Science Advisory Board/NOAA

5. Any training or educational certificates, diplomas or degrees or other educational experiences which add to your qualifications to testify on or knowledge of the subject matter of the hearing:

B.S. '52, M.S. '54, Ph.D. '58 (all from University of Michigan)
D.Sc. (honorary University Wisconsin-Milwaukee)

6. Any professional licenses, certifications, or affiliations held which are relevant to your qualifications to testify on or knowledge of the subject matter of the hearing:

Societas Internatinale Limologcae (Member),
Michigan Academy Science (Member)

7. Any employment, occupation, ownership in a firm or business, or work-related experiences which relate to your qualifications to testify on or knowledge of the subject matter of the hearing:

Adjunct Professor, School of Public Health, Dept. Industrial and Environmental Health, University of Michigan

8. Any offices, elected positions, or representational capacity held in the organization on whose behalf you are testifying:

Chairman

B. To be completed by nongovernmental witnesses only:

1. Any federal grants or contracts (including subgrants or subcontracts) which you have received since October 1, 1998, from the ___ ______*, the source and the amount of each grant or contract:

None

2. Any federal grants or contracts (including subgrants or subcontracts) which were received since October 1, 1998, from the ___________* by the organization(s) which you represent at this hearing, including the source and amount of each grant or contract:

None

3. Any other information you wish to convey which might aid the members of the Committee to better understand the context of your testimony:

None

*Note: When the witness letter is sent out, complete the blank to identify the federal agency or agencies overseeing the program or law which is the subject of the hearing.

ANSWERS TO POST-HEARING QUESTIONS

Questions submitted by the Honorable Robert Underwood, Subcommittee on Resources

Responses by Alfred M. Beeton, Senior Science Advisor, National Oceanic and Atmospheric Administration

1. You mention the current Global Ocean Observing System and their system for collecting and managing data. How would you foresee data being collected and managed in the U.S.? Should this be included as part of NOAA?

The Global Ocean Observing System (GOOS) is an umbrella term for many complementary activities planned and underway by governments all over the world. At the same time, within the U.S. the proposed integrated ocean observing system (or "Ocean.US"), which is the U.S. contribution to GOOS, is the combined effort of a number of Federal agencies. An Ocean.US Office has been established as a focal point for these agency activities. Because of the disparate nature and purposes of these activities, it is not practical to propose centralized management. But an Ocean.US Office can bring an enormous added value by effectively coordinating these efforts.

Enclosed is a copy of a report titled "Toward A U.S. Plan for an Integrated, Sustained Ocean Observing System", prepared in 1999 in response to a request from the Subcommittee on Fisheries Conservation, Wildlife, and Oceans. The report presents excellent recommendations for both coastal ocean and open ocean observations.

2. Please explain the Office for Ocean Exploration that has been established within NOAA. How do you foresee its role in future ocean exploration? How will it cooperate with other ocean exploration and observation also being undertaken?

On June 12, 2000, President William J. Clinton requested that the Secretary of Commerce convene a panel of leading scientists, explorers, and educators to develop a national strategy for ocean exploration. As a result, the National Oceanic and Atmospheric Administration (NOAA) was designated to be the leading federal agency for the initiative because of its role as the major agency for ocean observations. The Office for Ocean Exploration was created to be in charge of the program in collaboration with marine research institutions, universities and other relevant Federal agencies. Its role in the future of ocean exploration will be to identify resources available, facilitate partnerships, the dissemination of information and the development of new technologies. Cooperation with current exploration and observation initiatives is an intrinsic part of the effort to capitalize on joint opportunities with other compatible government missions and industry, as well as to avoid duplication of efforts.

3. Should there be a specific capitalized program to develop new technologies for ocean exploration and observation, providing incentives and seed money to encourage the public and private sector to get involved in development? Such a program would be similar to the Hybrid Automobile Partnership and the Advanced Technology Program at the Department of Commerce.

Recent advances in technologies for ocean exploration and observation now make it possible to develop systems that will routinely monitor the chemical and biological components of the ocean and coastal ecosystems. Recent advances made with sensors for monitoring the occurrence of harmful algae, as well as other organisms, are very encouraging and have enormous potential, but much more needs to be done. Only a few years ago monitoring and assessment of organisms relied on methods in use for almost a hundred years. A specific capitalized program will be very useful to enhance and stimulate development of new technologies. I suggest that the National Academy of Sciences/National Research Council be asked to establish a Committee to advise on the present state of such technology and what the opportunities are for enhancement and more rapid development of new technologies.

4. The observation system that you all talk about is primarily for the physical environment. What are the practical applications of applying this new stream of data to the management of biological species? How would this information ultimately support the management of resources through an understanding of such things as primary productivity, fish stocks and marine pollution?

There are indeed important practical applications for living marine resource management. The observing system will collect data on chemical and biological variables in addition to physical parameters. Because of the complexity of the chemistry and biology issues, these components of the system are not yet fully developed. More work is needed. However, GOOS is intended to provide operationally useful information on changes in the state of living resources and their ecosystems to be able to assess present stocks and predict their future states, as well as their vulnerability to changes in climate, fishing pressure, pollution, and the incidence of harmful algal blooms. New technologies are also being evaluated for more cost-effective sampling, such as remote sensing techniques (using ocean color, for example) and new sensors on *in situ* instruments.

Department of Oceanography

Alexander Malahoff

Professor, Department of Oceanography, and

Director, Hawaii Undersea Research Laboratory (HURL)

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Education

- BS 1960 - Geology, University of New Zealand
- MS 1962 - Geology (Geophysics), Victoria University of Wellington
- Ph.D 1965 - Geophysics, University of Hawaii

Research Interests

- Geological Oceanography
- Global Tectonics
- Mineral Formation Processes
- Active Research Programs

Teaching Activites

- OCN 330 - Mineral and Energy Resources of the Sea
- OCN 622 - Geological Oceanography

- OCN 631 - Ocean Minerals
- OCN 735 - Seminar in Geological Oceanography

Service

Publications

Go to the Oceanography Home Page

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Last Revised: 21 November 1996

DISCLOSURE REQUIREMENT
Required by House Rule XI, clause 2(g)
and Rules of the Committee on Resources

A. This part is to be completed by all witnesses:

1. Name: Alexander MALAHOFF, Ph.D.

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3. Business Phone Number: (808) 956-6802 Fax: (808) 956-2136 Email: malahoff@soest.hawaii.edu

4. Organization you are representing: University of Hawaii at Manoa
School of Ocean & Earth Science & Technology

5. Any training or educational certificates, diplomas or degrees or other educational experiences which add to your qualifications to testify on or knowledge of the subject matter of the hearing:
Bsc. in Geology, Univ. of New Zealand
Msc. in Geology/Geophysics, Victoria Univ. of Wellington, NZ
Ph.D. in Geophysics, University of Hawaii at Manoa
D.Sc. (Hon.), Victoria Univ. of Wellington, NZ

6. Any professional licenses, certifications, or affiliations held which are relevant to your qualifications to testify on or knowledge of the subject matter of the hearing:
Member: Marine Technology Society, American Geophysical Union,
Society of Exploration Geophysics
Fellow: Geological Society of America

7. Any employment, occupation, ownership in a firm or business, or work-related experiences which relate to your qualifications to testify on or knowledge of the subject matter of the hearing:
Professor, Dept. of Oceanography, Univ. of Hawaii/SOEST
Director, Hawaii Undersea Research Laboratory, " " (NOAA's NURC for HI & the Western Pacific)
Director, Marine Bioproducts & Engineering Center, " " (MarBEC)

8. Any offices, elected positions, or representational capacity held in the organization on whose behalf you are testifying:
None

B. To be completed by nongovernmental witnesses only:

1. Any federal grants or contracts (including subgrants or subcontracts) which you have received since October 1, 1998, from the NOAA/NURP, NSF, the source and the amount of each grant or contract:
NOAA/NURP - NOAA's National Undersea Research Center for Hawaii & the Western Pacific
1998: $2,494,000; 1999:$2,286,000; 2000: $2,488,398
NSF - Engineering Research for Marine Bioproducts Engineering - 1998-2003: $5,519,441

2. Any federal grants or contracts (including subgrants or subcontracts) which were received since October 1, 1998, from the NOAA/NURP, NSF * by the organization(s) which you represent at this hearing, including the source and amount of each grant or contract:
None.

3. Any other information you wish to convey which might aid the members of the Committee to better understand the context of your testimony:
Extensive experience in deep ocean exploration, ocean resources, manned and unmanned submersibles, and submarine volcanoes and hydrothermal vents.

*Note: When the witness letter is sent out, complete the blank to identify the federal agency or agencies overseeing the program or law which is the subject of the hearing.

ANSWERS TO POST-HEARING QUESTIONS

Questions submitted by the Honorable Robert Underwood, Committee on Resources

Responses by Dr. Alexander Malahoff, Director, Hawaii Undersea Research Laboratory, University of Hawaii

1. What is the University of Hawaii NURP Project doing in the Western Pacific at the moment? What has it done in the past and plan to do in the future?

Currently, NURP/NURC–H&P) is working on projects dealing with fisheries, corals and other living organisms at depths below 300 feet on the Hawaiian Island chain from Midway to the Big Island of Hawaii. Future work is also planned for Guam, the Northern Marianas and Samoa.

2. How do you anticipate NOAA's National Undersea Research Program cooperating with the National Ocean Exploration Initiative?

NURP has the expertise and facilities for deep submergence, such as the Pisces IV and Pisces V submersibles and mothership, based in Hawaii. It is this expertise and the vehicles that will be made available to the National Ocean Exploration Initiative.

3. Should there be a specific capitalized program to develop new technologies for ocean exploration and observation, providing incentives and seed money to encourage the public and private sector to get involved in development?

Such a program would be similar to the Hybrid Automobile Partnership and the Advanced Technology Program at the Department of Commerce. A new generation of deep diving submersibles has to be built in order to allow the full exploration of the ocean floor. None have been built during the past 25 years. Specialized remotely-operated vehicles, specifically designed for deep ocean exploration need to be designed and built. New sensors and remote observatories would fill in the gaps between submersible and ROV traverses. This is an excellent technology field for partnerships between universities, government and the public ocean engineering and technology sectors.

4. The observation system you all talk about is primarily for the physical environment. What are the practical applications of applying this new stream of data to the management of biological species? How would this information ultimately support the management of resources through an understanding of such things as primary productivity, fish stocks and marine pollution?

A prime objective in ocean exploration is to study the animals, especially fishes in their natural environment. The many stages in the lives of these animals occupy different niches. The systems, such as submersible, ROVs, observatories and bottom stations utilizing exotic technology in order to work at the great ocean depths are the prime vehicles for observing the behavior of fish species. The thorough understanding of the complete life cycles of fish and other animals will enable us to conserve, restock and culture valuable species. The special sensors on deep submergence vehicles are designed to monitor the chemistry of the water and any human-derived pollutions.

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Appendix 4:

Additional Material for the Record

SUBMITTED STATEMENT OF WILLIAM J. MERRELL

Good afternoon, Chairman Gilchrest, Chairman Ehlers, Chairman Smith and members of the subcommittees. I am William Merrell, President of The H. John Heinz III Center for Science, Economics and the Environment. While serving as president of The Heinz Center, I am on leave of absence from the Texas A&M University, where I serve as Professor of Oceanography and Marine Sciences. I understand that the members of the subcommittees are interested in the recommendations of the President's Panel on Ocean Exploration, and what actions should be taken to implement those recommendations. My testimony will include brief comments on the work of the Panel on Ocean Exploration, of which I was a member. I will then focus specifically on a Heinz Center effort to involve the four sectors, i.e., government at all levels, academia, industry, and environmental organizations, in the creation of an Ocean Exploration Forum, one of the recommendations in the Panel's report.

The United States needs to support an Ocean Exploration Program to expand our present body of knowledge of the oceans, upon which we currently base our governance, management, commercial, and scientific decisions. Tremendous gains have been made in other sciences and outstanding technological advances have occurred over the last 50 years, yet our knowledge about the oceans has not kept abreast of our capabilities or our needs. As the Panel's report notes, the oceanographic research of the past was conducted as exploratory missions with interdisciplinary teams. Today, oceanographic research is more narrowly focused and hypothesis driven. In these times of increasing competitive uses and increasing pressures on our resources, a return to exploration to complement the ongoing hypothesis based research is necessary if we are to ensure a sustainable future. Through a program of ocean exploration, we will better understand the evolution of the earth, the distribution of living and nonliving resources and the magnitude of new and exotic life forms. We can use that improved knowledge to effectively manage, develop and conserve our oceans.

The President's panel, composed of leading experts in ocean science, policy, commerce and education, produced a report, entitled *Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration,* which outlines an Ocean Exploration Program. The panel's recommendations, key objectives, and priorities identified to guide such a program are:

1. Mapping the physical, geological, biological, chemical, and archaeological aspects of the ocean, such that the U.S. knowledge base is capable of supporting the large demand for this information from policy makers, regulators, commercial ventures, researchers and educators;
2. Exploring ocean dynamics and interactions at new scales, such that our understanding of the complex interactions in the living ocean supports our need for stewardship of this vital component of the planet's life support system;
3. Developing new sensors and systems for ocean exploration, so as to regain U.S. leadership in marine technology; and
4. Reaching out in new ways to stakeholders, to improve the literacy of learners of all ages with respect to ocean issues.

To meet objective four, the panel proposed the establishment of "an Ocean Exploration Forum to encourage partnerships and promote communication among commercial, academic, private, nongovernmental organizations and government stakeholders" as one of its recommendations for the management structure. To this end, The Heinz Center will form a small *ad hoc* Forum advisory group, with selected members of the Ocean Exploration Panel, to convene two regional workshops to consider and receive input on the establishment of such a forum. Leaders from industry, government, academia, and environmental organizations will participate in the workshops. Participants will consider the following issues: how the Forum should be constituted; what issues should be considered; whether the Forum should be established in partnership or as a joint activity with an outside organization or within the government; whether the Forum should provide special briefings on an informal basis or hold a large semiannual meeting; and what mechanisms would help the Forum "encourage partnerships and promote communication."

The Heinz Center agreed to undertake such an endeavor, because it meets our mission of fostering collaboration among industry, environmental organizations, academia, and government and the opportunity such a forum could provide to understanding the advances in ocean sciences and in new technologies and observing systems. Moreover, the findings and recommendations of The Heinz Center's projects and programs are widely disseminated to public and private sector decision-makers, the scientific community, and the public, which is in keeping with objective four mentioned above. This expertise in multi-sector collaboration and information dissemination is essential in developing a viable Ocean Exploration Forum.

By supporting the Ocean Exploration Program we will increase our understanding of ocean processes, an important step in maintaining an ocean science and technology enterprise that can meet the challenges of the coming decades. The interest within your subcommittees in this issue and your deliberations here today reaffirm my belief that we as a nation are prepared to realize the full potential of the oceans and to explore the 95 percent of the oceans still unexplored.

Thank you for giving me the opportunity to contribute to your deliberations on the important issue of ocean exploration and to explain The Heinz Center's efforts to implement one of the Panel's recommendations.

DISCLOSURE REQUIREMENT
Required by House Rule XI, clause 2(g)
and Rules of the Committee on Resources

A. This part is to be completed by all witnesses:

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3. Business Phone Number: 202-737-6307

4. Organization you are representing: The H. John Heinz III Center for Science, Economics and the Environment

5. Any training or educational certificates, diplomas or degrees or other educational experiences which add to your qualifications to testify on or knowledge of the subject matter of the hearing:

Ph.D. Oceanography - Texas A&M University

6. Any professional licenses, certifications, or affiliations held which are relevant to your qualifications to testify on or knowledge of the subject matter of the hearing: None

7. Any employment, occupation, ownership in a firm or business, or work-related experiences which relate to your qualifications to testify on or knowledge of the subject matter of the hearing: None

8. Any offices, elected positions, or representational capacity held in the organization on whose behalf you are testifying: President, The H. John Heinz III Center for Science, Economics and the Environment

B. To be completed by nongovernmental witnesses only:

1. Any federal grants or contracts (including subgrants or subcontracts) which you have received since October 1, 1998, from the NOAA *, the source and the amount of each grant or contract: None

2. Any federal grants or contracts (including subgrants or subcontracts) which were received since October 1, 1998, from the NOAA * by the organization(s) which you represent at this hearing, including the source and amount of each grant or contract: Please see attached

3. Any other information you wish to convey which might aid the members of the Committee to better understand the context of your testimony: None

*Note: When the witness letter is sent out, complete the blank to identify the federal agency or agencies overseeing the program or law which is the subject of the hearing.

International Commitments for Argo Floats *4/6/01*

Number of Floats by Country	Argo Funded FY99	Float Equiv's FY99	Argo Funded FY00	Float Equiv's FY00	Argo Funded FY01	Float Equiv's FY01	Proposed over next 3 years	Prop Float Equiv's over 3 yrs
Australia			10		10		90	
Canada			10		42		90	
China					10		80	
Denmark						5		30
European Commission					80			
France		8	70		65		200	
Germany				18		22	100	35
India					6		150	
Japan			20		90		300	
New Zealand					2		10	
Republic of Korea					20		90	
Spain							24	
United Kingdom			13		50	5	150	40
U.S.A.	55		132	51	150	40	825	60
TOTALS	55	8	255	69	525	72	2109	165
TOTALS BY YEAR	FY99 = 63		FY00 = 324		FY01 = 597		Ave/Yr = 758	

This table reflects the year in which funds are provided for floats; it takes on the order of a year until such floats are available for deployment.

To achieve a global array of 3,000 operating floats—assuming that 90% of the floats have an average lifetime of four years (the other 10% fail early)—it is necessary for the international community to provide floats at a sustained rate of 825 per year.

A "Float Equivalent" is defined as a float—while not funded under the Argo Program— whose data are available consistent with the Argo Data Policy and provides the information equivalent to one Argo float.

This table and the accompanying annotation have been reviewed and updated by the International Argo Science Team at its meeting in Sidney, BC, Canada March 20-22, 2001.

Australia *– FY02 starts Jul 1, 02 – 10 floats funded by Commonwealth Scientific and Industrial Research Organization (CSIRO) in FY00 and 10 by Bureau of Meteorology (BoM) in FY01; pending BOM/CSIRO ocean prediction request for 30 floats*

Canada *– FY starts Apr 1 – funded by Dept. of Fisheries & Oceans with potential funding from Dept. of National Defense, Environment Canada, and others*

China *– FY starts Jan 1 – funded by Ministry of Science & Technology (National Basic Research Priorities Program, National Climbing Program, and National Special Projects); implemented by State Oceanic Administration in collaboration with other organizations*

Denmark *– Niels Bohr Institute for Astronomy, Physics and Geophysics is deploying 5 floats in the Greenland Sea and is proposing 30 for next year*

European Commission *– Gyroscope proposal submitted by France, Germany, Spain, and U.K. has funded 80 floats*

France *– FY starts Jan 1 – Overall coordination under Coriolis Project; funded and implemented by Institut Francais de Recherche pour l' Exploitation de la Mer, Centre National de la Recherche Scientifique, and Service Hydrographique de la Marine; an additional 8 floats were funded as part of POMME*

Germany *– FY starts Jan 1 – Argo proposal for 100 floats submitted by AWI/BSH/IfM-Kiel to Ministry for Research & Technology (BMBF) in support of Ministry of Transport (Weather Service [DWD] & Hydrographic Service [BSH])—decision date TBD; other floats include: BSH has funded 18 and 5 floats in FY00 and FY01 for Mid-Atlantic Ridge, Alfred Wegener Institute has funded 10 floats in FY01 for Southern Ocean, Deutsche Forschungs Gemeinschaft (DFG) has funded Institute fuer Meerskunde (IfM) for 7 floats in FY01 for Lab. Sea, proposal submitted by IfM to DFG for 20 floats in Indian Ocean with decision ~Jul 01, and 15 BMBF-funded IfM floats deployed in Tropical Atlantic will be included when data are reported on GTS*

India *– FY starts Apr 1 – funded by Dept. of Ocean Development; implemented by National Center for Ocean Information Services (lead), National Institute of Ocean Technology, Center for Ocean and Atmospheric Sciences along with National Institute of Oceanography and 6 other academic/R&D/operational institutions*

Japan *– FY starts Apr 1 – funded by Ministry of Education, Culture, Sports, Science & Technology and Ministry of Land, Infrastructure & Transport; implemented by JAMSTEC, Frontier Research Program, Japanese Meteorological Agency, and Coast Guard; out-year commitment to ramp up to 100+ floats per year*

New Zealand *– FY02 starts Jul 1, 02 – funded and implemented by National Institute of Water & Atmospheric Research*

<u>Republic of Korea</u> – FY starts Jan 1 – funded by Ministry of Science & Technology/Korean Meteorological Administration and Ministry of Marine Affairs & Fisheries; implemented by Korea Argo Subcommittee of the Korea Oceanographic Committee

<u>Russia</u> – Hydromet/Vladivostok has deployed 4 Webb floats in Japan Sea and is proposing to purchase 2 more; data not yet being made available on the GTS

<u>Spain</u> – proposal submitted to Programa Nacional de Investigacion by Instituto Espanol de Oceanografia, Universidad de Las Palmas de GC, and Instituto de Ciencias del Mar de Barcelona-CSIC with decision ~ Oct 01

<u>U.K.</u> – FY starts Apr 1 – funded by Dept. of Environment, Transport & Regions, Ministry of Defense, and Natural Environment Research Council; managed and implemented by U.K. Meteorological Office in collaboration with Southampton Oceanography Center, British Oceanographic Data Center and U.K. Hydrographic Office; out-year commitment to ramp up to 50 Argo floats per year, to be supplemented by up to 40 additional research floats over 3 years depending on successful bids for funding

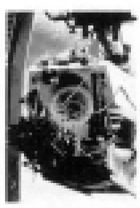
<u>U.S.A.</u> – FY02 starts Oct 1, 01 – funded by NOAA and Office of Naval Research via National Oceanographic Partnership Program; other contributions are from Naval Oceanographic Office (Navoceano, 16 in FY00, 20 in FY01) and NOAA via Consortium for Ocean Research & Climate (35 in FY00, 20 in FY01); an additional 60 Navoceano floats are dependent on availability of funding; does not include 10 floats funded by NOAA/OAR/Arctic Program Office for deployment in the Bering Sea; 275 floats per year requires funding at a level of $7.2M

noaaresearch

Ocean Exploration

The discovery of living and nonliving resources will be a great benefit to people the world over.

Education and outreach will strengthen and diversify exploration programs for the future.



Innovative technology must be developed if we are to unlock the secrets of the oceans.

What is requested?

NOAA is requesting an increase of $10.0 million for the Ocean Exploration Initiative, established in 2001 to systematically search and investigate the oceans for the purpose of discovery. This initiative proposes the most ambitious chapter ever in the history of human discovery on Earth: the exploration of the Earth's oceans. Although Ocean Exploration is a NOAA-wide effort incorporating the effort of many line offices, budget activity is located in the Office of Oceanic and Atmospheric Research's (OAR) Ocean and Great Lakes Research budget subactivity.

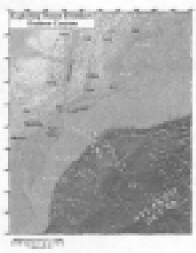
Why do we need it?

Covering more than 70% of the surface of the earth, with an average depth of 3,800 meters, the oceans are the last, largely unexplored frontier on our planet. In fact, ocean scientists estimate that only 5% of our oceans have been explored. This initiative seeks to bring a multi-disciplinary array of the best of our nation's ocean scientists to ocean frontiers to discover new species, ocean processes, cultural antiquities and artifacts, and biological and mineral resources. The need to extend U.S. leadership in Ocean Exploration was first articulated by the Stratton Commission which led to the formation of NOAA. For the past three decades, NOAA has pursued a course of ocean regulation and management without ever developing a comprehensive exploration program. Thus our science lacks a fundamental understanding of enormous ocean regions and important ocean systems. In June 2000, a U.S. panel of ocean scientists, explorers, and educators convened to create history's first National Strategy for Ocean Exploration. Their report, "Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration," is a responsible plan to undertake new activities in ocean exploration.

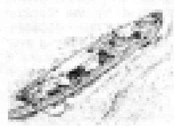
Recent progress in technology permits us to completely rethink how we conduct exploration and oceanographic studies. Developments in biotechnology, sensors, telemetry, power sources, microcomputers and materials science now permit the U.S. to dream of rivaling space exploration in our ability to go to and study the undersea frontier. We need not be limited by weather and blind sampling from ships, but like true explorers, can immerse ourselves in new places and events. NOAA proposes to embark on a national endeavor, to build on our initial efforts in ocean research, partner with existing public, private, and academic ocean exploration programs outside of NOAA, and to achieve international leadership in undersea exploration and research.

What will we do?

In the FY2002 Initiative plan, NOAA's Ocean Exploration Program will undertake several major and minor interdisciplinary expeditions to explore unknown regions and processes of the ocean. The regions planned for exploration in the FY2002 initiative include: The Gulf of Mexico; areas of the Pacific off California, Oregon, Washington, and Alaska; the South Atlantic Bight; and the Gulf of Maine. These expeditions will weave together five science themes integral to ocean research. These themes were developed by NOAA scientists and reflect the core science requirements articulated by the U.S. Panel on Ocean Exploration.



Hudson Canyon is one of the ocean regions explored by NOAA's Ocean Exploration program in 2001.



The wreck of the historic civil warship the USS Monitor is an example of a NOAA partnership to document America's maritime heritage.

For More Information:
NOAA Office of
Ocean Exploration
301-713-9444

These themes are:

- Finding New Ocean Resources,
- Exploring Ocean Acoustics,
- Documenting America's Maritime Heritage,
- The Census of Marine Life, and
- Exploring New Frontiers

A vital component of this initiative is education and outreach. This priority in NOAA is matched with a 10% commitment of all funds for Ocean Exploration going to education and outreach products. This commitment to sharing NOAA's science message captures the priority of outreach and education and provides the vehicle for catapulting ocean discovery to the forefront of the public's imagination. This activity builds on the investments already made within NOAA in the existing education programs to share the excitement of discovery.

By developing coordinated field campaigns aboard NOAA, University-National Oceanographic Laboratory System (UNOLS) and other partner vessels, NOAA will embark upon oceanic expeditions that may rival the historic HMS *Challenger* Expedition in 1872. By employing a full array of modern ocean technology, these explorations will survey, characterize, and define diverse marine environments. These innovative expeditions will undoubtedly rewrite oceanography and marine biology textbooks and redefine ocean maps.

What are the benefits?

History demonstrates that exploration results in discoveries of great value. For example, the relatively recent discovery of hydrothermal vent communities has resulted in key knowledge not only about geological processes and plate tectonics but also about biological processes of great potential use in medicine and industry. In turn, these discoveries have shown economic potential in the range of billions of dollars. Enzymes produced by microbes found at these sites have become critical to industries that replicate DNA, new anti-inflammatory drugs are being produced from deep-sea organisms, and new knowledge will allow us to be better stewards of ocean resources.

Each trip we take to further reaches of the Earth's oceans has the potential to reveal important information about the origin of life on earth, or new living or non-living resources that may have tremendous potential to improve the quality of life on earth. The sooner we take the step of seriously addressing our lack of understanding of how ocean processes affect life on land, the sooner we will be able to realize the scientific and economic payoffs applicable to a wide variety of societal issues. Ocean Exploration presents possibilities for new solutions to problems we face as we move into the 21st century.

NOAA Budget

	FY2002 Change $ millions
Oceanic & Atmospheric Research	
Ocean & Great Lakes Programs	
Ocean Exploration	$10.0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Ocean Observatories
Continuous Access to the Depths,
New Heights of Earth Knowledge

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Oceanus

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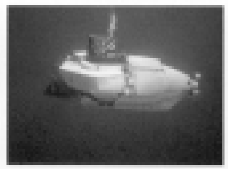
Ocean Observatories

Cover: *Components of a seafloor ocean observatory form the backdrop for a concept of a second-generation model of WHOI's Autonomous Benthic Explorer (ABE). Such autonomous underwater vehicles will play important roles in ocean observatories, with the capacity to upload power and download data from underwater observatory docking stations. ABE's principal designers are Dana Yoerger, Associate Scientist in the Deep Submergence Laboratory, Albert Bradley, Principal Engineer in the Applied Ocean Physics and Engineering Department, and Barrie Walden, Principal Engineer and Manager of Operational Science Services. The National Science Foundation funds their research. Illustration by E. Paul Oberlander*

Atlantis



Alvin

ABE II (artist's concept)

A Sea Change in Ocean Science

When new technology expands our ability to explore the oceans, we take quantum leaps in understanding our planet.

After World War II, new instruments aboard dedicated oceanographic ships revealed the seafloor as anything but featureless and static. The late-1960s plate tectonics revolution provided a new dynamic framework for understanding fundamental Earth processes that spawn earthquakes, build mountains, and create volcanoes, mid-ocean ridges, islands, undersea oil reservoirs, and other geologic features.

A decade later, new emphasis on deep-sea technology brought the discovery of previously unimagined oases of life at mid-ocean ridge hydrothermal vents.

Such discoveries provide convincing evidence that Earth's oceans, atmosphere, life, and the solid planet itself are all interrelated and that Earth constantly changes even as we try to understand it.

Imagine an extraterrestrial exploratory vehicle landing in a Vermont forest in February. Five days of zealous data-gathering might lead to the quite logical conclusion that an unknown phenomenon caused a rapid climate change that turned Earth into a cold, barren planet. We know the phenomenon as winter.

The lesson is that we must go beyond taking intermittent, isolated snapshots of the ocean. We need to know not only what's there, but also what's *going on* there. We must begin to monitor the dynamic, complex, intertwining Earth processes that unfold over long time periods and large areas and to capture important oceanic events that happen in an instant or in previously overlooked places. We need to establish a global, long-term *presence* in the oceans—a vast, hostile, hard-to-penetrate, extraterrestrial environment for humans.

Fortunately, the teaming of scientists and engineers makes this possible. As you will read in these pages, they are harnessing technological advances to create a revolutionary new way to conduct ocean research: ocean observatories. We are on the brink of the next era of major oceanographic discovery.

In an age when rapidly burgeoning human population imposes ever-mounting environmental stresses on our planet, ocean observatories will help us unravel Earth processes that have enormous societal impacts, including hurricanes, tsunamis, earthquakes, beach erosion, toxic algal blooms, declining fisheries, and coastal pollution. They will allow us to grasp the ocean's role in shaping our climate and give us the potential to predict short-term climate changes that spawn floods, droughts, heat waves, mudslides, and even weather- and water-related epidemics such as cholera and malaria. Ocean observatories are a window onto a huge, previously inaccessible, and hitherto unknown biosphere that may have biomedical and industrial potential, and that may teach us about the origin of life on Earth and elsewhere in the solar system.

I believe the oceans are key to sustaining life, and the quality of life, on this planet. The future is now, and it comes just in time.

—Bob Gagosian, WHOI Director

Seeding the Oceans with Observatories

Taking the next strategic steps to explore the Dynamics of Earth and Ocean Systems (DEOS)

Keir Becker, Professor, Rosenstiel School of Marine and Atmospheric Science, University of Miami and the DEOS Steering Committee*

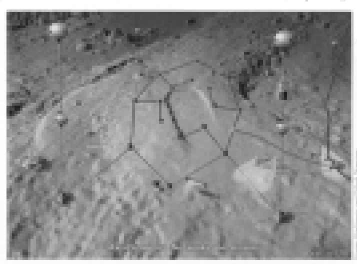
In the midst of the vast ocean, a moored observatory does its work, continually taking measurements to track oceanic and atmospheric processes that influence Earth's climate.

Ship-borne expeditions have been the dominant means of exploring the oceans in the 20th century. Scientists aboard ships made the observations and gathered the data that confirmed the revolutionary theory of plate tectonics, which demonstrated that the earth is a complex, multi-faceted system that changes over time. But that revelation also exposed a major shortcoming of the ship-based exploratory approach: its very limited ability to quantify change.

Geoscientists now realize that the earth is dynamic. It cannot be studied adequately in a static manner by simply examining limited regions for short periods. Traditional mapping and sampling strategies provide only infrequent, intermittent snapshots of myriad, ongoing, interlinked, global processes that actively shape the earth and have impacts on society.

Consider these three examples:

- El Niño events, especially in 1982–1983 and 1997–1998, clearly demonstrated the profound societal impacts of dynamic earth and ocean processes and the importance of understanding their behavior.
- Over the past two decades, geoscientists have discovered entirely new ecosystems around hydrothermal vents.



Seafloor observatories, like this one conceived for the NEPTUNE project, could host an array of sensors and serve as a base for robotic exploration.

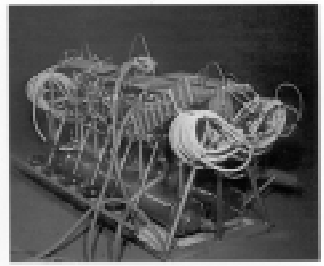
*Members of the DEOS Steering Committee: **Keir Becker**, University of Miami, co-chair; **Alan Chave**, WHOI, co-chair; **John Baross**, University of Washington; **Keith [illegible]**, Lehigh University; **John Delaney**, University of Washington; **Robert Detrick**, WHOI; **Tim Dixon**, University of Miami; **Fred Duennebier**, University of Hawaii; **Adam Dziewonski**, Harvard University; **Chuck Fisher**, Pennsylvania State University; **Chuck Nittrouer**, University of Washington; **John Orcutt**, Scripps Institution of Oceanography; **Adam Schultz**, Cambridge University.

whose existence is linked to ongoing or episodic volcanic and magmatic processes on and below the seafloor near mid-ocean ridges. The vents have generated exciting new lines of inquiry about the origin of life on Earth and the possibility of life on other planetary bodies that are similarly endowed with water and volcanism.

- Less well-known but certainly equally complex processes occur at subduction zones, where old seafloor sinks back into the mantle. These processes occur on scales of tens to thousands of kilometers over months to hundreds of millions of years, yet they generate catastrophic earthquakes and tsunamis that occur in seconds over small areas around the Pacific "Rim of Fire," for example. Subduction processes also play an important role in recycling chemicals to the mantle, and they are a primary cause of tectonic uplift and mountain- and island-building on Earth.

To fully understand the causes and effects of all these phenomena, we need a much better grasp of Earth's complex, dynamic processes before, as, and after they occur. This will entail a significant philosophical and cultural change in the way we conduct our science. It will require a coordinated investment in a new mode of marine geoscience investigations: the establishment of long-term ocean observatories. Such observatories offer an essential means to observe interrelated processes over time and/or to fill in the rather extensive gaps in remote ocean regions where data on deep Earth structures and properties have never been collected.

While scientists have maintained observatories on land for centuries, the practice has not yet received broad support in the oceans. But many national deep-water geoscience initiatives have recently embraced strategies involving seafloor observatories to investigate the earth, including the Ridge Inter-Disciplinary Global Experiments (RIDGE), the MARGINS study of rifted and convergent plate boundaries, the Ocean Seismic Network (OSN), and efforts with the eponymous names BOREHOLE and CABLE, which seek to take advantage of Ocean Drilling Program (ODP) boreholes and submarine cables for geosciences research. Since 1997, scientists involved in these initiatives have joined in a planning effort supported by the National Science Foundation to lay the groundwork for a proposed long-term observatory program called Dynamics of Earth and Ocean Systems (DEOS). And this philosophy is also being embraced in other disciplines of ocean sciences, as well as internationally, so there is an unprecedented opportunity and need for cross-disciplinary, multi-national coordination of scientific objectives and infrastructure.



The Hawaii-2 Observatory, the first long-term, mid-ocean seafloor observatory, was deployed in 1998, taking advantage of a retired trans-Pacific telephone cable.

Observing dynamic global processes

Current and planned seafloor observatory efforts come in two flavors:

1) "Active Process" observatories are located where particular Earth systems are presently most active near the surface. Many of the best examples are at plate boundaries: at mid-ocean ridges, the settings of possibly the most complex interplay among tectonic, magmatic, hydrothermal, and biological processes on Earth, and at subduction zones, where tectonic and magmatic processes have great destructive impact on society. Because these plate tectonic boundaries occur almost exclusively beneath the seas, a seafloor observatory capability is imperative on both scientific and societal grounds.

2) "Global Imaging" observatories would provide "blanket" data coverage of the earth, collecting data from all the necessary places and angles to give us a "big-picture" perspective of our planet. Such a global network of observatories would allow us to fully image the interior of the earth and to provide a comprehensive view of processes that occur over very long time scales and over the entire globe. With 70 percent of the earth's surface under the oceans, global networks will never be complete without seafloor observatories.

Because these obser-

Scientists at the Field Research Facility in Duck, North Carolina, use the Coastal Research Amphibious Buggy (CRAB) to deploy instruments for studies of the dynamic processes that shape beaches.

A prototype Argo float is tested in the Labrador Sea. Scientists hope to seed the oceans with 3,000 similar floats to measure oceanic conditions and transmit data to shore via satellite.

vatories open windows onto Earth processes that occur over expanses of both space and time, they are valuable for scientists specializing in many fields. Consequently, observatory networks can be located, configured, and used for multi-disciplinary studies to maximize the investment required to establish them.

Although individual seafloor observatories may have different primary scientific goals, they share many common technological needs. To deploy and maintain long-term monitoring equipment in the remote and hostile seafloor environment, scientists will have to address several requirements. They will need to deliver long-term power to seafloor instruments, a link for data transmission from the seafloor to land (preferably in near real time), a means of remote command and control of seafloor instruments, and ways to facilitate deployment and retrieval of instruments for repair or refurbishment. Ocean scientists today do not customarily consider these factors. They will have to reorient themselves intellectually and innovate technologically.

A CORK (Circulation Obviation Retrofit Kit) sits on a seafloor borehole, measuring subseafloor fluid circulation processes that may affect earthquakes, ore formation, and subseafloor microbial communities.

Different observatories for different missions

In a series of working group meetings in 1998 and 1999, DEOS developed a strategy to pursue two technologically distinct approaches to implement a national seafloor observatory capability:

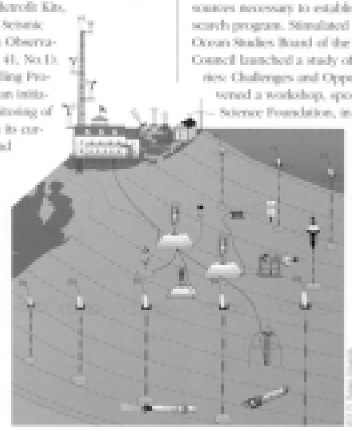
- *Observatories linked by submarine cables to land and the Internet.* These include observatories opportunistically deployed, using retired telecommunications cables that may become available in areas of current scientific interest, such as the Hawaii-2 Observatory (H2O). (See article on page 6.) They also include deploying new cables to create observatories in a few selected locations where interesting Earth and ocean processes are most active and near to land. Examples include the Long-term Ecosystem Observatory (LEO-15, page 28), the planned Martha's Vineyard Observatory (page 30), and NEPTUNE, the proposed North East Pacific Time-series Undersea Networked Experiments (page 10).
- *Moored, buoyed observatories that provide power to seafloor instruments and a satellite communication link to land* (see pages 12 and 17). These would require regular servicing and could be deployed in either of two ways: a) for long terms, to complete the distribution of global imaging observatories, or b) for moderate terms (up to a few years) in locations around the world where process-oriented problems can be investigated without a more extensive installation. Examples include experiments to examine processes that generate earthquakes (seismogenesis) in subduction setting, experiments in remote mid-ocean ridge locations, or experiments to investigate circulation and other physical processes that occur in the ocean.

Both buoyed and cabled technologies could be used for "active-process" observatories. Cabled observatories would be appropriate for long-term installations at selected sites where high amounts of power are needed and large amounts of data are collected. Buoyed observatories would be suitable for shorter-term, less intensive two- to five-year studies. They could be used, for example, to compare processes that occur in hydrothermal vent areas at fast- and slow-spreading ridges, or to study seismogenesis at subduction zones. They would be the principal tool to create a global seismic-wave recording network to "image" Earth's interior (except in the few cases where stations could be accommodated on retired cables).

Coordinating international efforts

Any of the observatory types discussed above—active process and global imaging, cabled and buoyed—may require deploying sensors beneath the seafloor, in the geologic formations where processes actually occur and/or where data quality is best. In many cases, DEOS seafloor observatories will include borehole components, such as CORKs (Circulation Obviation Retrofit Kits, page 14), or the Ocean Seismic Network Ocean Bottom Observatory (see *Oceanus*, Vol. 41, No.1). Notably, the Ocean Drilling Program (ODP) highlights an initiative on Long-Term Monitoring of Geological Processes in its current long-range plan, and DEOS has established strong links to ODP.

DEOS goals also strongly mesh with ongoing international initiatives that require coordinated seafloor observatory capabilities. Prime examples include: the International Ridge (InterRidge) initiative for long-term monitoring of the northern Mid-Atlantic Ridge (MOMAR, or MOnitoring the MAR), international MARGINS initiatives to understand seismogenic zones in subduction settings (SEIZE, or SEIsmogenic Zone Experiments), and International Ocean Network (ION) activities to coordinate global network observatory efforts.



Coastal observatories, like LEO-15 in New Jersey, are linked by submarine cable and augmented by robots, radars and buoyed meteorological sensors.

Bringing ocean science to the public & students

In addition to their scientific value, seafloor observatories with real-time communications capabilities offer an unprecedented opportunity for public outreach and education at all levels. Real-time data links to the deep ocean will allow seafloor instruments to serve as virtual extensions of the Internet and to involve students and the public directly in real science—as it is happening. The public is considerably interested in the remote seafloor in its own right, as well as its potential for learning about life on other planetary bodies. Consequently, DEOS is developing an open data access policy, with plans to devote a significant portion of its budgets to making seafloor data accessible to the public and to educational institutions.

Launching a new observatory initiative

Though DEOS originated in the geoscience community, we eagerly seek to cooperate with all branches of oceanography that share the desire and need to invest in seafloor observatory technologies. In the short term, DEOS aims to achieve broad consensus in the marine geosciences community on the scientific goals and financial resources necessary to establish a formal DEOS research program. Stimulated partly by DEOS, the Ocean Studies Board of the National Research Council launched a study of "Seafloor Observatories: Challenges and Opportunities" and convened a workshop, sponsored by the National Science Foundation, in January 2000, to assess the scientific community's interest. With representatives of all fields of ocean and earth sciences, as well as planetary exploration, we hope to launch the short- and long-term scientific and technological planning that will be required, at both national and international levels, to create a pioneering research program with lasting scientific impact. We believe that ocean observatories are an essential and exciting next step that will allow us to make a scientific quantum leap akin to the plate tectonics revolution. By gaining access to the depths, we can bring understanding of our planet to new heights.

Further information on DEOS, its working group reports, and links to its member initiatives can be found on the Internet at: vertigo.rsmas.miami.edu/deos.html.

A moored buoy observatory has meteorological sensors above the surface and a string of instruments extending into the deep.

Crew members of the University of Washington's R/V Thomas Thompson deploy the junction box that provides electrical outlets for scientific instruments at the Hawaii-2 Observatory (H2O), the first long-term, mid-ocean seafloor observatory. The junction box is spliced to a retired submarine telephone cable, which provides power to the instruments and allows data to be transmitted in real time from seafloor to shore.

Putting H2O in the Ocean

The Hawaii-2 Observatory is the first long-term, mid-ocean seafloor observatory

Alan D. Chave, Senior Scientist, Applied Ocean Physics and Engineering Department, WHOI
Fred K. Duennebier, Professor of Geophysics, University of Hawaii
Rhett Butler, Program Manager of Global Seismographic Network, Incorporated Research Institutions for Seismology

A major obstacle impeding our ability to understand many of the earth's fundamental, ongoing dynamics—quite frankly—has been a dearth of electrical outlets and phone jacks on the seafloor.

On land, scientists have long been able to plug in instruments to take long-term measurements of earthquakes, variations in Earth's magnetic field, and other episodic or continual geophysical processes. However, deploying instruments in the ocean, and on and below the seafloor, presents unique challenges. First, expeditions to remote ocean regions are more expensive and time-consuming, and they depend on the limited availability of ships. Marine scientists also must contend with corrosion problems peculiar to ocean environments. And without those oceanic outlets and phone jacks, scientists have had limited capacities to supply power to instruments and to store data recorded by them out in the middle of the ocean.

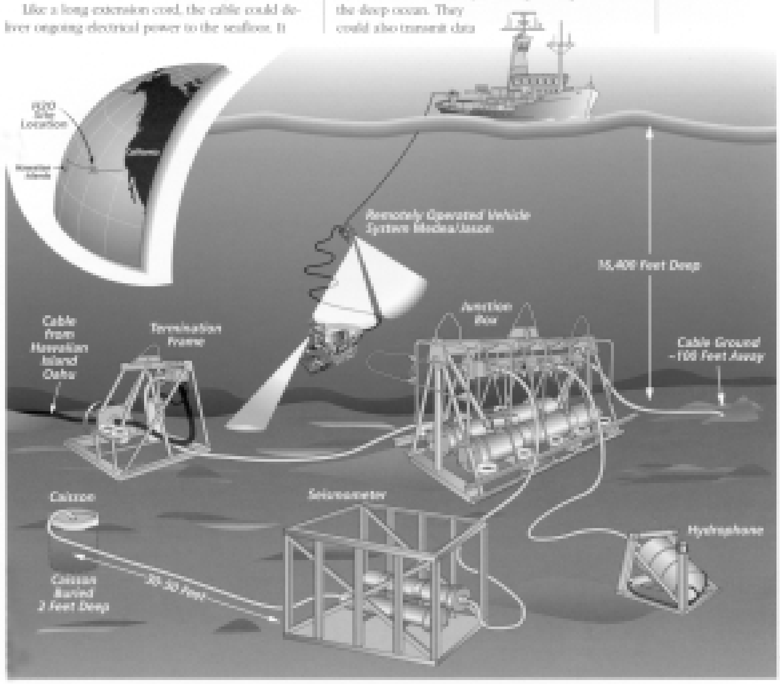
As a result, the record of land-based measurements contrasts starkly with the near-total absence of long-term geophysical data from the seafloor. Since the earth is mostly covered by ocean, that has been like trying to monitor the dynamics of a household, for example, by observing events in only the living room and one bedroom.

But in 1998, we seized an opportunity and took a long-sought, significant first step toward opening the relatively unexplored submerged regions of our own planet to more thorough examination. Beneath 5,000 meters of water midway between Hawaii and California, a submarine telephone cable called HAW-2 (Hawaii-2) stretched across the seafloor. Laid by AT&T in 1964, the cable conveyed trans-Pacific telephone calls until 1989, when it broke near California. Moving toward fiber-optic cable technology, AT&T decided not to fix HAW-2 and donated it to the Incorporated Research Institutions for Seismology (IRIS), a consortium of 91 research centers, for the benefit of the scientific community.

Like a long extension cord, the cable could deliver ongoing electrical power to the seafloor. It could also provide a means for two-way, shore-to-seafloor communications to operate instruments remotely and to get data—both in real time. The combination made the retired cable well-suited for a second productive career. In 1995 the National Science Foundation provided funding to develop the technology to take advantage of HAW-2's potential.

Using corrosion-resistant titanium and plastic, we built a junction box to be spliced into one end of the HAW-2 cable. The junction box was designed to provide six simple wet-mateable connectors, into which scientists could plug standard instruments with existing deep-submergence vehicles. No longer constrained by low power, limited internal data recorders, and temporary deployments, the instruments for the first time would be able to take continuous measurements of slowly evolving Earth processes in the deep ocean. They could also transmit data

WHOI Senior Scientist Alan Chave displays a section of the submarine cable that was cut during the installation of H2O. Below: scientists used the remotely operated vehicles Jason and Medea to splice an abandoned submarine telephone cable into a termination frame, which acts as an underwater phone jack. Attached by an umbilical to a junction box, which serves as an electrical outlet for up to six scientific instruments.



Thomas Thompson crew members prepare to submerge H2O's first "customer," a package of instruments to record earthquake-generated seismic waves.

28 sites identified by the seismological community for an Ocean Seismic Network (OSN) that will fill the wide gaps in the GSN.

Located at 28°N, 142°W, H2O substantially augments seismic coverage of the eastern Pacific for tomographic studies of the earth. It provides a strategic monitoring point for studies of earthquake sources in the United States' most earthquake-susceptible regions: California, the Pacific Northwest, Alaska, and Hawaii. With H2O seismic data transmitted via the submarine cable to Hawaii in real time and available

on rapidly occurring events, such as earthquakes, in real time. In 1998, the dream of the world's first long-term, mid-ocean seafloor observatory became a reality, with the establishment of H2O, the Hawaii-2 Observatory.

H2O was also in a scientifically ideal site to place a high-priority instrument: a seismometer to record seismic waves generated by earthquakes. Seismologists analyze these waves to locate and study earthquake sources. And—much the way physicians use ultrasound and CT (computerized tomographic) scans to obtain images of tissue inside human bodies—seismologists can also examine seismic waves traveling through Earth's layers to glean information about the structure and properties of rocks in ocean crust, and in Earth's inaccessible mantle, outer core, and inner core.

ROV Jason is deployed to plug instruments into the Hawaii-2 Observatory on the seafloor.

The key to improving all these studies is getting more high-quality measurements from more angles. But the current Global Seismographic Network (GSN) has been entirely land-based. To provide more global coverage, some seismometers have been placed on islands, but these are not generally representative samples of oceanic crust and, more important, vast areas of the oceans are islandless. Located 2,000 kilometers from the nearest land, H2O is the first of

immediately via the IRIS Data Management System, seismologists can precisely locate earthquake sources within tens of minutes after a seismic event.

H2O also has a deep-water pressure gauge to aid research on tsunamis, large waves generated by earthquakes in the open ocean. Tsunamis caused by earthquakes from the Gulf of Alaska to Central America can be recorded at H2O 30 minutes to two hours before they arrive in the Hawaiian Islands, so H2O eventually may be incorporated into tsunami warning networks.

H2O's enhanced global coverage also offers an advantage for studies of another global phenomenon—geomagnetism. Its power and communications capacities open up new opportunities for creative approaches by physical oceanographers, marine biologists, and other marine scientists.

Anticipating that H2O would be a prototype for future seafloor observatories, we aimed to make H2O as simple and cost-effective as possible to use and deploy. An initial requirement was designing a seafloor system that could be installed using a conventional oceanographic ship, rather than a specialized cable ship.

In September 1998, aboard the University of Washington's R/V *Thomas Thompson*, a survey showed that the proposed site to install H2O was clear of rock outcrops and other topographic complications and well-suited for an observatory. *Jason*, the remotely operated vehicle (ROV) operated by WHOI's Deep Submergence Laboratory, was deployed to find the 1¼-inch-wide cable on the seafloor. *Jason* followed the cable for 5,000 meters (one water depth from ship to seafloor) toward California and severed it using a special hydraulic cable cutter. This was done so that equal lengths of cable would hang from either side of an 800-pound grapnel lowered from the ship to snag and retrieve the cable—just the way you would pick up and balance a strand of spaghetti on a fork tine. Six miles of cable dragged through water put a load on the ship's wire and winch that approached their working limit of 24,000 pounds, and retrieval took nearly a day. Personnel from WHOI and Margus Inc., a commercial submarine cable company, accomplished the cable recovery.

Margus personnel spliced the HAW-2 cable to a corrosion-resistant "termination frame," which links via a short cable to the junction box. The system was designed to allow the junction box to be lowered separately to the seafloor during installation and to be retrieved for repair or improvements without the complications of dragging up the cable again.

The system was powered up from an AT&T cable station in Makaha, Hawaii, and for the first time in nine years, HAW-2 was operational.

After several days of testing the system, the termination frame and attached cable were lowered on a trawl wire for deployment on the seafloor—or, at least, that was the plan. The frame was barely over the side when the half-inch chain securing it to the trawl wire snapped, sending cable and frame to the bottom. Expecting the worst, we launched *Jason*'s mechanical teammate, *Medea*, to locate and inspect the damage. Tethered to the ship, *Medea* is a platform that separates *Jason* from the ship motion, allowing the ROV to maneuver more freely. It also has a wide-area camera and lights.

Fortune smiled. The cable was lying in loops 300 meters in diameter, but flat on the seafloor, so that *Jason* could be used without risk of entanglement. At the edge of the coils, the termination was sitting upright, intact, and not embedded in sediments. After powering up the cable, the system was found to be undamaged—though its planned location had abruptly moved about 2 kilometers closer to Hawaii. Installation of the junction box could proceed.

The junction box consists of a protective frame enclosing vulnerable equipment within. The equipment includes a manifold with the eight connectors (one each for the termination frame and a sea ground, and six for scientific instrument packages). The connectors are designed to be plugged in with standard ROV manipulator arms. The frame also encloses two cases designed to withstand deep-sea pressure. One case contains a system developed and built by University of Hawaii engineers to extract and control power from the cable. The other case contains the communication and control system, designed and built by WHOI engineers, that is the heart of the junction box.

The complex system of switches, modems, and computers allows scientists onshore to monitor and adjust individual instruments. It routes signals into and out of individual instruments, ensuring that data streams do not get muddled even though all signals eventually must travel via a common channel through the submarine cable to and from Hawaii. The system is designed with a great deal of redundancy and switching flexibility to keep it operational without making expensive mid-ocean service calls.

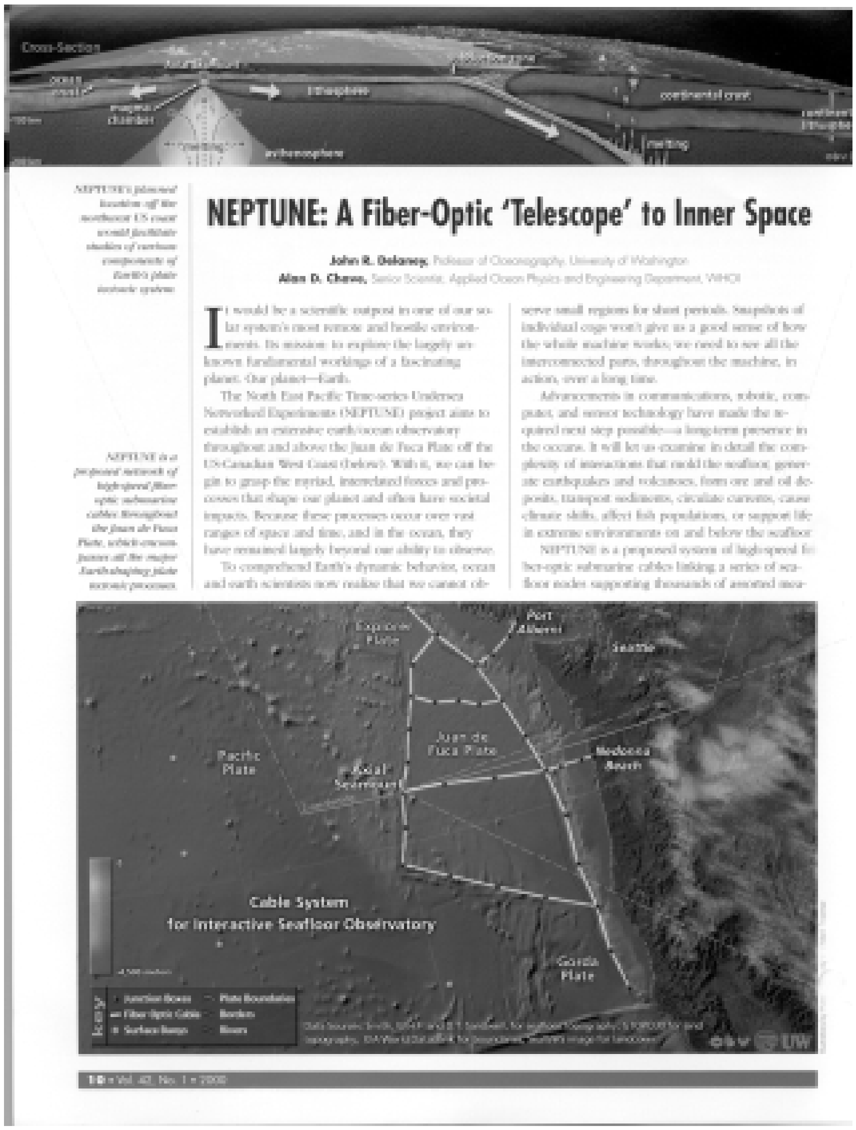
The junction box was lowered to the seafloor and *Jason* plugged the system together. The ability to retrieve the junction box separately came in handy immediately when it failed after just 12 hours. It was unplugged and retrieved by *Jason* and *Medea*, repaired aboard *Thompson*, and redeployed and reconnected two days later.

Jason plugged in H2O's first instrument, a multisensor seismo-acoustic package designed and built at the University of Hawaii. Then the ROV buried the seismometer sensor package in a seafloor hole to minimize distorting vibrations from currents. Data began to flow to Makaha, where communications equipment had been modernized and other equipment (salvaged from another retired trans-Pacific cable system from Guam to Japan) was added to provide a mirror image of the H2O junction box on shore.

After H2O had been operating for two months, a water current meter failed and corrupted the seismic data, necessitating a maintenance visit in September 1999. Once again, the system allowed *Jason* to unplug and retrieve the seismometer system for repair and the junction box for an upgrade without touching the main cable itself. The systems were redeployed and plugged in, as before. Four Benthos hydrophones, to measure pressure variations of seismic waves in water, were plugged into another of the junction box's connector ports.

Four more ports are available, and IRIS and NSF welcome interest in deploying new scientific sensors at H2O. Interested parties may contact the authors. Further information may be obtained from the H2O Web site at: www.whoi.edu/science/GG/DSO/H2O/.

WHOI Research Engineer Bob Petitt designed and built the complex communication and control system that routes signals into and out of individual instruments plugged into H2O. Above, Petitt tests the system with a call from R/V Thompson through the submarine cable to WHOI Senior Engineer Assistant John Bailey at the cable's terminus, a shore-based station in Makaha, Hawaii.



NEPTUNE's planned location off the northwest US coast would facilitate studies of various components of Earth's plate tectonic system.

NEPTUNE: A Fiber-Optic 'Telescope' to Inner Space

John R. Delaney, Professor of Oceanography, University of Washington
Alan D. Chave, Senior Scientist, Applied Ocean Physics and Engineering Department, WHOI

It would be a scientific outpost in one of our solar system's most remote and hostile environments. Its mission: to explore the largely unknown fundamental workings of a fascinating planet. Our planet—Earth.

The North East Pacific Time-series Undersea Networked Experiments (NEPTUNE) project aims to establish an extensive earth/ocean observatory throughout and above the Juan de Fuca Plate off the US-Canadian West Coast (below). With it, we can begin to grasp the myriad, interrelated forces and processes that shape our planet and often have societal impacts. Because these processes occur over vast ranges of space and time, and in the ocean, they have remained largely beyond our ability to observe.

To comprehend Earth's dynamic behavior, ocean and earth scientists now realize that we cannot observe small regions for short periods. Snapshots of individual cogs won't give us a good sense of how the whole machine works; we need to see all the interconnected parts, throughout the machine, in action, over a long time.

Advancements in communications, robotic, computer, and sensor technology have made the required next step possible—a long-term presence in the oceans. It will let us examine in detail the complexity of interactions that mold the seafloor, generate earthquakes and volcanoes, form ore and oil deposits, transport sediments, circulate currents, cause climate shifts, affect fish populations, or support life in extreme environments on and below the seafloor.

NEPTUNE is a proposed system of high-speed fiber-optic submarine cables linking a series of seafloor nodes supporting thousands of assorted mea-

NEPTUNE is a proposed network of high-speed fiber-optic submarine cables throughout the Juan de Fuca Plate, which encompasses all the major Earth-shaping plate tectonic processes.

suring instruments, video equipment, and robotic vehicles that could upload power and download data at undersea docks. Unlike conventional telephone cables, which supply power from shore in a straight line, end to end, NEPTUNE would operate like a power grid, distributing power simultaneously and as needed throughout the network. Working much like a campus data network (with nodes analogous to buildings and each instrument like a workstation), NEPTUNE would provide real-time transmission of data and two-way communications.

Bringing the power of the Internet to the seafloor, it would connect submarine experiments directly to scientists in their labs, where they could monitor and adjust instruments or dispatch robots to capture episodic events that now occur unnoticed. NEPTUNE's Internet accessibility also offers intimate, over-the-shoulder views of exploratory science in action that would engage the general public and educate students of all ages.

The Juan de Fuca Plate's proximity to shore and relatively small size make it a cost-effective candidate for incremental but eventually extensive cabling. Yet it encompasses all the major Earth-shaping plate tectonic processes, including submarine volcanism, earthquake activity, hydrothermal venting, seafloor spreading, and subduction. At its coastal edge, instrument arrays also could open new windows onto poorly understood processes that transport sediments from continents to the deep sea, that create energy resources such as oil and gas, or that affect delicately balanced coastal ecosystems.

Oceanographic instruments could shed light on ocean dynamics that affect weather and climate. Still other devices could track the ever-shifting population dynamics and migrations of the Pacific Northwest's great fisheries—offering better management strategies for this crucial, threatened resource.

We envision NEPTUNE as a national facility for many types of innovative ocean and planetary investigations that would engage the imaginations of researchers across a spectrum of scientific disciplines. One example—combining geology, chemistry, biology, and oceanography—is the recent discovery that erupting seafloor volcanoes release pulses of chemical nutrients, resulting in "blooms" of microbes that form the base of a submarine food chain. Hydrothermal vents may be "the tips of icebergs" for substantial subseafloor, high-temperature microbial communities, with potential biomedical properties.

Studies of these microbes offer insights into the origin of life on our planet and the possibility of life on other solar bodies, such as Europa, a moon of Jupiter, where similar submarine volcanic systems may exist. NEPTUNE would drive improvements in deep submergence technology and provide an unparalleled testbed for robotic exploration of extreme environments on other planetary bodies.

For roughly half the $280 million price tag to develop, launch, and operate the Mars Pathfinder mission, NEPTUNE would be a worthy investment in exploration of our own living planet.

Further information is available on the Web at: www.neptune.washington.edu.

The NEPTUNE system would link a series of seafloor nodes supporting thousands of assorted instruments.

Seafloor to Surface to Satellite to Shore

Moored buoys offer potential for continuous, real-time observations anywhere in the ocean

Robert S. Detrick, Senior Scientist, Geology and Geophysics Department, WHOI
John A. Collins, Associate Scientist, Geology and Geophysics Department, WHOI
Daniel E. Frye, Senior Research Specialist, Applied Ocean Physics and Engineering Department, WHOI

The next great leap in our understanding of the earth-ocean system will require us to put out "eyes" and "ears" in the ocean to observe the dynamic processes going on there as they are happening, in real time. In the oceans, physical, chemical, biological, and geological processes are continually interacting—over time scales ranging from seconds to millions of years and on space scales ranging from centimeters to the globe.

A key new tool to untangle these complex interactions will be ocean observatories, with sensors taking measurements in the water column, on the seafloor, and in the earth below. These observatories will require two-way communications capabilities to remotely control instruments and to transmit data in real time back to shore. And they will have to provide power to operate instruments unattended for months or years at a time.

The ability of buoyed observatories to make long-term measurements of ongoing processes anywhere in the world's oceans gives them the potential to play an important role in oceanographic and climatic studies.

The Dynamics of Earth and Ocean Systems (DEOS) program (see article on page 2) is exploring two technologically distinct approaches for seafloor observatories. The first entails using dedicated cables to link observatories to shore (such as the LEO-15, Martha's Vineyard, H2O, and NEPTUNE projects described elsewhere in this issue). The second involves linking observatories to moored buoys on the ocean surface and transmitting data back to shore via a constellation of Earth-orbiting telecommunications satellites.

Moored ocean buoy observatories have certain advantages. They can be located in very remote ocean areas, far from land, where the cost of laying a fiber-optic cable would be prohibitive. They are also portable and potentially could be used for shorter-term (two- to five-year) studies in one area, and then moved to a new location. This provides greater flexibility, as circumstances change, to reconfigure experiments that track processes continuously over long time periods. It also gives scientists the ability to respond in time to observe transient natural events, or even relocate to a new site, as their knowledge of an area increases incrementally over the course of a study.

Moored buoys, however, have certain limitations. They can't supply as much power to instruments as a fiber-optic cable can, and they can't transmit as much data via satellite. They also require more frequent servicing.

Moored buoy systems have been deployed in the deep ocean since the 1950s as platforms to acquire meteorological and oceanographic data in the upper ocean (see article on page 20), but they have not been used for seafloor observatory studies. So important design questions remain: What is the optimal buoy shape (spar- or disk-shaped floats)? What is the best mooring design (single-point or three-point)? What is the best way to isolate the electromechanical cable connecting the buoy to the seafloor from wave and current motion? How can maintenance costs be curtailed?

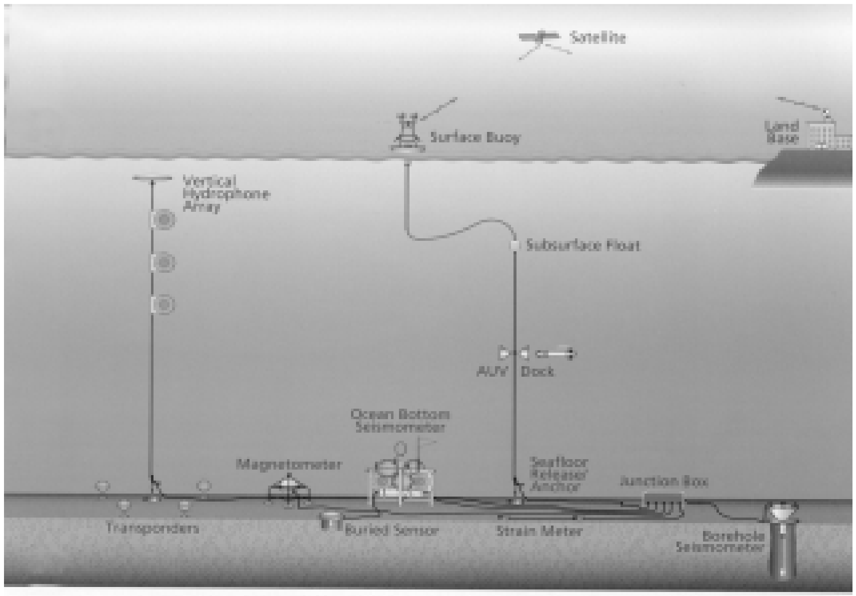
We are currently working with colleagues at the Scripps Institution of Oceanography and the Monterey Bay Aquarium Research Institute, and with a partner from industry, Deep Oil Technology, to design and build a prototype moored ocean buoy seafloor observatory for use in the deep ocean.

One design under study (right) consists of a large (4 to 6 meters in diameter) discus-shaped buoy on a single S-tether mooring, connected to an array of sensors on the seafloor. The S-tether mooring design, developed at WHOI in the early 1980s, combines the advantages of a subsurface mooring (isolation from surface waves and currents, durability and long life, and low cost) with the capabilities of a surface mooring (access to satellite telemetry and a platform for power generation).

It would consist of a surface float, a subsurface float, an "S"-shaped cable connection between the surface and subsurface floats, a standard mooring from the subsurface float to a seafloor anchor, and an on-bottom segment from the mooring to a seafloor junction box.

A variety of sensors (thermistors, flow meters, chemical sensors, seismometers, magnetometers, hydrophones, strain meters) could be plugged into the junction box. The box would transmit power from the surface buoy to these instruments through a double-armored, multi-conductor cable. Data from seafloor sensors would be transmitted up the cable to the surface float for transmission back to shore.

The electromechanical cable would connect to a large subsurface float—a sphere made of buoyant



syntactic material to support the weight of 3,000 meters of cable. A fluid-filled, stretchable rubber hose with an integral coil of electrical conductors would connect the subsurface and surface floats. By carefully distributing flotation along the upper cable section, we can maintain an "S"-shaped tether to effectively isolate the subsurface float from the motion of the surface buoy.

The surface float would be made of a Surlyn foam that is frequently used in marker or navigation buoys in shallow waters. It combines durability, light weight, and low cost. Solar panels, diesel generators, and batteries mounted on the buoy could provide up to 500 watts of continuous power to instruments on the seafloor. An omni-directional antenna atop the buoy would provide bi-directional communication via satellite to shore. We anticipate that a system like this would require annual servicing.

A moored ocean buoy observatory of this design could be used in a variety of experiments requiring long-term observations and real-time data telemetry. For example, a buoy observatory moored over a volcanically active section of the East Pacific Rise or Mid-Atlantic Ridge could monitor all the dynamically interacting volcanic, hydrothermal, and biological processes that occur over two or three years.

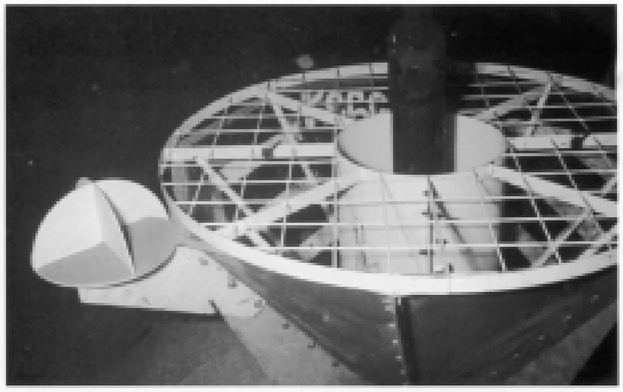
Autonomous underwater vehicles (AUVs) could be stationed at a mooring. On command from shore, these AUVs could resurvey the surrounding area and upload their observations to the buoy for transmission back to shore.

Other buoys could be permanently deployed at some of the 20 strategic (and remote) ocean sites needed to fill large gaps in the global network of broadband seismic stations, greatly enhancing our ability to use seismic waves to image the earth's internal structure. To study processes that generate earthquakes, buoy-based observatory systems linked to an array of seismic and geodetic sensors could be placed in earthquake-prone geological locales—along an ocean transform fault or above a subducting plate landward of an oceanic trench, for example.

The ability of buoyed observatories to make long-term measurements of ongoing processes anywhere in the world's oceans also gives them the potential to play an important role in other oceanographic and climatic studies. They could track the flow of major currents along the oceans' western boundaries or episodic upwelling of water and nutrients at eastern ocean boundaries. They could also be used for experiments using sound waves to monitor ocean temperature changes related to global climate change.

Our research is supported by the National Science Foundation.

In this prototype design for a moored buoy system, a surface buoy connects to an "S"-shaped tether that isolates a subsurface float from surface buoy motion. The surface buoy provides power via a cable to a seafloor junction box that accommodates a variety of sensors. Data from the sensors travel up the cable to the surface buoy for transmission via satellite to shore.



The Ocean Drilling Program's drill ship (left) has deployed several "CORK" observatories in seafloor boreholes to study the circulation of subseafloor fluids (see map below), including the one above in Hole 858G off the Pacific Northwest coast

Plugging the Seafloor with CORKs

A window into the plumbing system hidden beneath the ocean's floor

Keir Becker, Professor, Rosenstiel School of Marine and Atmospheric Science, University of Miami
Earl E. Davis, Senior Research Geophysicist, Pacific Geoscience Centre, Geological Survey of Canada

Hidden beneath the seafloor throughout most of the world's oceans lies a massive, dynamic plumbing system that is a central component of our planet's inner workings.

Heated and under pressure, seawater and other fluids flow and percolate up, down, and through myriad layers of subseafloor rock formations. At volcanically active mid-ocean ridges, where hot magma rises from the mantle to create new seafloor, this circulation vents heat from the earth's hot interior. It plays an important role in regulating the chemical balance of the oceans and in forming huge ore deposits. At subduction zones, where old seafloor collides with an overriding tectonic plate and sinks back down to the mantle, fluid pressures within subseafloor formations are believed to be an important factor in triggering many of the world's largest and most damaging earthquakes. Fluid flow beneath the seafloor also may help create the conditions that allow vast microbial communities to thrive in subseafloor formations. And it affects the migration of oil and gas and the formation of another common, potentially energy-producing hydrocarbon: gas hydrates. These are ice-like deposits of crystallized methane and water that form under higher pressures and frigid deep-sea temperatures.

Though we know that fluid flow beneath the ocean basins is fundamental and important, our ability to study conditions and processes that occur beneath the seafloor has been limited. To gain a window onto this relatively inaccessible domain, we took advantage of holes drilled deep into the ocean bottom by the international Ocean Drilling Program (ODP). The drilling thus did double duty—extracting scientifically valuable seafloor specimens, while simultaneously giving us an entryway for hydrologic experiments within subseafloor formations.

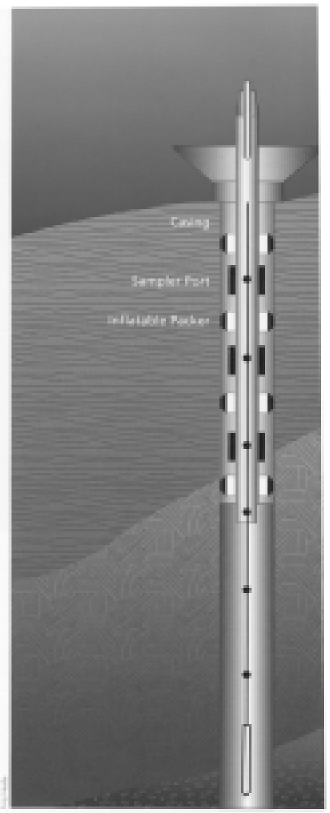
In a previous issue of *Oceanus* (Vol. 36, No. 4) we reported on our early efforts to seal two ODP holes and install instruments in them to create long-term observatories to investigate subseafloor fluid circulation. We called these observatories "CORKs" for Circulation Obviation Retrofit Kits, playing on the obvious analogy of a cork sealing a bottle. For our studies, we had to reseal boreholes because ODP holes left open act as shunts between the oceans and subseafloor formations and disrupt natural hydrological processes. Within the resealed holes, we suspended strings of sensors that were linked to a long-term data logger on the seafloor that could be accessed with a human-occupied or remotely operated vehicle. To date, our sensor strings have been relatively simple. They have included one pressure gauge at the seafloor and one in the sealed hole, temperature sensors distributed down within the holes, and, in some instances, fluid sampling devices near the bottoms of the holes.

Our initial installations were quite successful, and we and our growing group of CORK collaborators have gone on to deploy similar instrumentation in a total of 11 sites (see map opposite) in three representative types of seafloor hydrological environments: spreading centers, where new seafloor is spreading outward from mid-ocean ridges (ODP Holes 857D and 858G), young mid-ocean ridge flanks (395A, 1024C, 1025C, 1026B, 1027C), and accretionary prisms, where sediments scraped off descending seafloor plates accumulate in front of overriding plates, like debris in front of a locomotive's cowcatcher (889C, 892B, 948D and 949C). The CORK program has been an important contribution toward fulfilling the initiative, highlighted in ODP's current Long-Range Plan, for long-term in situ monitoring of geological processes. We gratefully acknowledge solid, forward-looking support from our funding agencies: the National Science Foundation, the Geological Survey of Canada, and the French Institute of Research and Exploration of the Sea (IFREMER), as well as ODP's planning body, the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES).

We emphasize the words "forward-looking," because the CORKs, like other observatories discussed in this issue, require investments not only in equipment and infrastructure, but also in time. They require waiting, possibly for years, before significant results become available. But eight years have now passed since our initial installations, and we have accumulated a growing body of important findings. They are collected in a recent workshop report available on the Internet site of the JOIDES Long-Term Observatories Program Planning Group (vertigo.rsmas.miami.edu/ltoppg.html). Among our more important findings, we have shown that:

- High fluid pressures can build up in the decollement, or plate boundary fault, at subduction zones (Hole 949C in the Barbados prism). This fluid pressure surely is a factor in the genesis of earthquakes that are so common in subduction zones.
- Fluids—driven by small pressure gradients—circulate laterally over many kilometers through the very highly permeable sediments of young oceanic crust in upper "basement" formations beneath the seafloor. This finding gives us a first glimpse of the mechanics of the subseafloor plumbing system, which, among other things, may prove important to vast subseafloor microbial ecosystems.
- Tides in the ocean exert periodic loads on the seafloor that propagate down into sediment and rock layers beneath the seafloor to varying degrees depending on the hydrological and elastic properties of the formations. This unexpected tidally driven flow in the subsurface may play an important role in regulating important subseafloor chemical interactions between fluids and rocks and in maintaining an environment to host microbiological communities. It could also mean that subseafloor formations serve to dissipate a modest amount of tidal energy.

CORKs may represent the best option for in situ sampling of fluids below the seafloor, which has



A new generation of Advanced CORKs will be deployed starting in 2001. These will have inflatable packers that isolate separate zones in subseafloor formations so that different processes occurring within each zone may be identified.

Aboard the ODP drill ship JOIDES Resolution, roughnecks position a CORK observatory on a long segmented drill pipe leading to a borehole in the seafloor.

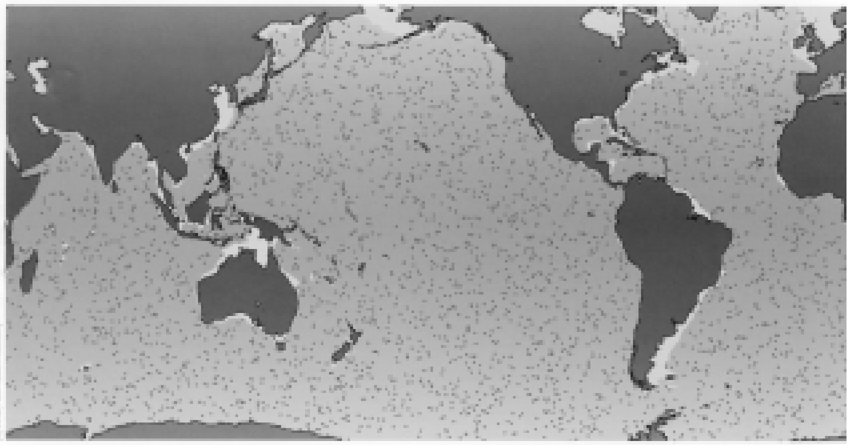
proven very elusive to date. Five of the CORKs presently deployed include long-term self-contained fluid samplers suspended within the sealed holes to sample formation fluids (as opposed to the seawater used in the drilling process). Four were just recovered this past September using WHOI's submersible *Alvin* and the wireline Control Vehicle of Scripps Institution of Oceanography's Marine Physical Laboratory (MPL). With access to the sealed holes via a valve at the seafloor, our installations are also excellent for setting up long-term experiments to produce and sample subseafloor formation fluids. Our experience now allows us to predict in which settings sealed holes are likely to produce fluids naturally. In other cases we can take advantage of what we have learned about tidal effects on subseafloor fluid flow to produce subseafloor fluids at the valves.

We are gratified at the success of the CORK effort, and are particularly excited to be involving a widening circle of collaborators, ranging from physical oceanographers interested in our deep ocean tidal records to microbiologists interested in microbial systems hosted within the subseafloor formations that we access with the CORKs. However, we recognize that the 1991–1997 CORK design has a key scientific limitation: Until now, our design incorporated a single seal near the top of the hole, and thus our sensors integrate signals from the full range of formations that the hole penetrates beneath the seafloor. But in reality, subseafloor formations are not uniform. Our results and many other lines of evidence clearly indicate that permeability and fluid flow in various subseafloor formations varies because of intrinsic permeability differences in formations or because flow is channeled in discrete faults and fractures.

CORK assemblies await deployment aboard JOIDES Resolution.

So we have proposed a new generation of "Advanced CORK" observatories starting with deployments planned for 2001. The next major advances in our understanding of subseafloor hydrology will come not only from expanding the range of in situ measurements and sampling devices incorporated in our sensor strings, but also and more importantly, from incorporating a capability to isolate many separate zones within the subseafloor formations and take measurements in each of them (see diagram, page 15).

Our funding agencies and JOIDES support this strategy, and we are simultaneously developing two technological approaches to implement this multi-sealing capability: a multi-packer instrumented casing system deployed by the ODP drill ship, and a wireline instrumented multi-packer system deployed by the MPL Control Vehicle. The first deployments of the former are scheduled for spring 2001 on ODP Leg 196 in two holes in the Nankai Trough subduction system off Shikoku Island, Japan (site of the Kobe earthquake). First deployments of the latter are scheduled for winter 2001 in a pair of existing young crustal holes in the Panama Basin (504B and 896A).



Launching the Argo Armada

Taking the ocean's pulse with 3,000 free-ranging floats

Stan Wilson, Deputy Chief Scientist, National Oceanic and Atmospheric Administration

The Argo program proposes to disperse 3,000 floats, like the one below, throughout the oceans to collect data on oceanic conditions that can be periodically transmitted to shore via satellite.

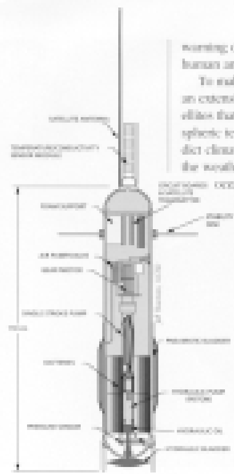
Will winter this year be colder and snowier than usual? Should farmers anticipate droughts or floods next spring? Will the fall hurricane season likely be more or less fierce? Should officials conserve water, stock up on fuel, or import grain now to prepare for potential climate conditions a few months hence?

We are on the brink of being able to answer those questions with a high degree of accuracy. But to do that, we can't just look to the atmosphere. We need to look to the ocean.

Over the past decade, our evolving understanding of the El Niño/Southern Oscillation (ENSO) has revealed how the ocean and atmosphere are intimately linked in a dynamic exchange of heat, moisture, and momentum that generates our climate. But while fast, ephemeral phenomena in the atmosphere produce storms, cold snaps, tornadoes, and other day-to-day events that comprise the weather, the oceans move at a much more lumbering pace. By storing and transferring vast amounts of heat around the planet, the oceans create the underlying conditions that—over seasons, years, or even decades—make broad global patterns of rainfall, winds, storms, and atmospheric circulation more or less likely to occur.

With ever-increasing accuracy, meteorologists have been able to produce three- to five-day weather forecasts. That helps one decide whether to carry an umbrella on Tuesday. But South American farmers—wavering between planting rice (which requires lots of water) or cotton (which doesn't)—would profit greatly if they knew that the coming growing season on average would likely bring more or less rainfall.

The best efforts of humankind have always been humbled by the unexpected vicissitudes of our planet's climate. Droughts cause famine, forest fires, epidemics, mass migrations, even wars. Floods, extended heat waves and cold periods, and other short-term climate shifts wreak their own havoc. Oceanic shifts by themselves can dramatically affect fish populations, disrupting an important industry and food source. In all these cases, a little advance



Above, the principal components of an Argo float. Each float sinks to depths of 2,000 meters, drifts with ocean currents for ten days, rises to the surface taking measurements along the way, and then transmits data back to shore via satellite.

warning offers a potential means to reduce or avoid human and economic devastation.

To make their forecasts, meteorologists rely on an extensive network of land-based stations and satellites that collect daily measurements of atmospheric temperatures, humidity, and winds. To predict climate as accurately as we now can forecast the weather, we require a network to monitor global ocean conditions as thoroughly as we monitor worldwide atmospheric conditions.

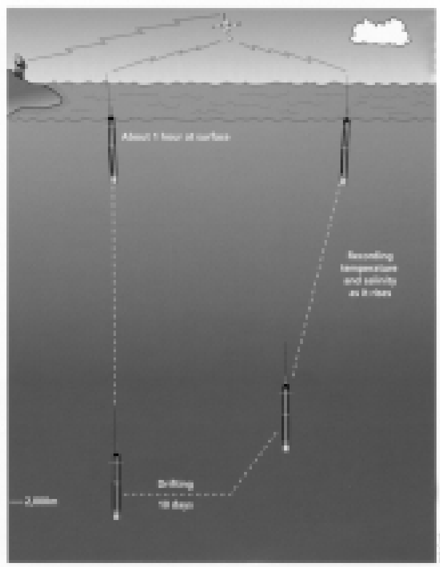
That's the motivation for the Argo program—a Johnny Appleseed-like proposal conceived by an international team of scientists to disperse 3,000 floating buoys throughout the world's oceans. Equipped with sensors to monitor fluctuating temperature and salinity in the upper layers of the ocean, Argo buoys will relay data via orbiting satellites in near real time to shore-based laboratories. Together with satellite and other available data, the Argo observations will be used to make "weather maps" of the ocean, to feed computer climate forecast models, and to improve our understanding of the ocean itself.

Argo is the result of more than two decades of research and development in float technology sponsored by the National Science Foundation (NSF) and the Office of Naval Research (ONR). In the United States, scientists and engineers at Woods Hole Oceanographic Institution, Scripps Institution of Oceanography, and Webb Research Corporation in Falmouth, Massachusetts, have led efforts to design, build, and test the floats. They are designed to sink to depths of 2,000 meters (slightly more than a mile), drift with ocean currents at that depth for ten days, and then rise to the surface, measuring the temperature and salinity of ocean layers along the way up. On the surface, the floats radio their data and positions to satellites before returning to depth and continuing another cycle (see diagram, right).

The satellites will relay Argo data to land-based receiving stations and then to scientists and forecast centers in near real time. The data will be openly available, without proprietary restrictions.

Computer model simulations have shown that the floats will not clump, but rather will go with the ocean's flow, maintaining a separation of a few hundred kilometers from each other (see diagram on page 17). Argo floats can be dropped overboard by hundreds of commercial vessels that ply trading routes across the globe, or parachuted by airplanes to seed remote ocean regions (see photos, opposite). They can continue to operate unattended over a design life of four to five years.

Argo was the ship of the mythological Greek hero Jason, and the program's name stresses the close connection between the floats and the Jason-1 satellite, a collaboration between the National Aeronautics and Space Administration (NASA) and the Centre National d'Études Spatiales (CNES, the French Space Agency). Jason-1 will be launched late this year to continue measurements of global sea level initiated by the NASA/CNES TOPEX/Poseidon satellite in 1992. Other satellites operated by NASA, the Japanese Space Agency, and the National Oceanic and Atmospheric Administration (NOAA) measure sea surface temperatures and the speed and di-



Argo floats (like the prototype shown in the Labrador Sea) can be deployed by ships, or parachuted by airplanes (below) to seed more remote ocean regions.

rection of winds blowing over the oceans. These satellites will complement the Argo floats, which, unlike the satellites, can observe beneath the surface.

Subsurface measurements are essential because the ocean's upper layers can store 1,000 times more heat than the atmosphere does. Changes in subsurface currents, temperature, and salinity eventually change conditions at the surface, where the ocean interfaces with the atmosphere.

When an El Niño occurs, for example, a great mass of warm water, usually pooled in the western Pacific, spreads eastward, accumulating off the west coast of the Americas. At the same time, prevailing trade winds diminish, rearranging global atmospheric circulation patterns and worldwide weather. Rain clouds, for example, accompany the warm waters eastward, taking rain from places where it is expected and dropping it unexpectedly in others.

As recently as 1982, scientists were unaware that one of the most powerful El Niños of the century was forming with inevitable and catastrophic momentum. It sparked climatic changes that caused devastating droughts and fires in Australia, flooding in normally arid regions of Peru and Ecuador, unusual storms that rearranged California beaches, and widespread mortality of fish and bird life. All told, it led to thousands of deaths and an estimated $13 billion in damage.

In the aftermath of this disastrous El Niño, NOAA, NSF, and international partners began to deploy an extensive observing system—moored instruments, surface drifting buoys, and Volunteer Observing Ships—to monitor oceanic conditions spanning 10,000 miles of the equatorial Pacific. These complement NASA, NOAA, French, and Japanese satellites that track shifting winds and sea levels. Completed in 1994, this ENSO Observing System provides a continuous stream of real-time observations to forecast the development, strength, and duration of El Niños and La Niñas, a cooling of eastern Pacific waters that sometimes follows an El Niño episode and causes its own set of weather conditions.

The monitoring system provided advance warning of the powerful 1997–98 El Niño, which helped save an estimated $1 billion in California alone.

Building on this success in unraveling ENSO, meteorologists and oceanographers have begun to identify a host of other ocean-atmosphere oscillations operating in the earth's climate system: the North Atlantic Oscillation, the Arctic Oscillation, the Antarctic Oscillation, the Pacific Decadal Oscillation, the Indian Ocean Dipole, and the Antarctic Circumpolar Wave. Shifting over months or decades, each is associated with different climate changes in different parts of the globe in quasi-periodic, but potentially predictable ways.

The Argo program offers a means to gather the consistent, long-term, observations within the upper layers of the global ocean needed to reveal the ocean's role in these newly identified climate oscillations and to incorporate their effects into climate forecasts. Once fully deployed, Argo and its satellite partners will give us for the oceans what meteorologists have had for the atmosphere—a worldwide observing network and the potential to forecast our climate six to 12 months in advance.

More information on the Argo program is available at: www.argo.ucsd.edu.

A WHOI moored surface buoy equipped with meteorological and underwater sensors is deployed in the eastern tropical Pacific Ocean from Scripps Institution of Oceanography's R/V Roger Revelle. Fixed in strategic ocean locations, surface and subsurface moored observatories (see diagram opposite) can track oceanic processes and air-sea interactions that influence Earth's climate.

Outposts in the Ocean

A global network of moored buoy observatories to track oceanic processes that affect our climate

Robert Weller, John Toole, Michael McCartney, and Nelson Hogg
Senior Scientists, Physical Oceanography Department, WHOI

Oceanographers and climatologists have something in common with politicians and stock market analysts: They are all trying to get a grasp on a complex, ever-shifting system.

To gauge the ebb and flow of public opinion, politicians today are constantly polling constituents. To track fluctuating financial markets, analysts receive a continual flurry of global economic data and information on companies and markets.

For oceanographers and climatologists, one of the most urgent goals is unraveling the ocean's crucial role in shaping our climate. To predict climate changes or extreme weather events that may have potential societal impacts, scientists desperately need the same sort of detailed, ongoing information that politicians and economists have to investigate their systems.

Specifically, oceanographers require long-term measurements to understand processes and changes that occur in the oceans over seasons, years, decades, or longer. Among the important climate questions oceanographers seek to answer are these: How does the ocean store and transport vast amounts of heat and fresh water around the globe? How do the ocean and atmosphere exchange heat, fresh water, and momentum? How are changes in ocean temperatures and salinity, ocean circulation, and climate all interrelated? Are long-term changes in the oceans naturally occurring, or are they the result of human activities, such as the buildup of greenhouse gases in the atmosphere?

Today, the world's oceans are sparsely observed. Oceanographers lack the means to gather the fundamental measurements they need to examine their system—putting scientists in the position of working on mysteries without many essential clues.

But a major effort is under way to establish a Global Ocean Observing System (GOOS)—a worldwide network that would collect the vast, far-flung, ever-changing data necessary to understand the processes by which the oceans help create climate conditions. GOOS would combine a variety of instrumentation. It would include satellite systems providing global coverage of the ocean surface, flotillas of oceanographic instruments drifting throughout the oceans, and autonomous ocean observatories moored at strategic sites in the ocean.

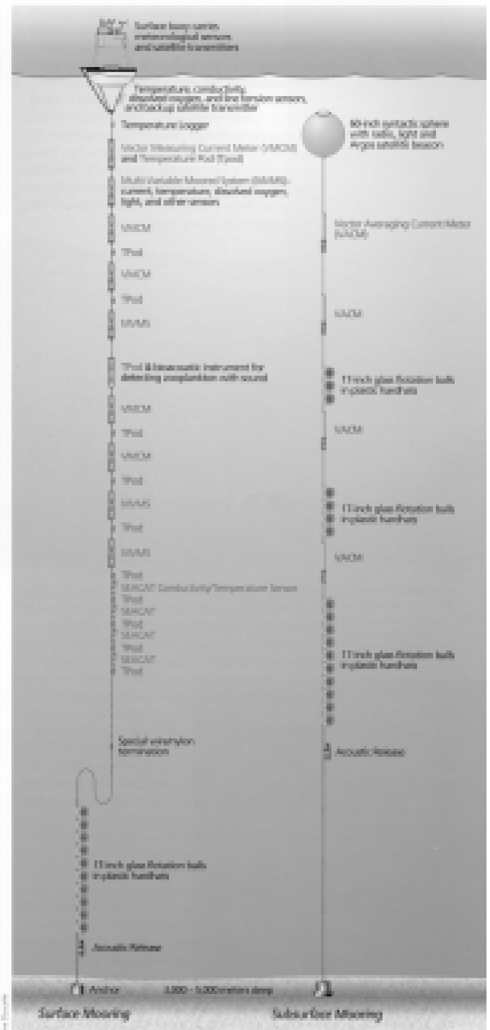
Fixed observatories moored at key geographic sites around the globe are unique in this mix of instrumentation because they can provide highly detailed observations of atmospheric processes just above the sea surface, as well as oceanographic measurements from the seafloor to the sea surface. Measurements collected at fixed sites over long time periods are particularly important for oceanographers trying to understand air-sea interactions, as well as relatively slow-evolving oceanic processes.

In the past, a network of ocean weather stations (OWSs) provided a treasure trove of data for oceanographers and played an essential role in early efforts to build initial understanding of how the ocean changed over time and how it responded to, and in turn influenced, atmospheric changes (see Oceanus, Vol. 39, No. 2). Primarily to guide trans-ocean-voyaging aircraft after World War II, the US and four other countries established 13 sites in the North Atlantic and the Pacific Oceans (labeled alphabetically, starting with "A") that were constantly occupied by ships. Planes would check in with ships to receive a position and weather data. Ship crews used weather balloons to gather air temperature, humidity, pressure, and wind direction and speed, and, while on site, they also collected a wealth of oceanographic measurements.

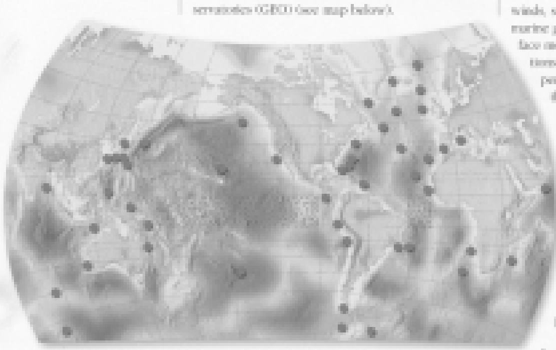
Unfortunately, by the 1970s satellites began to provide jet aircraft with the positioning and weather information they needed. The original reasons for maintaining the OWSs disappeared, and the program ended in 1981. The last remaining active station, OWS M off Norway, will end ship-based observations in 2000, and with it, the last vestige of a valuable system to collect long-term oceanographic data will disappear.

To fill the void in the future, we envision that among critical GOOS components will be a combination of free-drifting, or "Lagrangian," platforms (such as the Argo floats described on pages 17–19), and fixed, or "Eulerian," platforms, such as surface and subsurface moorings. (The names derive from two 18th century mathematicians, Euler and Lagrange, who originated alternative ways of measuring fluid flow—past a fixed point and between two points.)

Eulerian observatories are not new to ocean sciences. They have been, and remain, one of the major elements in developing theoretical understanding of the oceans. In the tropics—motivated by the need to improve our ability to predict El Niño events—we have already constructed a new net-



work of Eulerian observatories to obtain surface wind and upper ocean temperature observations. In the 1980s, the National Oceanic and Atmospheric Administration, the National Science Foundation, and international partners began to install the Tropical Atmosphere Ocean (TAO) array of more than 70 surface moorings in the equatorial Pacific. Completed in 1994, it provided the observations that helped give us advance warning of the powerful El Niño of 1997–98. The goal now is to build on TAO and occupy more sites across the world's ocean to create a network of Global Eulerian Observatories (GEO) (see map below).



A proposed network of fixed moored ocean observatories would be chosen among potential sites (red dots), whose strategic value for monitoring and understanding the ocean's role in climate has already been identified. The new sites would complement the existing Tropical Atmosphere Ocean (TAO) array of buoys in the tropical Pacific Ocean (shaded region) and the Pilot Research Moored Array in the Tropical Atlantic (PIRATA) (shaded region), whose deployment began in 1997.

Such observatories come in two types (see page 21). Since the 1960s, scientists have used subsurface moorings to observe ocean currents and water properties. These are instrumented cables, anchored to the seafloor and attached to buoyant floats, that reach upward toward, but not to, the sea surface. In contrast, surface moorings have surface floats with downward-hanging cables. Instruments along the submerged cables measure water temperature and salinity, and the speed and direction of currents. The surface floats additionally provide a platform for sensors that measure wind speed and direction, incoming shortwave radiation, incoming longwave radiation, relative humidity, air temperature, barometric pressure, and precipitation. The technology to make such meteorological observations, which was not even available until the 1970s, has improved significantly over the past 15 years, giving scientists the capacity to make highly reliable and accurate measurements.

Both types of mooring technologies have matured to the point where they can measure atmospheric and/or oceanic changes as frequently as once per minute and can take oceanographic measurements meter-by-meter in the water column. Both are now capable of sustained operation for long time periods.

Sensors on surface buoys now perform reliably for periods of six to 12 months. Data are both transmitted via satellite and recorded on board. A recent deployment of surface buoys in the Arabian Sea showed that they can perform well in severe environments. And it also demonstrated their ability to collect detailed measurements of previously undetected air-sea processes. Incorporating these previously overlooked processes into numerical weather prediction models will produce significantly more accurate forecasts.

Unlike surface moorings, which are exposed to winds, salt spray, surface wave motion, fouling by marine growth, and disturbances by vandals, subsurface moorings are subject to less stressful conditions and now routinely collect information for periods of up to two years without servicing. In the past 50 years WHOI alone has deployed almost 1,000 subsurface moorings in all parts of the world's oceans. Information gathered from them has been used to begin to understand how the oceans change over space and time—with an emphasis on time scales of less than a year or so. In some parts of the ocean, such as the northwest North Atlantic, we have made enough measurements to be able to construct a three-dimensional "picture" of the ocean's mean circulation and to estimate the speed and volume of waters transported by important currents.

For subsurface moorings, a new class of observing system is approaching operational status: moored profiling instruments. These devices, fitted with a suite of oceanographic sensors, move vertically along conventional mooring cables, returning measurements of water properties and ocean currents at very closely spaced intervals throughout the water column (see photo and diagram opposite). Using one mobile set of sensors versus many stationary, separate sensors not only reduces costs, it also removes the need to calibrate many different sensors to make sure their measurements are of comparable quality.

In each deployment, these instruments can make approximately 200 top-to-bottom ocean profiles—akin to those obtained from ships. Second-generation instruments may double this capacity. The addition of a bottom pressure sensor would grant the capacity to monitor fluctuations that are not dependent on depth (such as a tidal current, which has the same magnitude and direction throughout the water column), as well as fluctuations that do vary with depth (such as internal waves, moving beneath the surface and within the ocean, whose speed and direction may vary at different depths). The instruments can make such fine-scale observations of current velocities that scientists will be able to detect internal wave motions, as well as other flows that occur only infrequently. They will also be able to detect subtle variations in eddies—smaller-scale, episodically occurring currents that move contrary to main currents.

With these tools available, the international focus is now on identifying the strategically best GEO sites to investigate one or more of the four important scientific objectives listed below.

Direct measurements of ocean currents

At strategic sites, moored buoys can directly measure ocean currents flowing at the surface or down into the ocean's interior. These currents redistribute heat and fresh water around the globe. In particular, the ocean and atmosphere help maintain the planet's thermostatic balance by absorbing heat in the sun-drenched tropics and moving it toward Earth's poles. Cooler (and denser) waters sink and flow back equatorward.

The details of these processes are not yet fully understood, yet they are the underpinnings of our climate system. We need, for example, long-term Eulerian observatories to measure the dense overflows of cold Norwegian Sea waters as they move south through the Denmark Straits and Faroe Bank Channel. We also need moored stations to measure variations in the poleward transport of warm water in currents, such as the Gulf Stream, that hug the western boundaries of continents.

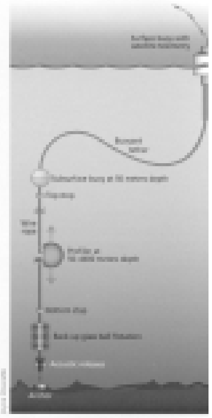
Examining 'water mass formation'

In some locations in the world ocean, surface waters become colder or saltier (and therefore denser) than surrounding waters and actually sink and flow into the ocean's interior—a process known as water mass formation or transformation. This happens when the atmosphere cools the waters or where evaporation or sea ice formation leaves salt behind. Winds can also push surface waters together, and these convergent flows force surface waters downward.

Like a hand pushing down in a bathtub, the downward flow of waters from the surface to the interior of the ocean provides the propulsion to redistribute heat and fresh water throughout the ocean and around the world. In this way, the oceans can absorb heat from the atmosphere in the tropics, for example, and release it back to the atmosphere over the North Atlantic decades to hundreds of years later. Moored ocean observatories in key sites of water mass formation and/or transformation could observe the slow variations in the process—documenting the depth to which cold water sinks and chronicling changes in ocean heat and fresh water content over time.

Obtaining measurements of air-sea interactions

Meteorological data obtained above the sea surface would provide accurate measurements of the heat and fresh water exchanged between the ocean and atmosphere. Deployed in regions where surface waters sink, these would help quantify the rate at which water mass transformation occurs. In other sites, these measurements would provide high-quality, accurate reference data to check, verify, and calibrate meteorological measurements taken by Volunteer Observing Ships (VOSs) and by satellites. They would also gather the actual data that provide reality checks for computer models that forecast weather and climate.



Moored profilers move vertically along mooring cables and measure water properties and currents throughout the water column.

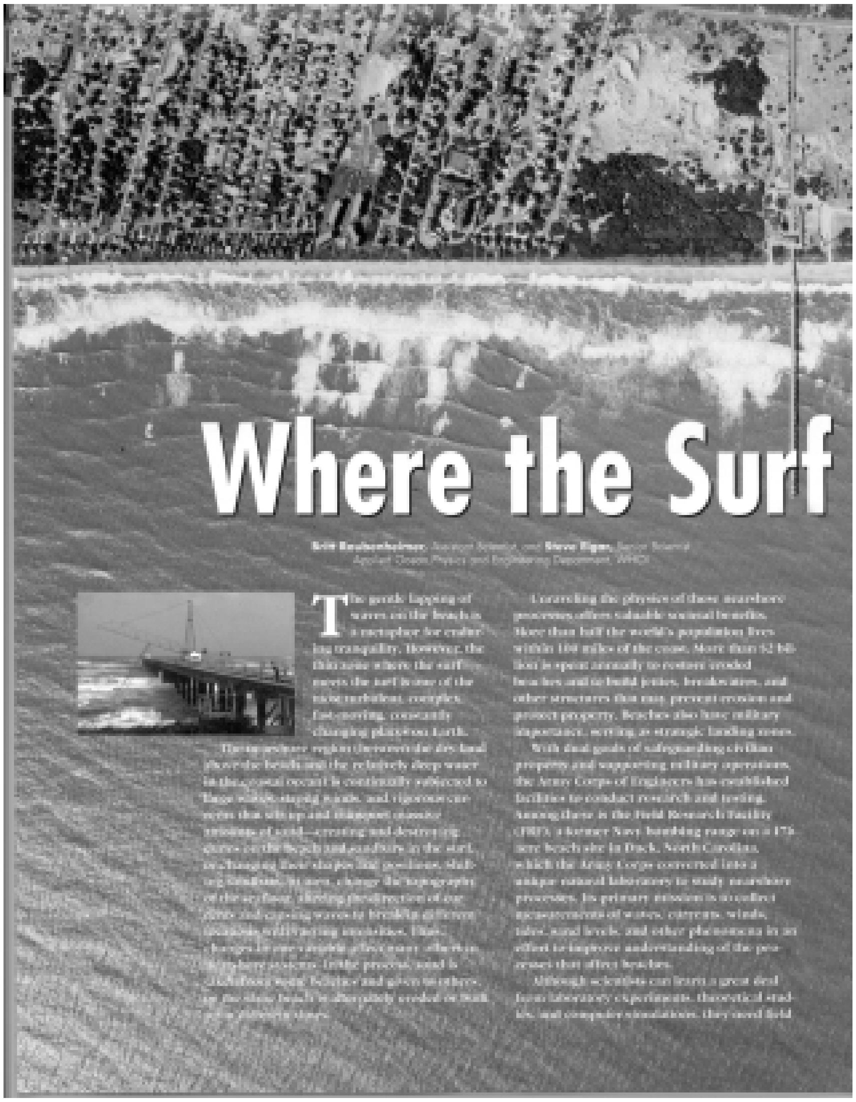
Investigating variability of the ocean's interior

Oceanographers believe that heat can be moved north and south not only by currents, but also by smaller, more-difficult-to-discern eddies within the oceans. With their ability to make frequent, detailed measurements of water velocities and properties throughout the water column, moorings can detect and document the presence and dynamics of eddies around the world. This will give us our first glimpse into understanding how eddies influence ocean transports of heat and fresh water. It will also provide initial data that can serve as benchmarks for developing numerical models of ocean dynamics—which in the future will be run on computers sufficiently powerful to include finer-scale dynamics such as eddy variations.

Today deep-sea currents have been observed over periods of more than two years at only a few locations. The longest available record is about 10 years. But new cost-effective subsurface moorings being developed by Nelson Hogg at WHOI are expected to permit moorings to last more than five years, with the capability for frequent data transmission back to the lab. GEO sites equipped with these new subsurface moorings could start to obtain the first global picture of long-term internal variability of the oceans.

Research Engineer Steve Liberatore, left, and Research Associate Terry Hammar test a moored profiler in Woods Hole.

We acknowledge NOAA, NSF, and the Office of Naval Research for continuing support for the development of the technologies needed to make global ocean observations and for the research to improve understanding of the ocean and its impacts.



Where the Surf

Britt Raubenheimer, Assistant Scientist, and **Steve Elgar**, Senior Scientist
Applied Ocean Physics and Engineering Department, WHOI

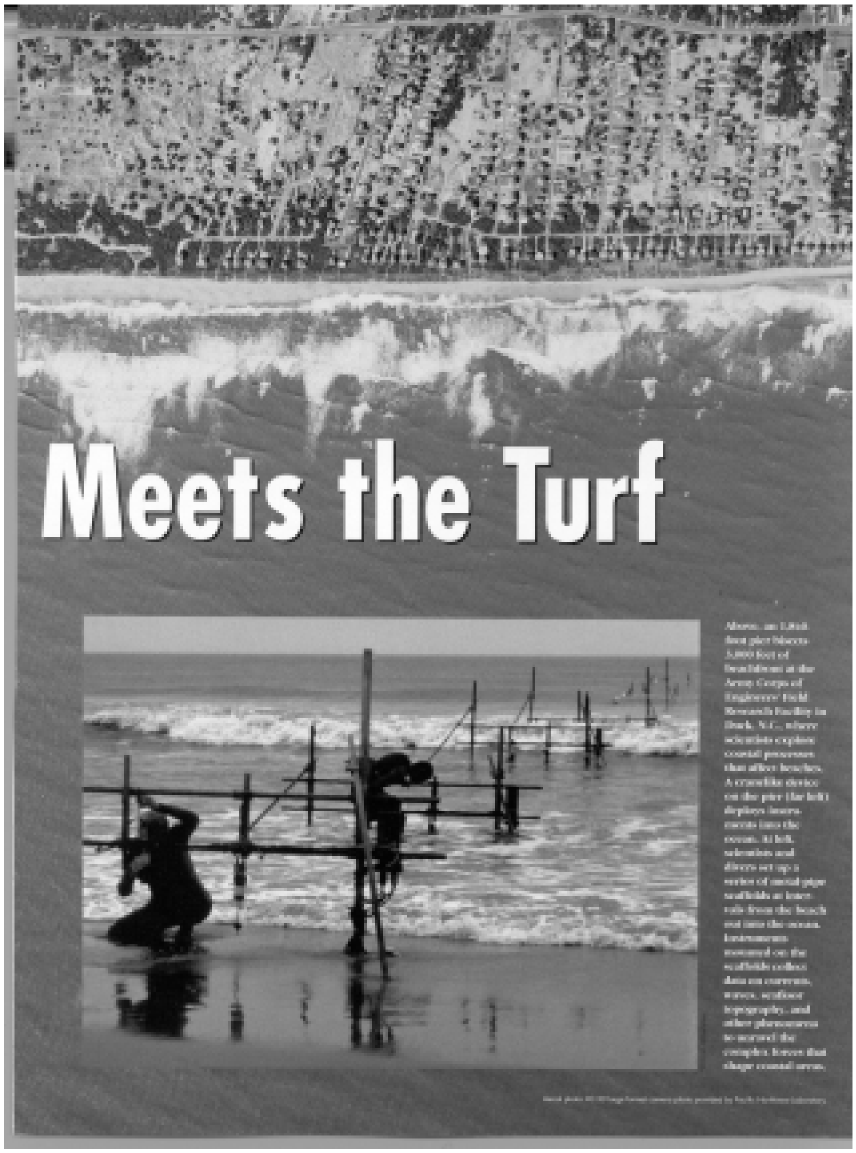
The gentle lapping of waves on the beach is a metaphor for enduring tranquility. However, the thin zone where the surf meets the turf is one of the most turbulent, complex, fast-moving, constantly changing places on Earth.

The nearshore region (between the dry land above the beach and the relatively deep water in the coastal ocean) is continually subjected to large [illegible] waves, and vigorous currents that stir up and transport massive amounts of sand—creating and destroying dunes on the beach and sandbars in the surf, exchanging their shapes and positions, shifting sandbars. [illegible] change the topography of the seafloor, altering the direction of currents and causing waves to break in different locations with varying intensities. Thus, changes in one variable affect many other nearshore systems. In the process, sand is [illegible] and given to others, [illegible] beach is alternately eroded or built up at different times.

Unraveling the physics of these nearshore processes offers valuable societal benefits. More than half the world's population lives within 100 miles of the coast. More than $2 billion is spent annually to restore eroded beaches and to build jetties, breakwaters, and other structures that may prevent erosion and protect property. Beaches also have military importance, serving as strategic landing zones.

With dual goals of safeguarding civilian property and supporting military operations, the Army Corps of Engineers has established facilities to conduct research and testing. Among these is the Field Research Facility (FRF), a former Navy bombing range on a 176-acre beach site in Duck, North Carolina, which the Army Corps converted into a unique natural laboratory to study nearshore processes. Its primary mission is to collect measurements of waves, currents, winds, tides, sand levels, and other phenomena in an effort to improve understanding of the processes that affect beaches.

Although scientists can learn a great deal from laboratory experiments, theoretical studies, and computer simulations, they need field


Meets the Turf
Above, an 1,840-foot pier bisects 3,000 feet of beachfront at the Army Corps of Engineers' Field Research Facility in Duck, N.C., where scientists explore coastal processes that affect beaches. A cranelike device on the pier (far left) deploys instruments into the ocean. At left, scientists and divers set up a series of metal pipe scaffolds at intervals from the beach out into the ocean. Instruments mounted on the scaffolds collect data on currents, waves, seafloor topography, and other phenomena to unravel the complex forces that shape coastal areas.

Among the specialized equipment at the Army Corps of Engineers' Field Research Facility is a motorized, three-wheeled vehicle with a stable platform atop a 35-foot tripod frame. The Coastal Research Amphibious Buggy, or CRAB, can be driven from the beach into the ocean, in wave heights up to six feet, to install and service instruments, to collect sediment samples, or to map the ocean bottom.

measurements to test the results of these studies and to determine the relative importance of various processes on natural beaches. However, large waves and evolving conditions make it difficult to install and maintain instruments, particularly during Nor'easter storms and hurricanes when the most dramatic beach changes occur.

For the past 20 years most of the large US nearshore field experiments have been conducted at the FRF. Scientists from around the world, including several from WHOI, have come to Duck to do research, attracted by the FRF's specialized equipment, experienced staff, and unique capabilities. The 3,000 feet of waterfront is bisected by a 1,840-foot pier extending from the dunes on the beach to water depths of about 23 feet (see pages 24–25). A cranelike device mounted on railroad tracks along the pier, called a Sensor Insertion System (SIS), can deploy instruments in precise locations in the ocean up to 75 feet on either side of the pier (see photo, page 24).

The FRF also offers specialized vehicles, including the Lighter Amphibious Resupply Cargo (LARC) ship, which can be loaded on shore and driven through the surf into deeper water, and the Coastal Research Amphibious Buggy (CRAB), a motorized, three-wheeled vehicle with a stable platform atop a 35-foot tripod frame (photo at left). The CRAB can be driven from the beach into the ocean, in wave heights up to six feet, to install and service instruments, to collect sediment samples, and to map the ocean bottom.

Observations are collected continuously with permanent instruments, providing a long-term, ever-growing data set of coastal changes. A waverider buoy located approximately a mile offshore of the FRF and pressure sensors in shallow waters are used to study the evolution of waves traveling from the deep coastal waters across the surf zone to the shoreline where they run up the beach. A tide gauge at the pier end measures fluctuating tidal elevations that are important to nearshore processes. Multiple video cameras mounted on a 140-foot-tall tower on shore record breaking waves and shifting sandbar locations. Changing sand levels from the beach out to 26-foot water depths are surveyed with the CRAB. Air temperature, atmospheric pressure, rainfall, winds, and other meteorological data are measured routinely. These data have been used, for example, by WHOI Associate Scientist Jim Edson and FRF Research Oceanographer Chuck Long to study interactions and exchanges between the air and ocean.

The FRF's continuous, long-term observations have been complemented by short, intense experiments. In 1994, scientists from many institutions convened at Duck to conduct an ambitious experiment to study the surf zone. Author Steve Elgar, now a Senior Scientist at WHOI, and Bob Guza of the Scripps Institution of Oceanography (SIO) used the CRAB and the LARC to deploy several metal-pipe scaffolds, each supported on six 20-foot-long, metal-posts inserted into the seafloor (see photo, page 25). Mounted on the scaffolds, which were located at intervals between the beach and 25-foot water depths, were current meters to measure the speed and direction of currents, sonar devices that use sound to record the changing seafloor topography, and pressure sensors that measure waves and water levels by measuring the weight of water above them.

With this instrument array, Elgar, Guza, and Edith Gallagher of the Naval Postgraduate School documented how offshore-directed currents (undertow) moved sandbars out to sea during storms. In one case, storm-related undertows moved a six-foot high sandbar about 100 yards seaward.

Combining observations from the surf zone array

with measurements from the FRF's permanent sensors, WHOI Associate Scientist Steve Lentz and author Britt Raubenheimer, now an Assistant Scientist at WHOI, showed that breaking waves cause mean water levels to increase by more than a foot in the surf zone. Using instruments deployed farther offshore, Lentz determined the relative effects of breaking waves, winds, and the earth's rotation on ocean circulation on the inner continental shelf. WHOI Senior Scientist and biological oceanographer Cheryl Ann Butman showed that wind-driven currents controlled the onshore and offshore transport of clam, snail, and worm larvae.

Building on what was learned during Duck94, FRF conducted an even larger experiment during fall 1997. More than 250 scientists, technicians, students, divers, and others deployed over 400 sensors. Using the CRAB, the authors and Guza installed more than 200 sensors to measure waves, circulation, water table fluctuations, and changing sand levels. WHOI Associate Scientist John Trowbridge investigated bottom stress associated with breaking waves and wind-driven currents using instruments mounted on a 1,000-pound frame deployed with the CRAB. Additional sensors deployed by other investigators included scanning acoustic altimeters to map the movement of ripples on the seafloor, and fiber-optic backscatter sensors to measure the amount of sand suspended and transported in the water above the seafloor. Frequent sand samples were collected from the CRAB and by divers to determine sediment grain sizes, which affect the amount of sand that can be lifted off the bottom and moved by waves and currents.

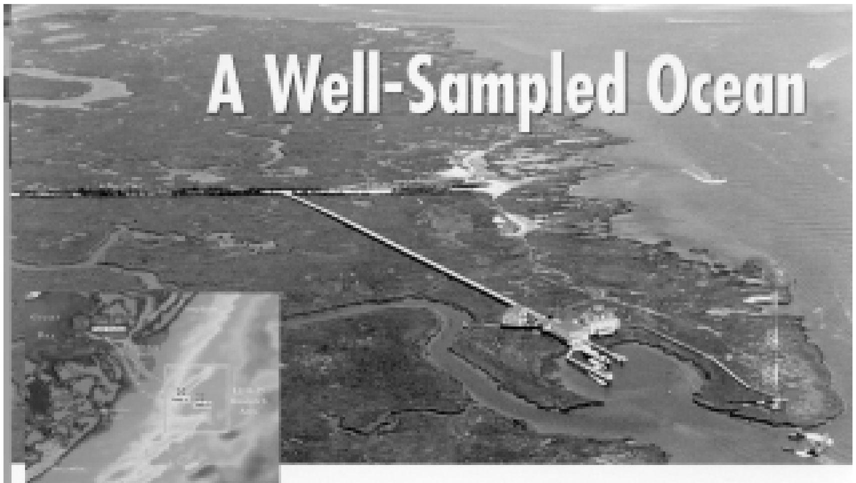
The more details we learn about nearshore physics, the more we will be able to elucidate the mechanisms that cause erosion or coastal damage, and begin to predict and prevent them. The fundamental physics learned at Duck is applicable to many beaches around the world that have similar characteristics and wave conditions. The FRF has established a beachhead of knowledge to solve problems that once seemed too complex to grasp.

Information on the FRF is available at www.frf.usace.army.mil.

The authors thank William Birkemeier, director of the Field Research Facility, and WHOI Senior Scientist Cheryl Ann Butman, who provided helpful comments. The Office of Naval Research, the National Science Foundation, and the Army Research Office have supported our research.

Waves, currents, sand grain sizes, sandbar configurations, water table levels beneath the beach, and other phenomena combine in complex ways, causing very different patterns along the same beach.

A diver services instruments collecting data in the surf zone.



A Well-Sampled Ocean

The LEO Approach

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J. Frederick Grassle, Director, Institute of Marine and Coastal Sciences, Rutgers University
Christopher J. von Alt, Principal Engineer, Applied Physics and Ocean Engineering Department, WHOI

Rutgers University's Marine Field Station in Tuckerton, New Jersey, is the headquarters of the Long-term Ecosystem Observatory (LEO)—a network of sensors taking continuous, real-time observations of a swath of coastal ocean. A backbone component of LEO is a subseafloor cable supplying power and two-way communications from the field station to permanent seafloor nodes, which, in turn, support a variety of instruments.

Unlike the oceans, the sky is relatively visible and accessible to us. We are well acquainted with the range of processes that occur in the earth's ever-changing atmosphere. We know about rainstorms that slow daily commutes and even have a growing awareness of the long-term potential dangers of global climate change. Radio, television, and the World Wide Web provide instant access to weather conditions and forecasts on demand. Airplane pilots, farmers, or people planning outdoor activities can immediately assess the value of these forecasts simply by looking out their windows, and, if necessary, they can adjust their plans based on local conditions. Daily observations and experience, combined with readily available weather forecasts, both short- and long-term, have given us a common-sense knowledge of how the atmosphere works and an ability to make informed judgments on how best to proceed in the face of present conditions.

But in the ocean, the situation is quite different. Conditions and processes at work on any given day in the ocean are usually a mystery to us. Satellites may observe the surface ocean from space, but what is happening below the surface, out of sight of our orbiting viewers? Unlike the atmosphere, much of the ocean is not routinely monitored or sampled, so the only way to learn what might be going on in a particular ocean location is to visit it by boat, and, if weather conditions are especially good, dive under the ocean surface. But diving vehicles are expensive, and they provide only a fleeting glimpse of a largely unknown environment. Short-term events may not occur during a research cruise, and thus remain undetected. Critical trends that occur over large areas and long time periods are difficult to confirm with spotty coverage from ships and ocean moorings.

What we require are permanent windows on the sea to help us develop the same instinctive, common-sense feel for the ocean that we have achieved for the atmosphere. That was a fundamental goal of scientists, engineers, and educators who designed and built Rutgers University's Long-term Ecosystem Observatory (LEO-15).

The concept began during a conversation in 1986 between authors von Alt and Grassle, then a Senior Scientist at WHOI, who envisioned a network of underwater observatories from which robots could be deployed and directed by computers anywhere in the world. These visions became a joint research program funded by the National Science Foundation in 1992. Additional support has come from the National Oceanic and Atmospheric Administration, the Office of Naval Research, the National Ocean Partnership Program, and Rutgers University. Installation and construction of LEO-15 started in 1994.

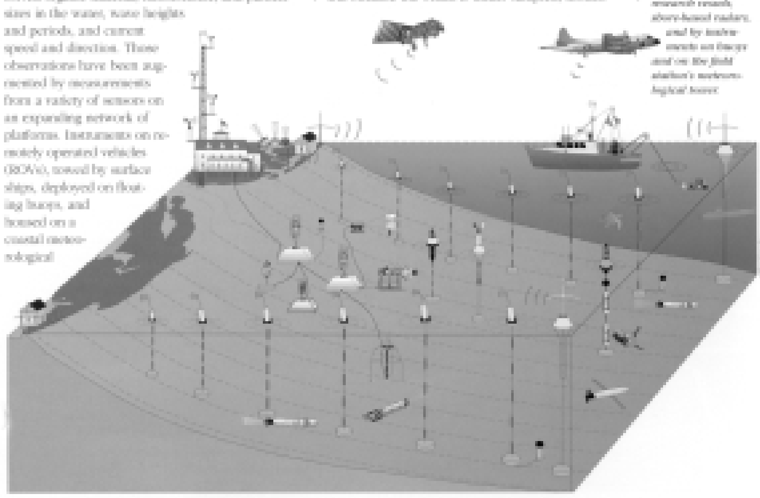
The "15" comes from the system's original and still central components: permanent seafloor nodes at 15 meters depths about 9 kilometers off the coast of Tuckerton, New Jersey. A buried subseafloor electric/fiber-optic cable extending from the field station in Tuckerton provides continuous, ample power to the nodes, which support instruments, other remote platforms, or Autonomous Underwater Vehicles (AUVs). The cable also provides two-way, real-time, high-bandwidth communications (including video) between the nodes and the field station. Linked to the Internet, the system gives scientists the ability to monitor and control experiments and vehicles from any laboratory in the world. Instantaneous distribution via the World Wide Web also offers educators and the public a direct link to the undersea world off New Jersey from classroom or home computers.

Instruments supported by the nodes measure water temperature and salinity, chlorophyll, dissolved organic material, fluorescence, and particle sizes in the water, wave heights and periods, and current speed and direction. These observations have been augmented by measurements from a variety of sensors on an expanding network of platforms. Instruments on remotely operated vehicles (ROVs), towed by surface ships, deployed on floating buoys, and housed on a coastal meteorological tower all contribute data, as do satellites and shore-based radar remote sensing systems, which can tell us about sea surface temperature, water quality, and phytoplankton content over wide areas.

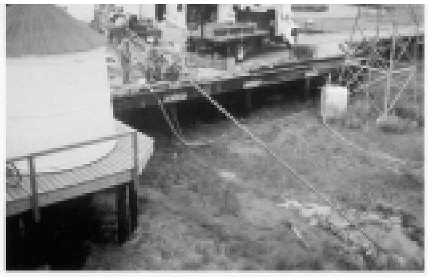
Together, this network now lets us continuously sample a 30-by-30-kilometer research area spanning water depths of 5 to 30 meters. This region, the inner continental shelf, has often been ignored in the past because its complex dynamics and turbulent waters have made both scientific studies and operating conditions difficult. Yet it is a region that has important impact on people.

Much the way meteorologists use continuously available atmospheric data to create weather forecasts, we can assimilate ocean data into numerical computer models that simulate ocean dynamics and generate forecasts of ocean conditions that would be useful to fishers, beach visitors, scientists, and others. In a well-sampled ocean, developing trends from model-generated forecasts can be compared with the trends in rapidly updated observations to see where the model is staying on track, and where it is drifting away from observed behavior. Just as weather forecasters develop a feel for the biases of different atmospheric models, ocean forecasters will start to develop the same feel for ocean models.

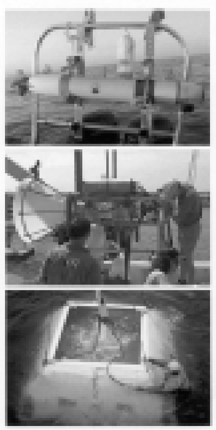
The ability to operate in a well-sampled ocean profoundly affects ocean research. Ocean models use the laws of physics to extrapolate how current conditions will likely evolve into future conditions. But because the ocean is under-sampled, models



At LEO, instruments supported by permanent seafloor nodes are complemented by a wide range of measurements taken by robotic vehicles, satellites, aircraft, research vessels, shore-based radars, and by instruments on buoys and on the field station's meteorological tower.



Above, LEO's cable from the field station is directionally drilled underneath a marsh and inter-coastal waterway and toward the continental shelf in 1996. Below (top to bottom), the WHOI-designed remotely operated vehicle REMUS (Remote Environmental Monitoring Units); an underwater docking station where REMUS can upload power or download data; one of LEO's seafloor nodes is deployed.



may start with incorrect initial conditions and end up off course.

Because intensive sampling of given ocean regions is too expensive, a science called "adaptive sampling" has evolved. Adaptive sampling uses model forecasts to identify regions where additional data are critical, so that scientists can focus their limited sampling resources in these critical regions and improve the model forecasts at reduced cost.

In the well-sampled ocean, errors in initial ocean conditions would no longer poison the accuracy of ocean model forecasts from the start. Instead, errors would more likely result from imperfect understanding of the physical processes going on in the ocean. That fundamentally shifts the still critical role of adaptive sampling. Instead of focusing on sampling to improve the accuracy of initial conditions, adaptive sampling systems could focus on regions where crucial physical processes are poorly understood or highly sensitive. These measurements would improve scientists' ability to understand underlying physical processes, to verify the models' accuracy, and to keep the models on track if their results begin to deviate from observed conditions.

Once we begin to get our own common-sense feel of ocean processes, we can begin to ask what a fish, diving bird, porpoise, clam, or starfish sees during a lifetime in the ocean. With our air-bound sensory equipment and inability to be present during many important oceanic events, we have not been able to visualize, let alone experience, the habitat of any ocean creature.

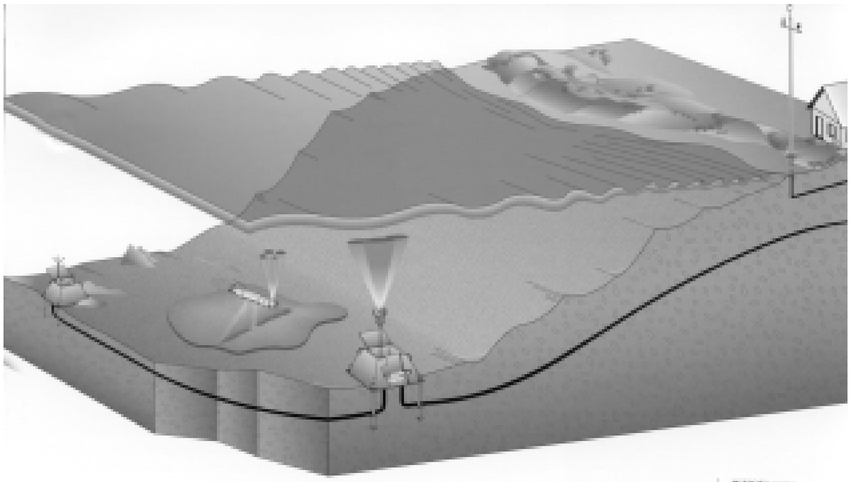
Whenever scientists have had a more continuous presence in the marine environment, major advances in understanding have occurred. Frequent visits to intertidal rocky shores to conduct experiments have demonstrated the importance of interactions among individuals of different species with each other and their environment. Underwater observations by divers on a daily basis have provided insight into the behavior and life cycle of reef fishes and corals. From the submersible *Alvin*, deep-sea ecologists received their first view of the ocean floor and the responses of some of the inhabitants to their surroundings. These advances were achieved simply by extending our visual and manipulative capabilities into the ocean. With LEO technologies, the environments not visible to human eyes can be visualized and studied remotely for the first time.

Our inability to routinely observe the ocean and its life compromises our ability to apply usual land-based management practices in the marine environment. We once believed the oceans could sustain any demand on their resources and could accommodate all but the most extreme assaults from exotic chemicals and any amount of excess nutrients. These ideas turn out to be untrue. The success of our ports requires efficient, safe traffic management, reduced sediment contamination, and better methods for using dredged material beneficially. Coastal economies will benefit from real-time information about beach conditions. Better tools for predicting and rapidly responding to coastal hazards such as storms, erosion, toxic algal blooms, and oil spills can minimize the harm they cause. Naval commanders have enormous interest in new methods to reconnoiter unfamiliar and possibly mined beach landing zones. Improved understanding of marine ecosystems and the need to manage living marine resources requires information about the habitats of all stages in the life cycle of each species and about the interactions among species and their physical surroundings.

With additional new technology (high-resolution color satellites, piloted and autonomous aircraft, floating radar stations, and long-duration AUV gliders), LEO-15 will be able to expand its reach toward deeper-water shelf areas, farther north and south along the shelf, and into shallower water at the outer edge of the surf zone. We hope it will eventually become part of a national and ultimately global network of coastal observatories.

Other LEO systems are planned by Rutgers and WHOI in the Mid-Atlantic Bight, including deeper stations at the edge of the continental shelf and shallower stations offshore Martha's Vineyard (see page 53), and in some of our nation's busiest ports, such as New York and New Jersey. Other universities are implementing LEO-like systems along our coasts and in the Great Lakes. The challenge will be to link this patchwork of local well-sampled systems in a distributed national network that shares regional-scale information.

More information about LEO-15 is available at marine.rutgers.edu/mrs/LEO15.html.



WHOI's new nearshore observatory on Martha's Vineyard, scheduled to be completed by the fall of 2000, will have land-based and sea-based sensors to continuously monitor oceanic and atmospheric conditions. The observations will be combined via underground and submarine cables at a shore station and available instantaneously on the Internet.

A New Coastal Observatory Is Born

Martha's Vineyard offers scientifically exciting site

James B. Edson, Associate Scientist, **Wade R. McGillis**, Assistant Scientist, and **Thomas C. Austin**, Senior Engineer
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People are not uniformly distributed on our planet. They tend to hug the coastline. An estimated 50 percent of humanity lives within 100 miles of a coastline, and this figure is growing. Here on Cape Cod, we are all keenly aware that the coast is a unique environment that is routinely affected by wave- and storm-driven events. Like most people along the eastern coast of the United States, we know these events often have adverse impacts. We've witnessed beaches eroding more than 10 feet per year. In 1991, even a relatively weak tropical cyclone like Hurricane Bob caused severe damage to New England and North Carolina.

Worldwide, tropical cyclones constitute one of the most important weather forecasting problems. In developing nations, tropical cyclones are the leading cause of death from natural phenomena. A single event took more than 100,000 lives as recently as 1991 in Bangladesh. A year later in the US, Hurricane Andrew killed more than 60 people and caused nearly $30 billion in damage.

Hurricanes, storms, beach erosion, and other natural processes can only exact greater tolls as we turn more of our coastlines into residential and business properties. In addition, a combination of biological, chemical, and physical processes can result in the outbreak of red tides or the dispersal of oil spills or other pollutants along our coastlines. Such events, caused by nature and/or by humans, damage property and natural habitats and harm fisheries, tourism, and the local economies.

Woods Hole scientists and their colleagues have been actively involved in coastal research for many decades. WHOI researcher Alfred Woodcock, for example, discovered in 1948 that red tide outbreaks increased respiratory illnesses in coastal residents because they inhaled contaminated airborne sea spray generated by breaking waves. More recently, WHOI scientists have conducted coastal research at the US Army Corps of Engineers' Field Research Facility (FRF) in Duck, North Carolina, (see page 20) and have helped conceive and build the Long-Term Ecosystem Observatory (LEO-15) off the coast of New Jersey (see page 28).

Interestingly enough, however, WHOI scientists haven't taken full advantage of the coast in their own back yard—primarily for the same reason that they have exploited it as a port for ocean-going research vessels. Martha's Vineyard and the Elizabeth Islands protect Woods Hole and make it a

The combination of the new Martha's Vineyard Observatory, Rutgers University's Long-term Ecosystem Observatory (LEO-15), and the US Army Corps of Engineers Field Research Facility will provide a valuable network of research installations along the East Coast to study coastal processes.

safe harbor, but they also block scientists from immediate access to undisturbed ocean waves and alongshore currents. In contrast, the southward shoreline of Martha's Vineyard faces the open ocean. Thus, it offers an ideal and still relatively accessible site for studying coastal processes. In fact, its south-facing beachfront is particularly valuable to scientists because prevailing winds blow directly onshore and in line with the direction of the ocean's waves.

With funding from the National Science Foundation, WHOI scientists and engineers have designed a nearshore observatory in the Katama section of Edgartown on Martha's Vineyard. Construction of this observatory began in December 1999 and is scheduled to be completed in time to monitor the fall 2000 hurricane season.

The Martha's Vineyard Observatory will have sensors mounted on two seafloor nodes, at depths of about 5 and 15 meters, respectively, connected to a shore station via a buried cable. Instruments mounted on the nodes will continually monitor mean sea and wave heights, current strengths, seawater turbulence, subsurface sediment movement, sunlight intensity, and the temperature, salinity, and carbon dioxide levels of the ocean's waters. Onshore, a mast extending about 8 meters above the beach's dunes will house meteorological instruments that will sample the near-coast air transported to land by the southerly winds. The onshore instruments will continuously measure wind speed and direction, atmospheric carbon dioxide levels, temperature, humidity, and the concentration of sea salt, water vapor, and small organic or inorganic particles (collectively called aerosols) that are ejected out of the sea and into the air. Measurements made in the atmosphere and the ocean will be jointly collected via underground cables at a shore station in the Katama Air Park, and made available in near real time on the Internet.

Information collected at the Martha's Vineyard Observatory will be combined with data collected at the LEO-15 site off New Jersey and at the FRF in North Carolina. Together, these three facilities will provide a unique network along the East Coast for studying coastal processes (see map, left).

Like FRF and LEO-15, the Martha's Vineyard Observatory will provide scientists with a well-characterized natural laboratory that will enable them to study how winds, waves, currents, seafloor topography and sediment structure, and other factors combine to affect the coastline. In addition, it will enable them to learn about the processes and conditions that affect coastal marine life. However, one of our main objectives for the Martha's Vineyard Observatory is to gain a better understanding of coastal weather phenomena.

Meteorologists are only now beginning to identify and investigate physical processes that are unique to the coastal environment. The same, ever-shifting wind and wave patterns that combine to create such turbulent, dynamic systems at the shoreline and beneath the sea surface, also generate a great deal of action in the air above the sea surface. Winds and waves constantly disrupt the boundary between air and sea, promoting exchanges of gases, particles, heat, and momentum between the ocean and atmosphere.

One of the many outcomes of this lively border exchange is the production of sea spray. Measurements of aerosol concentrations at the Martha's Vineyard Observatory will enable us to learn how sea spray is produced and transported. This, in turn, will help improve our ability to predict marine haze and fog in coastal regions. In addition, we will be able to study how the evaporation of sea spray into the atmosphere affects the transfer of heat and moisture near the ocean surface.

We can also use the observatory to explore how solar energy radiating into the sea surface affects the system. Warmer surface waters, just like warmer air, are more buoyant; thus, warmer waters rise, pushing up air masses above the sea surface, and initiating another series of dynamic processes in the atmosphere.

At the Martha's Vineyard Observatory, we can focus on observing, at a small scale, a range of complex air-sea interactions such as those noted above, which may also take place on a larger scale in the vaster ocean. One high-priority research topic is the study of air-sea exchange of carbon dioxide, a heat-trapping, industrial greenhouse gas that has been accumulating in the earth's atmosphere for the past several decades. Such studies will help us estimate how the oceans absorb and retain this gas, and thus allow us to assess the extent to which the oceans can store excess carbon dioxide, thereby reducing the threat of global climate change.

Many of the studies we propose at the observatory require the expertise of scientists in several disciplines. Carbon dioxide is not the only trace gas

The Martha's Vineyard Observatory will be located on South Beach near the Katama Air Park.

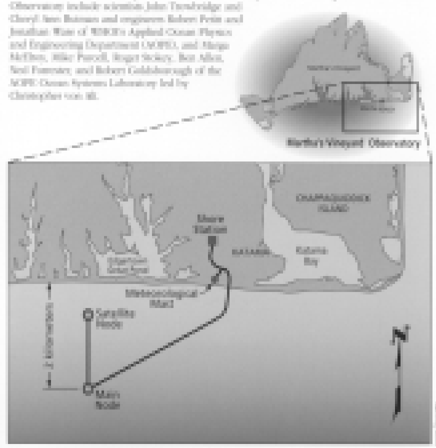
with potentially important biogeochemical consequences. In one scenario, for example, increased sunlight might spark a bloom of phytoplankton that produces an abundance of a gas called dimethylsulfide. Wind and wave action transport dimethylsulfide into the air, where it may create aerosol particles that reflect or block sunlight, possibly cooling the earth's surface and eventually leading to fewer phytoplankton.

Another area of research that we propose to initiate at the observatory is a study of the interaction between ocean waves and winds during a hurricane event. For example, we could use measurements made at the observatory to prove (or disprove) the theory that winds and waves from hurricanes agitate the ocean like a washing machine, generating foam on the sea surface that acts as a lubricant—thus reducing the drag on the hurricane from the sea surface and possibly keeping it from dissipating faster. Martha's Vineyard's exposure to the open ocean and frequent storms, while hardly a blessing to the island's inhabitants, will provide us with an invaluable means to study the effects of severe storms and possibly hurricanes. The permanent equipment deployed at the facility will include a set of rugged instrumentation able to withstand extremely high wind speeds and rain, allowing measurements that have rarely been collected before, and providing us with the real-time data necessary to improve the computer simulation models that currently predict hurricane events.

As we quickly move toward computer models that couple ocean and atmosphere processes to generate better weather forecasts, we require continuous, long-term, high-resolution measurements of phenomena in the air and water to test and improve these models. Observations from our nascent network of East Coast nearshore observatories and moored ocean buoy observatories represent a first step toward supplying the comprehensive, high-quality data needed to make these coupled models effective. Ultimately, we expect that the improved understanding of coastal processes afforded by the Martha's Vineyard Observatory will be combined within this observational network to improve our abilities to forecast waves, ocean circulation, and weather.

Collaborators on the development of the Martha's Vineyard Observatory include scientists John Trowbridge and Cheryl Ann Butman and engineers Robert Petitt and Jonathan Ware of WHOI's Applied Ocean Physics and Engineering Department (AOPE), and Marga McElroy, Mike Purcell, Roger Stokey, Ben Allen, Ned Forrester, and Robert Goldsborough of the AOPE Ocean Systems Laboratory led by Christopher von Alt.

The Martha's Vineyard Observatory's south-facing beachfront is particularly valuable to scientists because prevailing winds blow directly onshore and in line with the direction of waves.



A long line of glass balls in yellow "hardhats" will provide flotation for a moored buoy observatory in the Pacific Ocean.