Critical Ocean Infrastructure Needs For the US in the Year 2030

The National Research Council Assesses Ocean Infrastructure Needs For the Next Two Decades of Marine Research and Societal Use

By Eric J. Barron
Chair
Rana A. Fine
Vice Chair
and
Oscar Schofield
Committee Member
Infrastructure Strategy for U.S. Ocean Research in 2030
The National Research Council

The U.S. marine exclusive economic zone is critical to the national economy, serving maritime transportation, national security, energy and mineral extraction, fisheries, aquaculture, tourism and recreational industries. It is also the source of large disasters, both natural and man-made, that include tsunamis, hurricanes, offshore industrial accidents and human health issues such as outbreaks of waterborne disease.

The *Deepwater Horizon* oil spill and Japan's earthquake and tsunami were sobering lessons that the ocean's threats are often underestimated. Further, the ability to predict, respond to, manage and mitigate these events is astonishingly poor. These deficiencies reflect a lack of understanding of fundamental ocean processes, a limited capacity to maintain a sustained spatial presence at sea, and the long lead time and high capital costs of developing and deploying infrastructure in the ocean.

To this end, the United States has spent the past decade developing a national plan to promote the enhancement and sustained deployment of cutting-edge infrastructure in the oceans.

The first document in that effort was the 2004 U.S. Commission on Ocean Policy report, *An Ocean Blueprint for the 21st Century*. The report called for "a renewed commitment to ocean science and technology" to realize the benefits of the ocean while ensuring its sustainability for future generations.

Since the release of that report, federal agencies have been working together through the National Science and Technology Council's Subcommittee on Ocean Science and Technology (SOST), which is mandated to identify research priorities, facilitate coordination of ocean research, and develop ocean technology and infrastructure. This committee commissioned a National Research Council study to assist in planning the nation's ocean research infrastructure needs in the year 2030.

New Infrastructure Report

Released in April 2011, the report, *Infrastructure Strategy for U.S. Ocean Research in 2030* was designed to identify major research questions anticipated to be at the forefront of ocean science in 2030, to define the categories of infrastructure that should be included in next-generation planning, to provide advice on criteria that could set priorities for asset development or replacement and to recommend ways that federal agencies could maximize the value of ocean infrastructure investments. This article highlights selected the findings of from the full report, posted online at http://bit.ly/rivACX.

The committee adopted a focused definition of infrastructure as the resources accessible to the U.S. ocean research community, including the full portfolio of platforms, sensors, data sets and systems, models, supporting personnel, facilities and enabling organizations that the nation can answer ocean-related questions.

As defined here, ocean research infrastructure represents the national portfolio of resources and assets, including technology, facilities, data, people and institutions. However, many components of the national infrastructure are insufficient to meet the growing societal demand for scientific information that enables safe, efficient and environmentally sustainable use of the ocean. A comprehensive range of new ocean research infrastructure is required to overcome these challenges, as increasingly interdisciplinary research is the priority.

Recommendations and Major Themes

Recommendations. The report recommends that federal ocean agencies should establish and maintain a coordinated national strategic plan for critical shared ocean infrastructure investment, maintenance and retirement. Such a plan should focus on trends in scientific needs and advances in technology while taking into consideration life cycle costs, efficient use, surge capacity for unforeseen events and new opportunities or national needs. The plan should be based upon known priorities and updated through periodic reviews.

The scientific issues confronting the oceanographic community in the next 20 years are daunting and will require significant investment to fully address. The committee suggested that the nation prioritize investments based on the usefulness of the infrastructure for addressing science questions, the affordability, efficiency and longevity of infrastructure, and the ability of the infrastructure to contribute to other national economic, management, mitigation and security needs.

These criteria would allow flexibility to address a wide range of issues, including whether specific infrastructure can help address multiple scientific questions or needs; data quality and continuity; future technology trends; balance between risk and benefit; and national strategic or economic importance. From an economic viewpoint, this type of prioritization acknowledges uncertainties regarding the ability of future ocean science research to produce information relevant to critical ocean-related societal issues. This strategy could allow a coordinated, adaptable, long-term approach for the use of shared, federally funded infrastructure assets, with possibilities to include locally and state-funded infrastructure, and periodic reviews of ocean infrastructure to fully optimize and capitalize on investments made by individual agencies.

Major Themes. Given the scientific focus of this report, the committee identified four major themes that are of compelling interest to society and will drive scientific research for the next two decades. These themes are enabling stewardship of the environment, protecting life and property, promoting economic vitality and increasing fundamental scientific understanding.

The report highlighted a number of questions that fell under these themes and then determined the wide range of required ocean infrastructure needed to answer those questions. While by no means an exhaustive list, the questions showcase the importance of ocean-related research and the continued demand for investment in ocean research infrastructure. Many of these questions are currently relevant, but they are not simple issues and will likely take decades to solve, especially if resources are limited. These questions require a global observational framework that allows for the sustained ability to monitor change in the ocean, makes accurate predictions of the coupled ocean-atmosphere system, enables process studies that improve understanding, provides data in environmentally sensitive regions or areas of national security and has sufficient flexibility to be deployed during events or emergencies.

Major Recommendations

The following were viewed as a means to ensure that the U.S has the capacity in 2030 to undertake and benefit from knowledge and innovations possible with oceanographic research. The nation should:

- Implement a long-term research fleet plan to retain access to the sea.
- Recover U.S. capability to access fully and partially ice-covered seas.
- Expand abilities for autonomous monitoring at a wide range of spatial and temporal scales.
- Enable sustained, continuous time-series measurements.
- Maintain continuity of satellite remote sensing and communication capabilities for oceanographic data and sustain plans for new satellite platforms, sensors and communication systems.
- Support continued innovation in ocean infrastructure development. Of particular note is the need to develop in-situ sensors, especially biogeochemical sensors.
- Engage allied disciplines and diverse fields to leverage technological developments outside oceanography.
- Increase the number and capabilities of broadly accessible computing and modeling facilities with exascale or petascale capability that are dedicated to future oceanographic needs.
- Establish broadly accessible virtual (distributed) data centers that have seamless integration of federal, state and locally held databases, accompanying metadata-compliant with proven standards, and intuitive archiving and synthesizing tools.
- Examine and adopt proven data management practices from allied disciplines.
- Facilitate broad community access to infrastructure assets, including mobile and fixed platforms, and costly analytical equipment.
- Expand interdisciplinary education and promote a technically skilled workforce.

Present and Future Technological Trends

The wide array of infrastructure assets currently in use and needed for 2030 include mobile and fixed platforms, in-situ sensors and sampling, remote sensing and modeling, and data management and communications. In addition, enabling organizations will be necessary to foster technology innovation and to help train the future ocean science workforce.

More Use of Autonomous and Unmanned Platforms. An examination of trends revealed that, in the past two decades, the use of floats, gliders, ROVs, AUVs and scientific seafloor cables has increased; the use of ships, drifters, moorings and towed platforms has remained stable; and the use of human-occupied vehicles has declined. Based on these trends and on the major science questions for 2030, it is anticipated that utilization and capabilities for floats, gliders, ROVs, AUVs, submarine scientific cables and moorings will continue to increase significantly for the next 20 years. Ships will continue to be an essential component of ocean research infrastructure; however, the increasing use of autonomous and unmanned assets will broaden the demands for a wide range of ship capabilities.

Improving Sensor Capabilities. Many sensor capabilities have increased, including longevity, stability, data communications, adaptability and access to harsh environments. These improvements are mostly dependent on innovations occurring outside the ocean science field, and the oceanographic community will continue to benefit from innovations in sensor and other technologies across many fields. Developing the mechanisms to maximize this technology transfer should be a major focus for the community.

Increased Remote Data Users. Ultimately, the success of ocean infrastructure will be measured by how well it enables advancement of the ocean sciences. However, the process by which science is accomplished is being transformed by access to a data-rich environment. In 1990, the user community of most ocean infrastructure largely consisted of seagoing scientists who

Major Themes

Four major themes will drive scientific research over the next two decades.

Enabling Stewardship of the Environment

- How will sea level change, and what are the potential impacts?
- What advances will be made in prediction and mitigation of oil spills and marine industrial accidents?
- How will marine ecosystem structure, biodiversity and population dynamics be shaped by a changing ocean?
- How will marine organisms and ecosystems be affected by ocean acidification?
- How will climate change influence the distribution of chemical elements?
- How do the distributions and fluxes of organic carbon components evolve in an altered ocean?
- How and why will ocean circulation and the distribution of heat in the ocean and atmosphere change?
- How will alterations in the global water cycle influence the ocean?
- How will changes at coastal boundaries alter physical and geochemical processes?
- How will coastal ecosystems respond to multiple stressors?
- What are the interactions of the ocean, ice, land and atmosphere in polar regions?
- What are the potential impacts on the ocean from geoengineering?

Protecting Life and Property

- How does strain accumulate in underwater volcanoes and fault zones?
- How can the understanding and prediction of tsunamis be improved?
- How can the understanding and prediction of path and intensity of severe storms be improved?
- How will the extent and characteristics of sea ice and icebergs change?
- What is the role of coastal pollutants and pathogens on human and ecosystem health?
- How do changes in the coupled ocean-climate system affect human health and welfare?
- What is needed for better forecasting of major events?
- How can the impacts of sea ice change be mitigated?

Promoting Economic Vitality

- How can humanity ensure sustainable food production in the ocean?
- How can humanity maximize energy and mineral resource extraction while minimizing impacts?
- What is the ocean's potential as a source of renewable energy?

Increasing Fundamental Scientific Understanding

- How does Earth's interior work, and how does it affect plate boundaries, hot spots and surface manifestations?
- What are the plausible rates and magnitudes of climate change?
- How can the effects of ocean and atmosphere interactions be better parameterized?
- What processes dominate mixing in the ocean and on what space and timescales?
- How does fluid circulation within the ocean crust impact chemistry and biology of the subseafloor and the hydrosphere?
- How does the deep ocean biosphere inform the origin and evolution of life?
- What regulates the diversity and rates of molecular and biochemical evolution in the ocean?
- What is the biodiversity of the deep sea?
- What are the sensory and communication systems in marine ecosystems?
- How does the ocean contribute to the Earth's carrying capacity?

required access to ships and submersibles. In 2030, the user community will likely be quite different, with a greater percentage of scientists who only interact with the ocean remotely, through data supplied via the Internet.

Increasing Partnerships and Collaboration. While the trajectory of science cannot be predicted, it seems likely that significant transformations are in store and indeed will likely be enabled by a more effective ocean infrastructure. This argues above all for an ocean infrastructure that is highly responsive to the needs of a changing ocean science enterprise. Substantial and meaningful collaboration between nations; across agencies; among federal, state and local governments; among academic, government, nongovernmental and industry sectors; and between disciplines will not only maximize the value of infrastructure investments but will in fact be required to meet the growing science and societal needs of 2030 and beyond. These partnerships will work at a maximum level when the goals, responsibilities, resources and data sharing, and limits are agreed upon at the onset. For the ocean research enterprise, these types of collaborations are inherently interdisciplinary and multidisciplinary. However, the overall success rates and effectiveness of all collaborations need to be improved.

Helping to Develop New Capabilities

The technological foundations underpinning ocean infrastructure continue to evolve rapidly, enabling both incremental changes and revolutionary new capabilities. Development of future ocean research infrastructure will encourage exploration of new pathways to make successful technologies broadly available to the research, commercial and operational communities.

New capabilities are also often accompanied by the creation of business opportunities that support economic growth. Best practices for encouraging the next generation of ocean infrastructure include allocating adequate resources for developing new innovations, which ensures continual improvement of research infrastructure, and sustaining efforts in the long term (a decade or more), which allows research teams to pursue promising technologies for the full development-to-application cycle. Another good practice is supporting refinement and validation of prototype technologies, building user awareness, and promoting early opportunities for commercial exploitation.

While it is impossible to predict which technologies and capabilities will attract

Committee Members	Institution
Eric J. Barron (**Chair**)	Florida State University
Rana A. Fine (**Vice Chair**)	University of Miami
James G. Bellingham	Monterey Bay Aquarium Research Institute
Emmanuel S. Boss	University of Maine
Edward A. Boyle	Massachusetts Institute of Technology
Margo Edwards	University of Hawai'i at Manoa
Kenneth S. Johnson	Monterey Bay Aquarium Research Institute
Deborah S. Kelley	University of Washington
Hauke Kite-Powell	Woods Hole Oceanographic Institution
Steven Ramberg	National Defense University/Pennsylvania State University
Daniel L. Rudnick	Scripps Institution of Oceanography
Oscar Schofield	Rutgers University, New Jersey
Mario N. Tamburri	University of Maryland Center for Environmental Science
Peter H. Wiebe	Woods Hole Oceanographic Institution
Dawn J. Wright	Oregon State University
Deborah Glickson	National Research Council
Heather Chiarello	National Research Council
Will Tyburczy	National Research Council

The National Research Council committee and staff responsible for the **Infrastructure Strategy for U.S. Ocean Research in 2030** *report.*

capital in the global marketplace of 2030, it is likely that many ocean science infrastructure components will appeal to small markets. In these cases, incentives could be provided to develop assets that have potential to address societal needs. Ensuring that optimal investments transition from research to operation and commercialization could be part of the five-to-10-year formal infrastructure review.

Encouraging high-risk, high-reward activities would ensure novel approaches remain part of the technology portfolio. This could be incentivized through collaboration, which encourages communication and lowers barriers between oceanography and allied disciplines (e.g., medicine, engineering, computer science). A final but essential step is educating and training the next generation of engineers, technologists and scientific users. ■

Eric J. Barron is president of Florida State University. He was the director of the National Center for Atmospheric Research and was dean of the Jackson School of Geosciences at the University of Texas at Austin. Barron's research interests are climatology, numerical modeling and Earth history.

Rana A. Fine is a professor of marine and atmospheric chemistry at the University of Miami's Rosenstiel School of Marine and Atmospheric Science. Her current research objective is to better understand the role of the oceans in climate change occurring on timescales of up to decades.

Oscar Schofield is a professor at the Institute of Marine and Coastal Science at Rutgers University. His research interests include environmental regulation of primary productivity in aquatic ecosystems, physiological ecology of phytoplankton, hydrological optics and integrated ocean observatories.