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Introduction to the Special Issue on the

Ocean Observatories Initiative

By Leslie M. Smith, Timothy J. Cowles, Robert D. Vaillancourt, and Subbarao Yelisetti

INTRODUCTION

The Ocean Observatories Initiative (OOI) is a National Science Foundation (NSF)-funded major research facility operated as a community resource to provide continuous observations of the ocean and seafloor from several key locations. The data collected, maintained, and disseminated by OOI addresses large-scale scientific challenges such as coastal ocean dynamics, climate and ecosystem health, the global carbon cycle, and linkages among seafloor volcanism and life. The system was designed to grow as it incorporates new technologies and accommodates novel research ideas and approaches proposed by individual research scientists. Unlike most facilities, the OOI is mostly operated remotely; engagement by the user community is online through dedicated cyberinfrastructure. The OOI allows scientists unprecedented access to ocean data collected in remote locations and delivers it at high temporal and spatial resolutions, in near-real time, when practicable (**Smith et al.**).

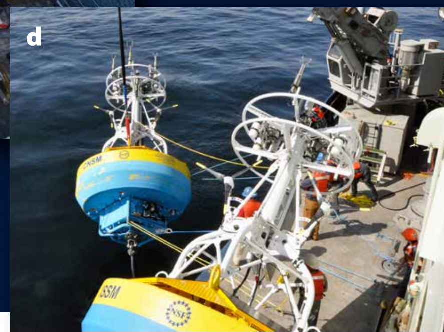
What follows in the pages of this special issue of *Oceanography* brings readers, in many cases, the results of the first scientific studies using the diverse and unique data sets collected from the OOI's Coastal, Global, and Cabled Arrays. The articles and sidebars highlight unique features of this facility, focusing on key OOI data and science themes, community-developed tools, and ways that OOI data can provide the environmental and observational context for initializing and designing novel research and technologies. The articles examine ocean processes across multiple dimensions, revealing previously difficult-to-capture phenomena on temporal scales from seconds to years and spatial scales from centimeters to kilometers.

OBSERVATIONS ACROSS SCALES

The continuously operating OOI permits sampling of short-lived, episodic events, enabling scientists to be in the "right place at the right time," such as capturing the 2.5-minute window of the total solar eclipse in 2017 (**Barth et al.**) or watching the progression of the 2015 Axial Seamount eruption in near-real time (**Wilcock et al.**). Capturing events as they occur provides key insights into preconditions, initial onset, and event evolution often missed by traditional sampling approaches and platforms. Data collected at OOI sites before, during, and after events can enhance understanding of other events where previously only after-event information was collected. For example, OOI data recorded during the 2015 Axial Seamount eruption led to a new interpretation of the cause of a 2006 eruption in the equatorial Pacific (**Tolstoy et al.**). Real-time monitoring of an event also enables scientists to quickly mobilize to collect additional samples. For example, **Spietz et al.** conducted a rapid response cruise following the 2015 Axial Seamount eruption to sample microbial communities surrounding the eruption site. Real-time sampling and near real-time data access are also critical for earthquake monitoring (**Tréhu et al.**)

In some cases, the OOI provides the first year-round observations at previously sparsely sampled locations. For example, insight into mixed layer processes during winter in the Irminger Sea provided a key missing link for understanding the biological pump in the subarctic Atlantic Ocean (**Palevsky and Nicholson**). During the 25 years of the OOI's planned lifetime, it will be possible to examine decadal dynamics, such as the El Niño-Southern Oscillation in the Northeast Pacific and the Arctic Oscillation in the North Atlantic. We are still years from extracting decadal dynamics from the OOI data, but shorter, multiyear-scale phenomena are now being observed, such as the "warm blob" event in the Northeast Pacific as well as the seasonal formation of hypoxia (**Barth et al.**).

Detailed spatial coverage within each OOI array permits examination



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(b) *OOI Pioneer Array Program, WHOI*
(c) *OOI Cabled Array Program, UW: V15*
(d) *OOI Pioneer Array Program, WHOI*
(e) *OOI Endurance Array Program, OSU*

of patchy phenomena such as heat balance (**Chen et al.**) and warm core rings (**Gawarkiewicz et al.**) in the Northwest Atlantic, and the juxtaposing forces of upwelling and riverine freshwater input in the Northeast Pacific (**Henderikx Freitas et al.**). On a larger scale, the OOI provides data to support regional-scale observations of phenomena among multiple OOI arrays, such as tracing the warm blob from the Gulf of Alaska to Oregon coastal waters (**Barth et al.**). Additionally, OOI data can aid in regional spatial analyses, such as in the Irminger Sea (**de Jong et al.**), when used in concert with data from other nearby observatories, and off the coast of New England (**Stocks et al.**), where a diversity of data sets and sampling assets are available.

OVERVIEW AND GLOBAL CONTEXT

This *Oceanography* special issue begins with an overarching summary of the OOI (**Smith et al.**) that describes its scientific motivations and overall design, outlines its infrastructure, and provides details of how data are collected, transmitted, processed, quality controlled, and distributed. Further details of data access can be found in the **Vardaro and McDonnell** sidebar. **Lindstrom** highlights how the OOI fits into the broader global ocean observing efforts, not only through its contribution of data but also through its commitment to driving and providing a testbed for technological innovation in ocean observing platform and sensor design. **Reimers and Wolf** exemplify this commitment, wherein authors describe their novel Benthic Observer powered by energy harvested with a benthic microbial fuel cell. This autonomous platform offers a potential low-cost alternative for benthic boundary layer observations. These platforms were deployed next to an Endurance Array Cabled Benthic Experiment Package off the coast of Oregon during OOI maintenance cruises in order to compare and validate their data.

GLOBAL IRMINGER SEA ARRAY

Two articles in this special issue highlight the Global Irminger Sea Array off the coast of Greenland. In the first article, **Palevsky and Nicholson** synthesize biogeochemical sensor data from the first two years of operations at the array. These data provide the first simultaneous year-round observations of biological carbon cycling processes in both the surface ocean and the seasonal thermocline in this critical region of the subpolar North Atlantic. These data show significant mixed layer net autotrophy during the spring bloom, respiration in the seasonal thermocline during the stratified season, and subsequent ventilation during winter convective mixing. The results represent a measurable reduction in potential carbon sequestration, highlighting the importance of year-round observations to accurately constrain the biological pump in the subpolar North Atlantic.

In the second article, **de Jong et al.** further investigate deep mixing and convection in the subpolar North Atlantic. In this study, the authors use observations from the OOI Irminger Sea mooring array in combination with other nearby moorings (an 86 × 35 km domain) to evaluate spatial differences in the cycles of deep convection and restratification off southern Greenland over two annual cycles. Although surface forcing was observed to be stronger in the northern portion of the domain, the deeper convection occurred in the southern portion of the domain. The OOI moorings in the north were subject to intermittent lateral advection, via eddies and filaments, of slightly warmer water from the Irminger Current. These events initiated more frequent restratification in the north than occurred in the southern portion of the domain. The findings point to the critical importance of mesoscale resolution of overturning and atmospheric forcing at frequent intervals within an annual cycle.

COASTAL PIONEER ARRAY

To the south, off the coast of New England, exchange processes across the continental shelf and slope are examined using Pioneer Array data. **Gawarkiewicz et al.**

(a) *NSF-OOI/UW/ISS; Dive R1767; V14*
(b) *OOI Global Array Program, WHOI*
(c) *OOI Endurance Array Program, OSU*

examine shelf-slope exchange processes that were previously difficult to study at the appropriate temporal and spatial resolution. In this study, the authors report that coastal ocean dynamics are changing rapidly, with more frequent extreme events of warm, salty Gulf Stream waters intruding onto the shelf and penetrating further onshore than previous studies suggested. A better understanding of these exchanges is critical as these warm, salty intrusions can potentially have large impacts on commercial fisheries, ecosystems, and storm intensity.

Using the capability of the Pioneer Array to capture multiscale processes, **Chen et al.** demonstrate the scale dependence of the heat balance at the southern New England shelf break, and show the importance of advective processes in the overall heat balance over the continental shelf and slope. Knowledge of the temperature variability and heat budget of the outer continental shelf and shelf break region are fundamentally important to understanding the influence of climate change in the coastal ocean as well as the direct economic impact on the harvesting of living marine resources.

Finally, the **Stocks et al.** sidebar places the Pioneer data in a regional context, highlighting the SeaView Pioneer Array data collection. One of three SeaView thematic collections, the Pioneer collection is a free resource for obtaining nearby oceanographic data that are integrated and reformatted in the SeaView repository for ease of download and use.

COASTAL ENDURANCE ARRAY

On the other side of the continent, coastal processes are examined in the Northeast Pacific off the coast of Oregon and Washington. **Henderikx Freitas et al.** present a multiyear, multiplatform study of the cross- and along-shelf patterns of river flow, upwelling, and chlorophyll dynamics. Satellite observations—traditionally used to study the area—are compared to in situ OOI Endurance Array mooring and glider data. In situ observations from OOI instrumentation reveal chlorophyll concentrations of similar magnitude between Oregon and Washington coasts, contrasting with satellite data, which consistently show higher chlorophyll concentrations off the Washington coast. The authors suggest that observed elevated chromophoric dissolved organic matter (CDOM), likely from the nearby Columbia River plume, may help to explain the differences between satellite-derived chlorophyll and in situ observations. This preliminary report demonstrates the strength of the approach of using multiplatform, multiyear data sets to understand complexity within this dynamic coastal system.

Barth et al. describe three phenomena with durations that span from minutes to years to demonstrate the unique ability of these platforms to capture ocean phenomena that vary across a wide range of timescales: (1) a diel biological response to the total eclipse of the sun on August 21, 2017, where a layer of zooplankton was observed to vertically migrate upward during the midday total solar eclipse in what is a typical nighttime response to diminished light, (2) the devastating effects of a seasonal-scale hypoxic event in July off the central Oregon coast on a population of Dungeness crabs, and (3) the appearance and multiyear persistence of an anomalously warm upper-ocean feature in the Northeast Pacific, the warm blob.

CABLED ARRAY

The OOI Cabled Array spans the Juan de Fuca Plate in the Northeast Pacific, providing observations both at an offshore seafloor spreading center with its active underwater volcano, Axial Seamount (**Wilcock, et al.**), and at the Cascadia subduction zone closer to the coast (**Tréhu et al.**).

Tréhu et al. provide background on the Cascadia subduction zone, highlighting some of its unusual aspects, such as past great earthquakes. The Cascadia subduction zone is fairly quiet during interseismic times, which makes monitoring the earthquake-producing zone a challenge. The authors use available offshore seismic data, including from the OOI, to demonstrate the benefits of using offshore data in detection and accurate location of small magnitude earthquakes in this region. They show that the quality of data from buried OOI seismometers is better than that from campaign style ocean bottom seismometer deployments. The authors make the case for obtaining real-time ocean bottom seismic recordings to improve earthquake monitoring offshore of the Cascadia margin, rather than depending only on data from instruments recovered after several months on the seafloor.

Several papers capture various aspects of the 2015 Axial Seamount eruption, the first undersea volcanic eruption observed in real time. **Wilcock et al.** provide a comprehensive analysis of Axial Seamount using data from the OOI Cabled Array system. Cabled Array seismic data show that inflation and deflation are accommodated by fault motions beneath the caldera, and eruptions appear to occur at a predictable level of inflation. The authors also compare the 2015 Axial volcanic eruption results with two historical eruptions from 1998 and 2011, and conclude by discussing how the observatory might be enhanced prior to the next eruption. **Tolstoy et al.** show how the real-time observations of the 2015 Axial Seamount eruption described by **Wilcock et al.** inspired a fresh look at older data recorded at the East Pacific Rise, and led to new discoveries. They compare geophysical signals leading up to and during eruptions at both locations, and note the difference in timing of the magmatic tremor. They conclude that one of the eruptions appears to have initiated from a "tearing" of the seafloor due to plate spreading (East Pacific Rise), while the other initiated from the more typical buildup of magma pressure observed in volcanic systems (Axial Seamount). Lastly, **Spietz et al.** present the results from a rapid response cruise following the same 2015 eruption. They report post-eruption changes in the chemical and microbiological properties of the water column with an elevated level of presumed chemosynthetic microbial lineages. This study relied on OOI data for the locations of seismic events and activity to identify sampling sites, further demonstrating the necessity of real-time detection for future biological studies.

EDUCATION AND PUBLIC ENGAGEMENT

As described in the articles and sidebars of this issue, there are a variety of ways to engage with the OOI system and its data (enumerated in **Ulses et al.**). In addition to its utility for the oceanographic community, the OOI is a resource for the educational community. **McDonnell et al.** provide valuable insights into the development and application of software tools for educators wishing to engage students with real-time data. The authors use the outcomes of the development and testing process to illustrate successful pedagogical approaches using OOI data in classroom settings. **Bigham** describes the digital catalog of deep-sea creatures built by undergraduates from video and still imagery collected by remotely operated vehicles at the Axial Seamount Cabled Observatory. The Axial Seamount Biology Catalog project engaged students in the research process, provided a wealth of seagoing experiences, and led to the creation of a one-of-a-kind resource for Northeast Pacific biology intended for scientists, educators, news agencies, and documentary producers. An overview of the Seastate project by **Kelley and Grünbaum** focuses on student-driven design, building, and implementation of sensors to address locally relevant environmental problems. In this project, K20 teachers and students are trained to improve their computing, science, technology, engineering, and mathematics (C+STEM) knowledge.

SUMMARY

This special issue of *Oceanography* provides an initial view of the breadth and scope of scientific analysis and evaluation made possible by the data flowing from the extensive OOI infrastructure. The articles illustrate the value the OOI and its data offer the scientific community, including opportunities to:

- Observe phenomena across multiple temporal and spatial scales
- Capture rare and episodic events
- Create long-term data records in previously poorly sampled ocean regions
- Make observations of patchy distributions of materials, energy fluxes, and processes
- Augment OOI observations with those from other ocean observing assets (e.g., remote sensing, shipboard, Argo profiling floats, US Geological Survey river gauges)
- Provide a testbed for technological innovation, extending the capabilities of present assets and instrumentation
- Enhance learning opportunities with real-time ocean observations

We encourage readers of this special issue to build upon this list, and extend the opportunities for the use of OOI data to address compelling scientific, educational, and societal issues.

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AUTHORS

Leslie M. Smith (lsmith@oceanleadership.org) is OOI Science Communicator, Consortium for Ocean Leadership, Washington, DC, USA. **Timothy J. Cowles** is Professor Emeritus, Oregon State University, Corvallis, OR, USA. **Robert D. Vaillancourt** is Associate Professor of Oceanography, Millersville University, Millersville, PA, USA. **Subbarao Yelisetti** is Assistant Professor of Geophysics, Texas A&M University-Kingsville, Kingsville, TX, USA.

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