NATIONAL ACADEMY OF SCIENCES
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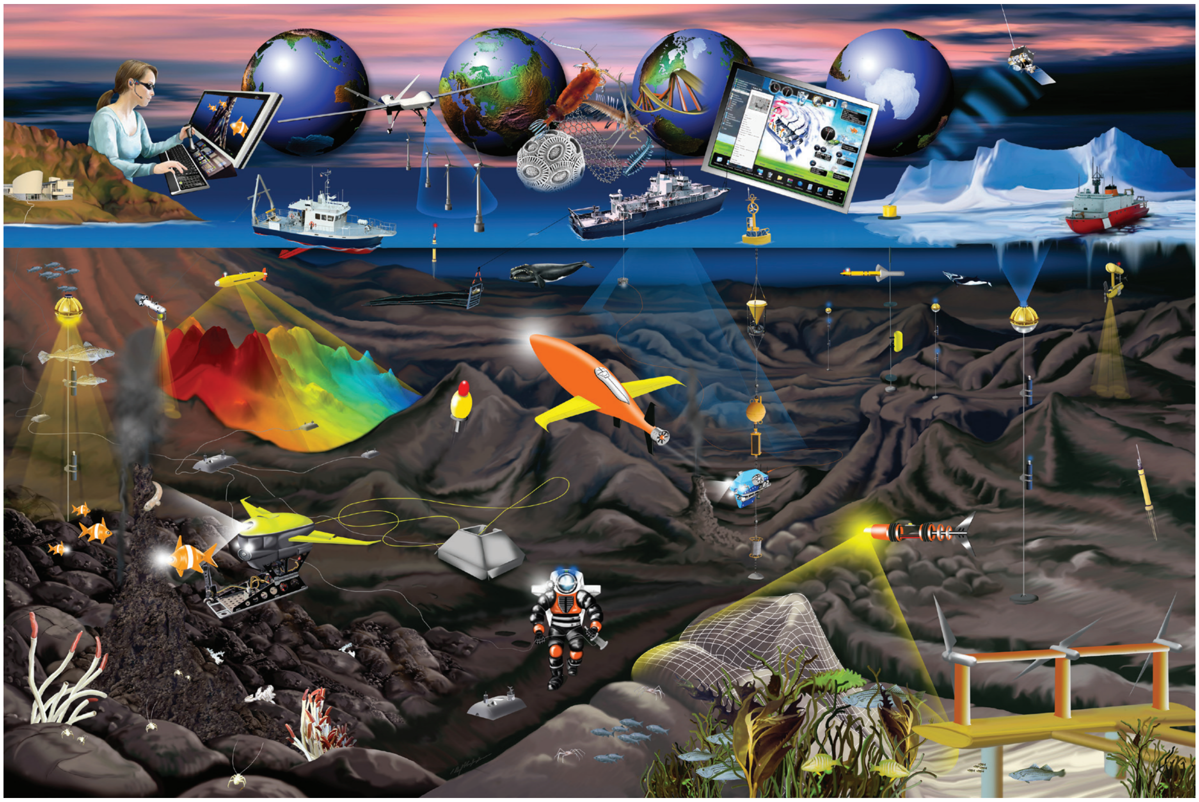
Critical Infrastructure for Ocean Research and Societal Needs in 2030

U.S. ocean research depends on a broad range of ocean infrastructure assets—the national inventory of ships and other platforms, sensors and samplers, computational and data systems, supporting facilities, and trained personnel. In order to ensure that essential infrastructure is available for both fundamental research and issues of social importance in 2030, a coordinated national plan for making future strategic investments is necessary. A growing suite of infrastructure will be needed to address urgent societal issues in coming years, such as climate change, offshore energy production, tsunami detection, and sustainable fisheries. This report identifies major ocean science questions anticipated to be significant in 2030, defines the categories of infrastructure needed to support such research over the next two decades, identifies criteria that could help prioritize infrastructure development or replacement, and suggests ways to maximize investments in ocean infrastructure.



The United States has jurisdiction over 3.4 million square miles of ocean—an expanse greater than the land area of all 50 states combined. This vast marine area offers many environmental resources and economic opportunities, but also presents threats, such as damaging tsunamis and hurricanes, industrial accidents, and outbreaks of waterborne pathogens. The 2010 Gulf of Mexico *Deepwater Horizon* oil spill and 2011 Japanese earthquake and tsunami are vivid reminders that our understanding of the ocean system is still incomplete.

The nation's portfolio of ocean infrastructure changes over time in response to scientific needs, investments, and to advances in technology. However, because of lengthy lead times for planning, designing, funding and building major infrastructure assets, and because of the long service life of many of these assets (often 25–30 years or more), federal agencies with ocean responsibilities need to anticipate the directions that ocean research could take in coming decades. Some critical pieces of ocean infrastructure, for example heavy icebreakers and ocean color satellites, are degrading and will be in need of replacement in coming years. To assist in planning for the nation's future ocean infrastructure needs, the National Science and Technology Council's Subcommittee on Ocean Science and Technology requested that the National Research Council convene a committee of experts to provide advice on the types of U.S. ocean infrastructure that will facilitate research in 2030.

Major Ocean Research Questions of 2030

Using input from the worldwide scientific community, a range of recent government plans, task force documents, research planning assessments, and a review of primary literature, the committee identified compelling research questions anticipated to be at the forefront of ocean science in 2030. These research questions fall under four themes:

1. Enabling stewardship of the environment
Many human activities have impacts on the ocean. With over 12,000 miles of coastline, the U.S. has particular interest in effects on the coastal ocean. The polar regions, with sensitivity to changes in climate and sea level, are also a high priority. Increased understanding of the ocean's physical, chemical, and biological responses to factors such as climate change, mineral and energy extraction, fishing, waste production, and nutrient pollution could help limit these impacts.

2. Protecting life and property
Recent catastrophic events in the U.S. and worldwide have raised interest in predicting and limiting the effects of natural hazards such as earthquakes, severe storms, and tsunamis. Growing concern about the effects of climate change, for example sea level rise and its effect on coastal infrastructure, is likely to drive interest in this research area in coming years and well beyond 2030.

3. Promoting economic vitality
Traditional uses of the ocean, such as oil and gas extraction, fisheries, transportation, shipping, and recreation, are large components of the U.S. ocean economy. Other activities such as aquaculture, wind power, and marine hydrokinetic resources, are poised to become more important over the next two decades. The sustainability of these resources for future generations is of great importance, as is minimizing adverse impacts on the marine environment.

4. Increasing fundamental scientific understanding
Basic research has a long history of producing discoveries that advance scientific understanding and that improve economic well-being. Many of these advances eventually lead to an increased ability to act on societal issues, such as stewardship of the environment, protection of life and property, and promotion of sustainable economic vitality.

Building the Ocean Infrastructure Inventory

A comprehensive range of ocean research infrastructure will be needed to meet growing demands for scientific information to enable the safe, efficient, and environmentally sustainable use of the ocean. Institutional barriers have inhibited collaborative efforts among federal agencies to plan for the operation and maintenance of high-cost critical infrastructure assets such as ships, satellites, and global observing systems. Establishing and maintaining a coordinated national strategic plan for shared ocean infrastructure investment and maintenance is essential to build the comprehensive range of ocean infrastructure that will be needed in coming years. Such a plan would focus on trends in scientific needs and advances in technology, while taking into account factors such as costs, efficient use, and the capacity to cope with unforeseen events.

Overarching Infrastructure Needs

The committee identified overarching infrastructure needs based on trends in ocean infrastructure use over the last two or more decades and on the major research questions anticipated for 2030. It focused on common or shared infrastructure, rather than equipment generally found in the inventory of an individual scientist. The committee expects that research vessels will continue to be an essential element of ocean research infrastructure. Ships serve as platforms for sample collection, for deployment of remotely operated and autonomous vehicles, and as tenders for instrument maintenance. Shore-based laboratory facilities will also continue to be required as a natural extension to ship-based sampling, for analytical work, and for coastal observations.

Satellite observations will be increasingly important for the ocean sciences, providing data on vector sea surface wind, sea surface temperature and salinity, sea ice distribution and thickness, and ocean carbon and ecosystem dynamics.

Another critical component is the global array of Argo profiling floats, which measure ocean temperature and salinity at varying depths. Expansion of the current network of 3000 floats by addition of novel sensors would further enable study of the ocean's physical, biological, and chemical processes. New sensors for oxygen, nitrate, chlorophyll, zooplankton, pH, and carbon dioxide measurements are currently available or in development.

The committee noted the increasing use of autonomous platforms, such as gliders and autonomous underwater vehicles, with a wider range of sensors. The capabilities of both sensors and platforms will continue to improve in such areas as longevity, stability, data communications, adaptability, and access to harsh environments.

Continued developments in ocean infrastructure increasingly depend on innovations in other fields, including engineering and computer science. This is in part due to decreases in funding for high risk, high reward research and for development of novel ocean research technologies. To foster innovation and technological advancements in the ocean sciences, federal agencies will need to encourage a risk-taking environment for the development of new infrastructure, which is difficult under the current systems of research funding.

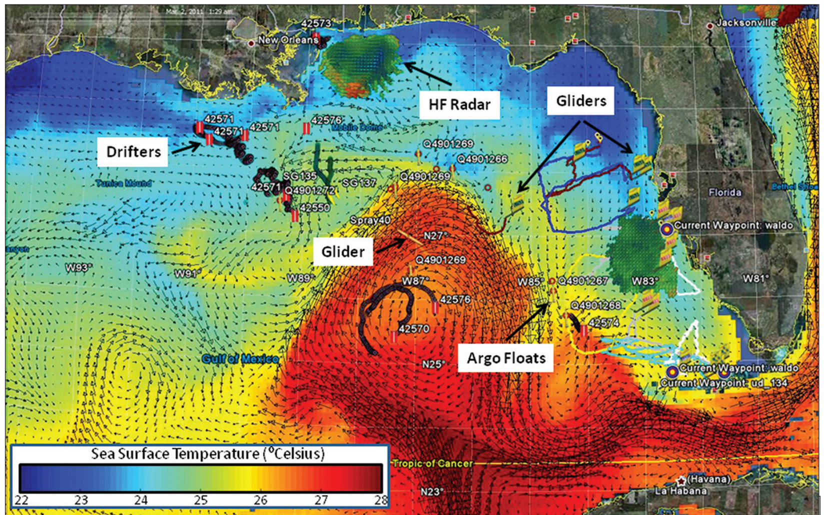
In situ sensors and sampling tools allow researchers to collect direct observations of the ocean's physical, chemical, biological, geophysical, and geological properties. Relatively small and inexpensive versions of biological sensors that can replicate today's complicated laboratory techniques will be essential in coastal and near-shore environments. New biogeochemical sensors that enable better observations of the carbon system, including pH, and micronutrients will also be central to ocean science in the future.

The committee concluded that the following actions would help ensure that the U.S. has the capacity in 2030 to undertake and benefit from knowledge and innovations possible with oceanographic research:

- **Implement a comprehensive, long-term research fleet plan to retain access to the sea**
- **Recover U.S. capability to access full and partially ice-covered seas**
- **Expand abilities for autonomous monitoring at a wide range of spatial and temporal scales with greater sensor and platform capabilities**
- **Enable sustained, continuous timeseries 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 federally, 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**

Setting Priorities and Maximizing Investments

Prioritizing investments in ocean infrastructure involves choosing optimal combinations of assets within budget restraints. The committee devised criteria that could help agencies prioritize investments, taking account of issues such as whether the infrastructure can help address more than one research question, the quality of the data collected using the infrastructure, and future technology trends. **The committee concluded that the development, maintenance, and replacement of ocean research infrastructure should be prioritized in such a way to maximize the benefits from the infrastructure. This type of economic optimization includes consideration of factors such as:**



The 2010 Deepwater Horizon oil spill demonstrated the diverse range of infrastructure needed to provide a timely, integrated response to a disaster. The color map and vectors represents a Naval Oceanographic Office ocean model simulation, and graphics and tracks represent *in situ* assets such as drifters, underwater gliders, and remotely operated vehicles.

1. **usefulness of the infrastructure for addressing important science questions**
2. **affordability, efficiency, and longevity of the infrastructure**
3. **ability to contribute to other missions or applications**

Federal agencies can maximize the value of ocean infrastructure by following a number of best practices, including efficiently managing resources, providing broad access to data and facilities, fostering collaboration at many levels, and enabling the transition from research to broader use. **Conducting formal reviews of ocean infrastructure assets approximately every 5–10 years would help ensure the infrastructure remains useful across the full range of ocean science research needs.**

Committee on an Ocean Infrastructure Strategy for U.S. Ocean Research in 2030: Eric J. Barron (*Chair*), Florida State University; **Rana A. Fine** (*Vice Chair*), University of Miami, Florida; **James G. Bellingham**, Monterey Bay Aquarium Research Institute, California; **Emmanuel S. Boss**, University of Maine; **Edward A. Boyle** (NAS), Massachusetts Institute of Technology; **Margo Edwards**, University of Hawaii at Manoa; **Kenneth S. Johnson**, Monterey Bay Aquarium Research Institute, California; **Deborah S. Kelley**, University of Washington; **Hauke Kite-Powell**, Woods Hole Oceanographic Institution, Massachusetts; **Steven Ramberg**, National Defense University / Pennsylvania State University; **Daniel L. Rudnick**, Scripps Institution of Oceanography, California; **Oscar M.E. Schofield**, Rutgers University; **Mario Tamburri**, University of Maryland Center for Environmental Science; **Peter H. Wiebe**, Woods Hole Oceanographic Institution, Massachusetts; **Dawn J. Wright**, Oregon State University; **Deborah Glickson** (*Senior Program Officer*), **Heather Chiarello** (*Senior Program Assistant, until October 2010*), **Emily Oliver** (*Program Assistant, from October 2010*), **Will Tyburczy** *(Mirzayan Science and Technology Policy Fellow, Fall 2010),* National Research Council.

The National Academies appointed the above committee of experts to address the specific task requested by the National Oceanic and Atmospheric Administration, National Science Foundation, National Aeronautics and Space Administration, U.S. Geological Survey, National Institute of Environmental Health Science, Department of Energy, Environmental Protection Agency, Marine Mammal Commission, Arctic Research Commission, Minerals Management Service, and the Food and Drug Administration.The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.

EXPERT CONSENSUS REPORT

For more information, contact the Ocean Studies Board at (202) 334-2714 or visit http://dels.nas.edu/osb. Copies of *Critical Infrastructure for Ocean Research and Societal Needs in 2030* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.