I. Executive Summary

The classic problem. *If I were to choose a single phrase to characterize the first century of modern oceanography, it would be a century of under-sampling.* Walter Munk

The vision. *I walk into our control room, with its panoply of views of the sea. There are the updated global pictures from the remote sensors on satellites, there are the evolving maps of subsurface variables, there are the charts that show the position and status of all our Slocum scientific platforms, and I am satisfied that we are looking at the ocean more intensely and more deeply than anyone anywhere else.* Henry Stommel

The new reality. *The ocean sciences are now on the threshold of another major technological advance as the scientific community begins to establish a global, long-term presence in the ocean.* Robert Detrick

The ORION Workshop, held in San Juan, Puerto Rico from January 4 to 8, 2004, brought together 300 scientists, engineers, educators, and science managers to articulate the scientific priorities to be addressed using ocean observatories. Through four days of discussions in fifteen working groups, scientists with a wide range of expertise devised experiments, conferred with engineers on a variety of technical issues, and worked with science educators to formulate an observatory plan that would significantly advance understanding and increase the visibility of the ocean sciences in the coming decades. Working group deliberations are summarized in this report.

ORION will provide high-frequency, continuous, time-series measurements in broad-scale spatial arrays needed to define the links among physical, biological, chemical, and geological variables in the oceans and provide spatially coherent data to study processes and enable modeling efforts. With these attributes in mind, several common scientific themes emerged from the working groups, which are applicable across the wide range of environments and processes of interest:

What role do episodic events play in the oceans? Most researchers readily acknowledge that episodic events, such as earthquakes, volcanic eruptions, algal blooms, and hurricanes can have large influences on oceanic processes. Traditional techniques have not been adequate or effective in quantifying their impact. ORION will provide the tools for making observations prior to, during, and following events, allowing quantification of the roles that they play in processes of interest (e.g., in contributing to mass and heat flux from land to the oceans, mass flux from the ocean surface to the seafloor, sediment transport on continental shelves).

What is the relationship between non-periodic (secular) and cyclical processes in the ocean, and how does this interaction drive observed variability? Many processes in the oceans are subject to annual, multi-year, and decadal cycles. Superimposed on these cycles are secular trends (analogous to the increasing trend in atmospheric CO_2). Defining the relationships and fundamental mechanisms that underlie these

cyclical and secular processes in the world's oceans requires ORION's assets, which will allow collection of needed sustained, *in situ* spatial time series.

Do human activities underlie many of the observed changes in the ocean? Humans are exerting an increasingly large influence on the ocean, but the consequences of these activities have yet to be defined. As these human impacts increase they likely will alter natural cycles. Understanding the influence of human activities on the oceans requires understanding the interplay of ocean physics, chemistry, geology, and biology over local and global scales, and over long, continuous time periods. ORION will provide this understanding by collecting spatial and temporal data over a range of scales, and then using these data in numerical models.

In addition to these common themes, scientific groups identified a number of exciting research opportunities that can only be accomplished through use of ocean observatory infrastructure. Examples include: the ability to document Earth's internal structure and dynamics (something currently impossible given the lack of geophysical stations over large portions of Earth's surface); to have controlled access to carry out *in situ* observations and study the deep biosphere; and to determine what mediates changes in biological communities.

The technology group considered a number of issues, including the need to deploy existing workable technology as soon as possible, to develop new sensors and technical capabilities, and to maximize communication and understanding between engineers and scientists. The group's recommendations are to (1) use common engineering methods to develop and operate Ocean Observatories Initiative (OOI) facilities, (2) employ a careful process to permit the engineering community to understand scientific needs, (3) promote collaboration between ORION and the information technology's computer-science community to ensure that the observatories have a truly interactive 24:7 capability for scientists sitting onshore, (4) develop the capability for event response adaptive sampling using ocean observatories, and (5) continue development of sensors and samplers, and integration of instrumentation that can aid communication.

The education and outreach group identified several goals: to increase student and public awareness, understanding, and appreciation of the oceans in the Earth system, and to strengthen science and technology education. Specific recommendations are to (1) enhance communication between researchers and educators, (2) promote the development and diversity of the ocean-related workforce, and (3) stimulate young and old to understand and appreciate the vital role of the ocean in the Earth system, and its importance to well-being.

Challenges. As with all great endeavors, significant challenges need to be overcome. Some of these challenges were identified by the science, education, and engineering attendees in Puerto Rico, and all will require a concerted and proactive effort by the U.S. ORION community. Identified challenges are to (1) vigorously pursue international partnerships, (2) provide an effective voice to help ensure that all ocean-observing efforts for the United States complement and augment one other, (3) develop education programs in parallel with the observatory construction that build upon existing efforts and capabilities, (4) develop a clear and transparent procedure for scientists to gain access to observatories, (5) pursue a system engineering approach for developing the OOI given the scale of the proposed observatory network, and (6) build a management structure that ensures that the scientific community has sufficient control of observatory infrastructure to permit execution of bold and innovative experiments not yet conceived. This last challenge may require changes in funding structure, the proposal process (including proposal review), and institutional reward structures for scientists. Finally, and most importantly, oceanography has had great success with individual and small research groups conducting focused research. As the community embarks on these large interdisciplinary efforts, it must safeguard individual research efforts. The core science budgets at NSF Ocean Sciences must be expanded so that the new ocean observing initiatives do not come at the expense of individual researchers' science activities. The call by the Ocean Commission (http://www.oceancommission.gov) to double the amount of money for ocean research must be vigorously pursued, especially as ocean sciences budgets as a whole in the United States have been stagnant over the last decade.