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Warm Blobs, Low-Oxygen Events, and an Eclipse

THE OCEAN OBSERVATORIES INITIATIVE ENDURANCE ARRAY CAPTURES THEM ALL

By John A. Barth, Jonathan P. Fram, Edward P. Dever, Craig M. Risien, Chris E. Wingard, Robert W. Collier, and Thomas D. Kearney

ABSTRACT. The Ocean Observatories Initiative (OOI) Endurance Array in the Northeast Pacific off the coasts of Oregon and Washington is designed to measure changes in the ocean on timescales from hours to decades. The Endurance Array is located halfway between the pole and the equator in one of the major coastal upwelling systems on our planet, the California Current System. This area is forced locally by winds, waves, tides, and freshwater inputs from rivers and, more broadly, by large-scale ocean-atmosphere phenomena from both the south, for example, the El Niño-Southern Oscillation, and the north, for example, changes originating in the subarctic Gulf of Alaska. The Endurance Array spans the continental shelf and slope and hosts a variety of platforms and sensors for measuring physical-biogeochemical oceanographic processes. After briefly introducing the unique OOI platforms and range of sensors that make up the Endurance Array, we describe three phenomena with durations spanning hours to years. These include an ocean response to the total eclipse of the Sun on August 21, 2017, the devastating effects of a low-oxygen event off central Oregon, and the appearance of an anomalously warm upper-ocean feature off the Pacific Northwest in recent years.

INTRODUCTION

The Ocean Observatories Initiative (OOI) Endurance Array spans the continental shelf and slope in the Northeast Pacific. The scientific motivation behind the array design was the need to measure and understand a wide variety of ocean-atmosphere and physical-biogeochemical processes that influence marine ecosystems in this region. Spring and summer wind-driven coastal upwellings strongly influence the Oregon and Washington shelves (R.L. Smith, 1974). Understanding gained from this upwelling region is valuable for comparisons with the other major upwelling systems around the world, including the Humboldt Current, the Benguela Current, and the Canary Current. In winter, the Oregon and Washington coasts are subject to strong wind-driven downwelling, large waves, and swift northward currents. The Columbia River, the largest source of freshwater to the US west coast, also influences the region. The oceanographic instruments and measurement platforms, and their placement across the continental margin off Oregon and Washington, were chosen to study physical-biogeochemical interactions in the ocean. Here, we describe early results from the OOI Endurance Array that demonstrate the observatory's utility for studying phenomena that change over hours to years.

The OOI Endurance Array is part of the more extensive ocean observing network in the Northeast Pacific that includes the OOI Cabled Array and the OOI Global Station Papa site (L.M. Smith et al., 2018, in this issue), the latter in partnership with a mooring maintained by the National Oceanic and Atmospheric Administration (NOAA). The Ocean Networks Canada NEPTUNE and VENUS arrays (http://www.oceannetworks.ca) and the NOAA-supported Northwest Association of Networked Ocean Observatories (NANOOS; http://nanoos.org) assets provide even greater coverage in this region. This combination of ocean observatories affords an exceptional opportunity to study coastal ocean processes and long-term change within the context of regional climate and ocean changes.

Pacific Northwest (PNW) waters are home to a diverse range of highly productive, profitable marine fisheries, including iconic species such as Dungeness crab, razor clams, salmon, groundfish, and hake. These successful fisheries rely on the injection of nutrients into the euphotic zone by upwelling and the subsequent blooms of phytoplankton that form the base of the oceanic food web. However, this productive chain of events can sometimes be altered to the detriment of fisheries by a variety of atmospheric, oceanographic, and biogeochemical processes, as well as anthropogenic influence.

Over the last 15 years, PNW waters have been exposed to hypoxic and even anoxic events (Grantham et al., 2004; Chan et al., 2008) that have the potential to severely disrupt local fisheries. The region is also known for the appearance of harmful algal blooms that generate toxic substances that become incorporated into the ocean food chain, leading to closures of valuable recreational and commercial fisheries. These interdisciplinary ocean challenges require measuring ocean properties from physics to chemistry to biology on many different timescales, a capability of the Endurance Array.

Climate and ocean anomalies on year-to-year ("interannual") and decade-to-decade ("interdecadal") timescales influence PNW waters. In response to interannual variability forced by the El Niño-Southern Oscillation at the equator, upper-ocean stratification, ocean currents, and local winds all change in the Northeast Pacific as a result of signals that travel to the PNW through both the ocean and the atmosphere (Huyer et al., 2002). On interdecadal timescales, PNW waters are affected by the Pacific Decadal Oscillation, which manifests itself as 10–40 year cycles in upper-ocean temperature and swings between dominance by northern, "fatty" zooplankton and southern, "skinny" zooplankton (Peterson and Schwing, 2003).

ENDURANCE ARRAY MEASUREMENT PLATFORMS AND SENSORS

Coastal waters in the Northeast Pacific change on timescales from hours to decades. This huge range, almost five orders of magnitude, requires programming ocean sensors to sample at intervals on the order of minutes while deployed on platforms designed and operated to endure for decades. After a brief introduction of the overall Endurance Array design, we describe in more detail the instruments and platforms used in the array.

The Endurance Array employs a variety of oceanographic sampling platforms, including coastal surface moorings, water column profilers, and instruments on the seafloor and on a midwater platform. The Endurance Array backbone includes the Oregon Line, off Newport near 44.6°N, and the Washington Line, off Grays Harbor near 47°N (Figure 1). These lines each have three sites: one at the inner shelf (~25–30 m water depth, 4–6 km from shore, referred to as "Inshore"), the "Shelf" (~80–90 m depth, 20–30 km from shore), and the continental slope (~500–600 m depth, 60–65 km from shore, "Offshore"). All Endurance Array platforms and sites measure fundamental ocean properties such as temperature, salinity, pressure, water velocity, chlorophyll fluorescence, and dissolved oxygen. The Endurance Array sensors and platforms return data to shore via either cellular or satellite links at the sea surface for autonomous moorings or via a seafloor cable. All data were obtained from the National Science Foundation Ocean Observatories Initiative Data Portal (http://ooinet.oceanobservatories.org).

Coastal surface moorings each consist of a surface buoy equipped with either a cellular or a satellite communications antenna, a mooring line supporting the delivery of power and data to instruments along the line and to the seafloor, and a seafloor instrument platform with an integrated anchor system. Moored instruments provide high temporal resolution at fixed points. Meteorological instruments (ASIMET, Star Engineering) on the buoys provide continuous measurements of winds, air temperature and humidity, and solar radiation at one-minute intervals. For this paper, solar radiation data from the sensors located onboard the large surface buoys at the Oregon and Washington Shelf and Offshore sites are used to examine the arrival of the August 2017 eclipse (Figure 1). We use wind measurements from the Oregon Shelf Site. The Endurance Oregon Inshore mooring has an instrumented platform on the seafloor on which temperature (Sea-Bird SBE 16plusV2) and dissolved oxygen (Aanderaa Optode 4831) are measured at 15-minute intervals. Measurements are sent to a surface buoy for relay to shore via the cellular network every four hours. We use the near-bottom dissolved oxygen and temperature data from the Oregon Inshore site to examine a summertime hypoxia event.

Profiling moorings have self-contained instrument packages that move up and down the water column and are paired adjacent to each surface mooring. They provide fine vertical resolution (~1 m) at a fixed location. The Endurance Array has four types of profilers, and we use data from one of them to describe the arrival of anomalously warm water to the Pacific Northwest, specifically an uncabled wire-following profiler (McLane Moored Profiler) located at the offshore end of the Washington line (Figure 1). Wire-following profilers carry low-power instruments that sample the water column from just below a subsurface float at 30 m depth down to 500 m, ascending and descending three times per day. We use temperature data from a profiler's onboard conductivity-temperature-depth sensor (Sea-Bird SBE 52MP). Data are reported to a surface buoy tethered to the subsurface float and then ultimately to shore via inductive and satellite modems, respectively.

The cabled bioacoustic sensors at the Oregon Shelf and Offshore locations are three-frequency systems (38, 120, and 200 kHz), and their cable-provided power allows for frequent sampling. The bioacoustic sensors are modified Kongsberg EK60 echosounders that obtain acoustic backscatter from targets in the water column like zooplankton and fish. The bioacoustics sensors collect data every one second for 20 minutes each hour and send 100% of those data to shore via the seafloor cable. The cabled bioacoustic sensors were used to examine zooplankton migration during the August 2017 eclipse.

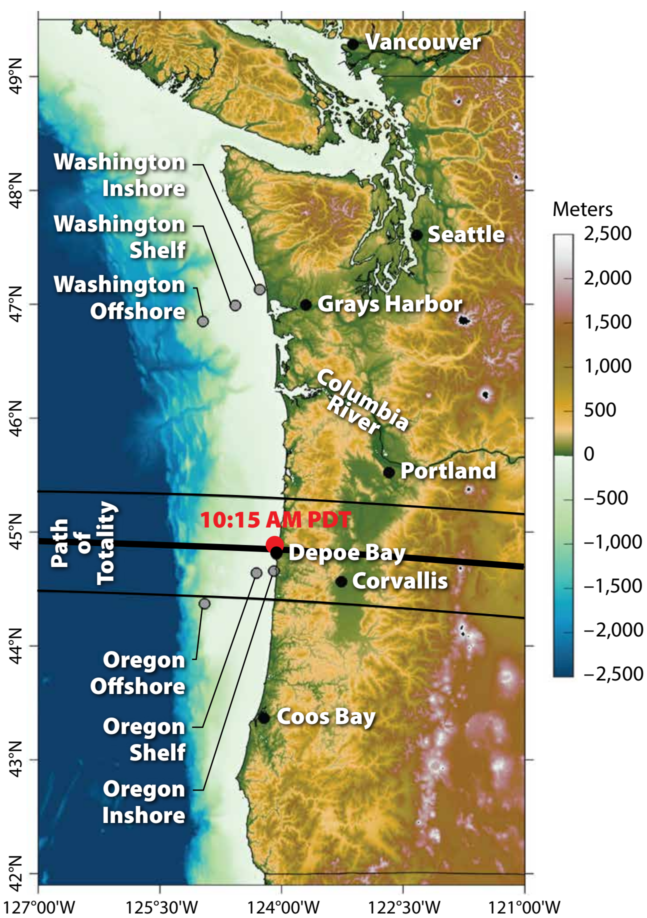

FIGURE 1. Map of the Ocean Observatories Initiative (OOI) Endurance Array located in the Northeast Pacific Ocean, spanning north and south of the Columbia River. Fixed platforms are shown as gray filled circles. The August 21, 2017, solar eclipse path of totality is shown crossing the Oregon line off Newport; the local time for the start of totality at the coast (red circle) is shown in red. Colored shades are ocean bathymetry and land topography.

THE NORTHEAST PACIFIC "WARM BLOB" REACHES THE COAST

Oceanographers have documented how air-sea interactions at high latitudes set the depth and characteristics of the surface ocean mixed layer that then subsequently affect ocean properties and ecosystem responses at latitudes to the south (e.g., for the North Pacific in Freeland, 2013; Wheeler et al., 2003; for the North Atlantic in Greene and Pershing, 2007). The OOI arrays in the Northeast Pacific extend from the global site at Station Papa in the central Gulf of Alaska, through the regional cabled array off the Pacific Northwest, to the Endurance Array on the continental slope and shelf off Oregon and Washington (L.M. Smith et al., 2018, in this issue; Figures 1 and 2). These arrays are well positioned to track long-period variations in ocean conditions, for example, El Niño/La Niña cycles and the Pacific Decadal Oscillation, between high and low latitudes in the Northeast Pacific.

During the winter of 2013–2014, the atmospheric Jet Stream shifted anomalously northward, leading to less wind-driven mixing in the central Gulf of Alaska, which subsequently led to the formation of a large region of anomalously warm surface water (Figure 2). This "warm blob" (Bond et al., 2015) was subsequently observed to be advected south and toward the Canadian and US west coasts (Peterson et al., 2017; Figure 2). Peterson et al. (2017) reported that the warm blob persisted at least through 2016.

The wire-following profiler cycling up and down three times per day at the offshore end of the Endurance Array line off Grays Harbor, Washington, captured the arrival and evolution of the warm blob as it was advected south and toward the US west coast (Figure 3). In late 2014 and early 2015, near-surface temperature anomalies exceeded 4°C, with 2°C anomalous water penetrating 150 m deep in the water column, commensurate with the depth of the continental shelf in this region. As wintertime downwelling pulled offshore waters toward shore, the entire shelf was bathed in warm blob waters (Peterson et al., 2017).

The warm anomaly was replaced with slightly colder water at depth in spring 2015, and near-surface (~30 m) waters were cooled by the offshore advection of cold upwelled waters during summertime upwelling off the Pacific Northwest. Warm blob waters returned in fall 2015 and again persisted until the following summer. However, during winter 2015–2016, the warm blob waters went even deeper, with 2°C anomalous water penetrating down to 250 m. This deeper extent of the large-scale warm anomalies is consistent with downward mixing and diffusion of the warm blob since its formation two years earlier. Note also that the maximum warm anomalies are at depth—the lingering signature of the surface warm blob—while the surface waters are returning ever so slightly back toward normal. During winter 2016, the 2015–2016 El Niño also influenced warm water

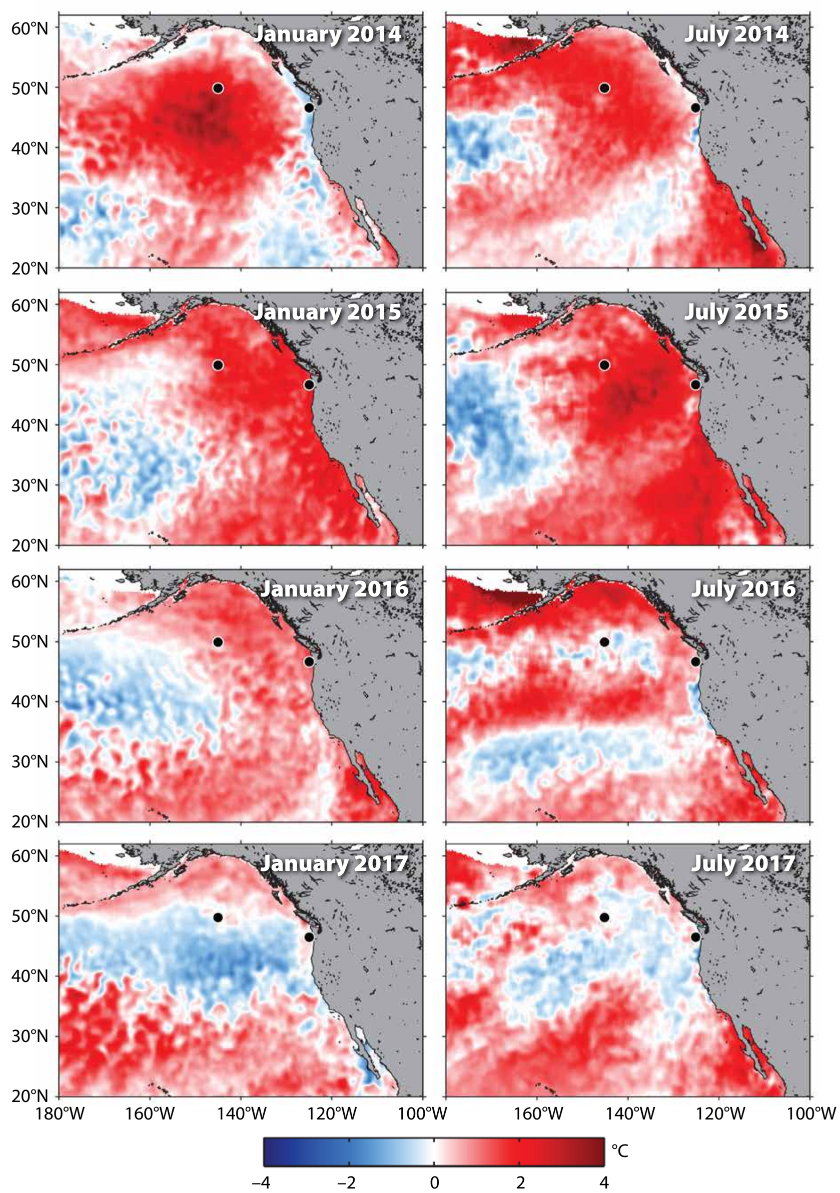

FIGURE 2. North Pacific sea surface temperature anomaly showing the evolution of the "warm blob" from its origination in winter 2013–2014 through the following four years. Satellite temperature data are from AVHRR-only Optimum Interpolation Sea Surface Temperature (OISST, https://www.ncdc.noaa.gov/oisst/data-access), and anomalies are computed relative to a 30-year climatology constructed from 1982 to 2011. The locations of the OOI Washington Offshore wire-following profiler mooring and the OOI Station Papa (50°N, 145°W) mooring are shown as filled black circles.

anomalies at depth.

In October 2016, an intense winter storm broke the wire-following profiler loose from its anchor. In April 2017, a replacement unit was installed during the regular Endurance Array refurbishment cruise. Data from summer and early fall 2017 show that the strength of the warm water anomaly has decreased, but it remains at depth at the edge of the continental shelf off the Pacific Northwest. During the October 2017 turnaround cruise, the wire-following profiler was upgraded to allow four profiles per day, leading to even greater data density at this site.

Since 2014, the warm blob waters have had a strong impact on the marine ecosystem off Washington, Oregon, and northern California. The warm waters were identified as contributing to enhanced harmful algal blooms (HABs) in the area (McCabe et al., 2016; McKibben et al, 2017). A toxic diatom bloom (*Pseudo-nitzschia*) led to the release of domoic acid that then appeared in one of the iconic and valuable commercial shellfish species off the US west coast, the Dungeness crab. In 2014, the commercial Dungeness crab fishery was valued at nearly $170 million (2014 Pacific States Marine Fisheries Commission Dungeness Crab Report, posted online at https://www.psmfc.org/crab). High levels of domoic acid in the crabs led to the delay (Oregon) or shutdown (California) of the commercial crab fishery during the 2015–2016 crabbing season. Delays in opening the Dungeness crab fishery hit again in late 2016. The warm blob waters also led to increased abundance of dinoflagellates and a reduced biomass of copepods and euphausiids on the Oregon shelf, the latter being an important food source for commercially and ecologically important species such as salmon (Peterson et al., 2017). See Cavole et al. (2016) for a review of other biological impacts of the 2013–2015 warm-water anomaly in the Northeast Pacific.

LOW-OXYGEN EVENT OFF CENTRAL OREGON

The surface waters of coastal upwelling zones such as the one off the Pacific Northwest are extremely productive because injection of nutrients into the surface light zone fuels a robust ocean food web. However, a potentially harmful low-oxygen layer can sometimes exist near the seafloor beneath the productive surface waters. Near-bottom waters over the continental shelf off Oregon in the northern California Current have become increasingly hypoxic over the last decade and a half, including the appearance of anoxia in summer 2006 (Chan et al., 2008). Observed ecosystem impacts include the absence of fish and die-offs of invertebrates (Grantham et al., 2004).

Upwelling of low-oxygen, nutrient-rich source water onto the continental shelf, followed by the decay of organic matter from surface phytoplankton blooms, drives near-bottom, inner-shelf hypoxia. This process can form a pool of near-bottom water that can sometimes reach dissolved oxygen levels that are less than ~62 μMol kg^{-1} (1.4 mL L^{-1}), adversely affecting many organisms (Diaz and Rosenberg, 1995). Under "severe" hypoxia, with dissolved oxygen levels less than ~22 μMol kg^{-1} (0.5 mL L^{-1}), the condition of the commercially valuable Dungeness crab (*Cancer magister*) can deteriorate (Keller et al., 2010).

Changes in near-bottom oxygen levels off central Oregon vary through the spring-summer upwelling season, decreasing toward July and August (Adams et al., 2013). These levels can also vary on a timescale of days as the wind-driven upwelling circulation advects the low dissolved oxygen pool back and forth across the shelf. To illustrate this variability, we use data from July 2017 when several upwelling-favorable (southward) and downwelling-favorable (northward) wind events lasting from 2–10 days influenced near-bottom oxygen off Newport, Oregon (Figure 4). This late in the upwelling season, which began in late April, near-bottom dissolved oxygen levels at the bottom of the OOI Oregon Inshore Surface mooring were below the hypoxia threshold for much of the month.

Note that when winds blow to the south, the near-bottom temperature decreases due to coastal upwelling, with a slight lag relative to the wind. During these upwelling events, near-bottom oxygen usually decreases, as exemplified by

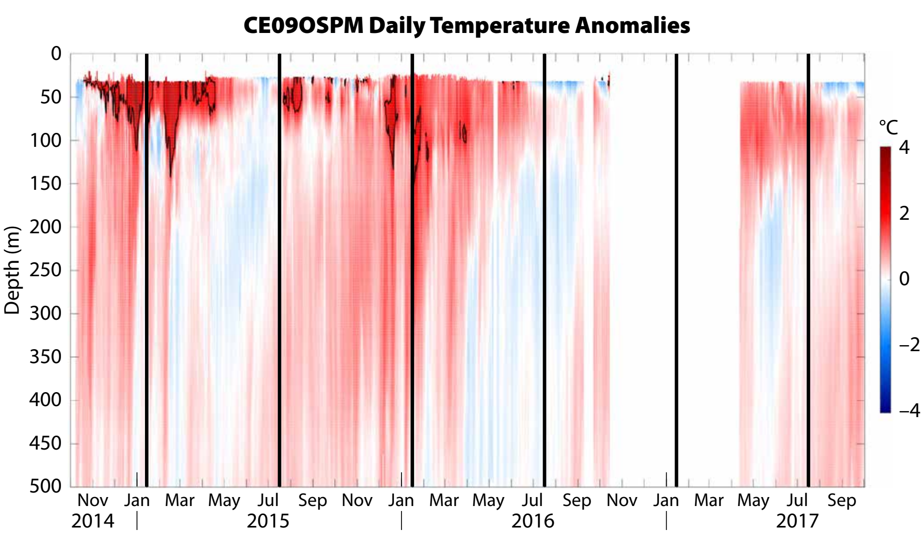

FIGURE 3. Temperature anomaly (°C) as a function of time and depth from the OOI Endurance Array Washington Offshore wire-following profiler. The anomalies are computed from the "Averaged Decades" World Ocean Atlas climatology (https://www.nodc.noaa.gov/cgi-bin/OC5/woa13/woa13.pl?parameter=t). There are over 5,400 vertical profiles in the wire-following profiler time series. The gap in late 2016/early 2017 is when the wire-following profiler broke loose from its anchor as a result of an intense winter storm. The vertical black bars mark the times of the 2015–2017 satellite images in Figure 2.

July 23–25. Conversely, during wind relaxation or downwelling, near-bottom temperature and dissolved oxygen increase rapidly. These changes are consistent with near-bottom cold water low in dissolved oxygen being drawn toward the coast during upwelling and warm water containing more oxygen being pushed down and away from the coast near the bottom during downwelling. Note that the dissolved oxygen does not follow the winds or temperature as clearly as temperature follows the wind because the additional biological processes of photosynthesis and microbial decay raise or lower dissolved oxygen levels, respectively.

Incidentally, on July12, 2017, scientists from the Oregon Department of Fish and Wildlife (ODFW) deployed a seafloor crab pot equipped with a video camera in 48 m of water off Newport, Oregon (http://oregonmarinereserves.com/2017/09/06/hypoxia-central-coast). This location is approximately 3.5 km from the OOI Oregon Inshore Mooring. Images recorded just after deployment show healthy active crabs in the pot, but starting on July 17, the crabs in the pot began to look lethargic, and by July 26 there was little to no movement in the crab pot (Figure 5). This die-off coincided with the decrease of dissolved oxygen to severely hypoxic levels starting on about July 17, with final values on July 24 of less than 10 μMol kg^{-1} (0.2 mL L^{-1}). The decrease in dissolved oxygen happened in two pulses of upwelling-favorable winds around July 17 and July 24. When the video-equipped crab pot was recovered on August 3, 2017, ODFW scientists recovered 30 dead and two live crabs (Kelly Corbett, ODFW, *pers. comm.*, 2017).

The hypoxic event of July 2017 demonstrates how near-bottom oceanographic data, in combination with surface winds, capture the "event-scale" response of the coastal ocean to wind forcing. The OOI Endurance Array has a wealth of other oceanographic data available to be analyzed, including near-bottom and water-column measurements of temperature, salinity, velocity, chlorophyll fluorescence, and light transmission (a measure of suspended particles). These data show just how quickly the coastal ocean can change and how ocean properties can strongly impact marine organisms.

RISING ZOOPLANKTON DURING THE 2017 TOTAL ECLIPSE OF THE SUN

On August 21, 2017, the United States experienced a total eclipse of the sun, one of only a handful visible from the continental United States over the last 60 years and the first of the twenty-first century. The 110 km wide path of totality stretched from Oregon to South Carolina and, fortuitously, passed directly over the Newport line of the OOI Endurance Array (Figure 1). Similar to land animals, which are known to react to the appearance of darkness during a total solar eclipse, vertically migrating zooplankton also react to this irregular darkening of the sky (Kampa, 1975; Strömberg et al., 2002). Zooplankton migrate vertically each day, rising at dusk from the depths where they seek refuge from predators to the sea surface where they feed at night. At dawn, they descend again to depths of several hundred meters, depending on the species and local bottom depth. Off central Oregon, the vertically migrating zooplankton species include *Euphausia pacifica*, based on past studies of this region (e.g., Peterson and Schwing, 2003).

Knowing that the eclipse would happen and realizing that the path of totality would pass over the OOI Newport line, the Oregon State University Endurance Array team responded to requests from non-OOI scientists to reprogram the Endurance Array cabled bioacoustic sensors at the Oregon Shelf and Offshore sites to sample continuously rather than at their regular sampling rate of once per second for 20 minutes each hour in order to see whether the zooplankton off Oregon would react to the total solar eclipse. Through the OOI Engineering Change Request system, this request was

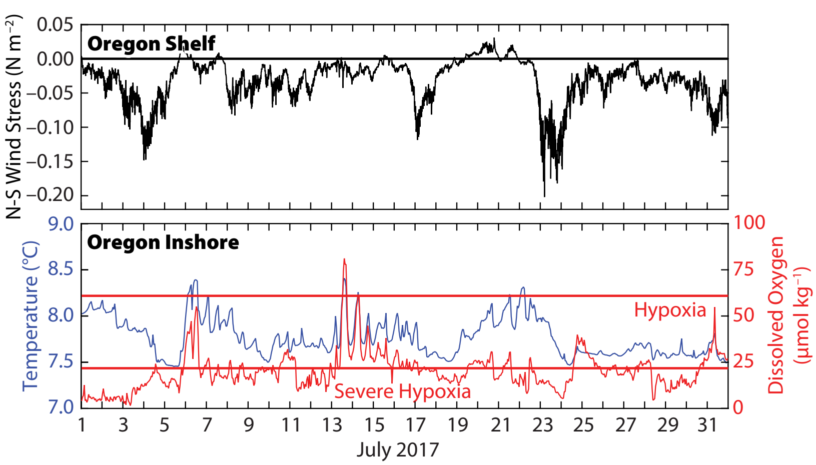

FIGURE 4. Dissolved oxygen (μMol kg^{-1}, red) and temperature (°C, blue) from near the bottom at the 25 m OOI Oregon Inshore mooring, and north-south wind stress (N m^{-2}, black) from the OOI Oregon Shelf surface mooring. Levels of dissolved oxygen for hypoxia (~62 μMol kg^{-1}, 1.4 mL L^{-1}) and "severe" hypoxia (~22 μMol kg^{-1}, 0.5 mL L^{-1}) are indicated by horizontal red lines.

FIGURE 5. This July 26, 2017, still frame is from a video showing the die-off of Dungeness crabs (*Cancer magister*) caught in an Oregon Department of Fish and Wildlife pot off Newport, Oregon (http://oregonmarinereserves.com/2017/09/06/hypoxia-central-coast).

reviewed, approved, and implemented in time for the eclipse. This change was possible within the power constraints of the cabled system because there are fewer power constraints on the bioacoustic instruments than when the sampling was first implemented three years earlier. Moving forward, the cabled bioacoustic sensors will continue to sample continuously.

The idea to use the OOI sensors to visualize animal behavior in the ocean captivated people's attention as the eclipse approached. With much of the pre-eclipse hype focused on humans and land-based animals, the unique view into the ocean afforded by the Endurance Array offered a new twist to an eager audience. The *Los Angeles Times* ran pre- and post-eclipse stories (Netburn, 2017) that included the whimsical headline "Poor little zooplankton—they got totally punk'd by Monday's eclipse." The story was also picked up by National Public Radio and the Coastal Society among others.

Shortly after 9 a.m. Pacific Daylight Time (UTC minus seven hours), sensors on the OOI surface buoys measured the beginning of the decrease in incoming solar radiation (Figure 6). The partial eclipse lasted for over two hours, but the time of totality lasted just about two minutes centered on 10:16 am PDT. In response to this darkening, zooplankton began to rise in the water column above the 200 m bioacoustic sensor at the Oregon Offshore site (Figure 6). The regular diel vertical migration is evident during the days before the eclipse. The acoustic scatterers rose from around 170 m to 120 m, covering 50 m in about 45 minutes, a vertical migration speed of about 0.02 m s^{-1}. This speed is in agreement with past studies of zooplankton vertical migration speeds.

Putting data online in near-real time is important for education and outreach, just as it is important for science. Eclipse-related data plots were online by the end of August 21, so they could be shared with the public while the eclipse was still front-page news. Follow-up stories on these data by the *Los Angeles Times* and National Public Radio were retweeted and "liked" far more than the news stories about our zooplankton migration prediction before the eclipse.

In addition to the continuously sampling, cabled bioacoustic sensors, an Endurance Array glider, two Coastal Surface Piercing Profilers (CSPP), and a variety of fixed sensors on the coastal moorings, including a spectral irradiance instrument, were programmed to run more often during the eclipse period. The CSPPs were commanded to make vertical profiles during the two minutes of totality. An underwater glider conducted continuous profiles next to the Oregon Shelf Surface Mooring during the day of the eclipse, temporarily breaking from its normal across-shelf profiling. We hope this demonstration of adaptive sampling stimulates others to utilize this OOI capability.

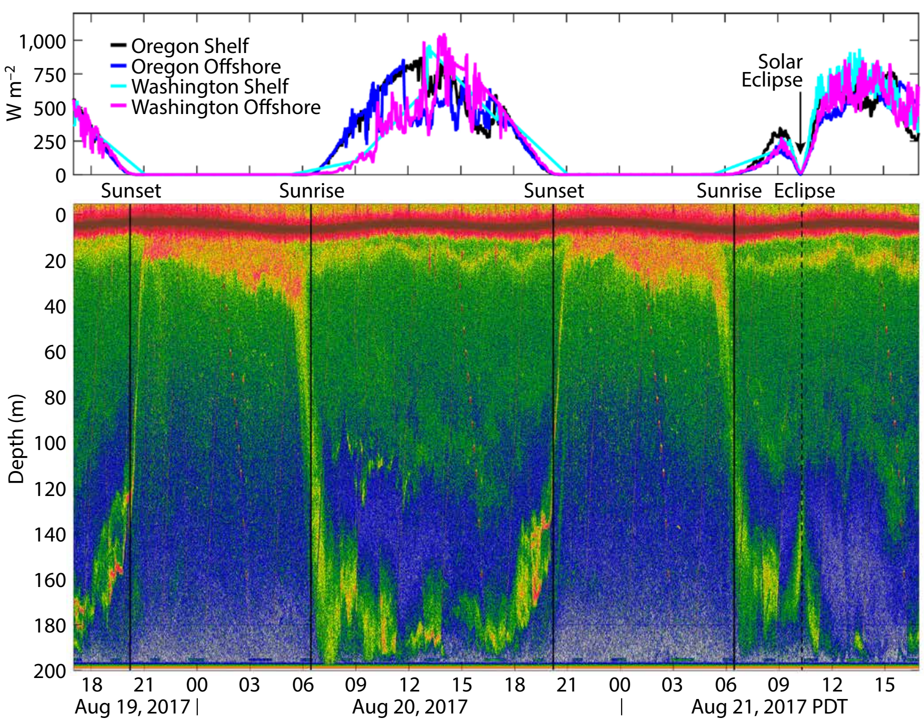

FIGURE 6. (top) Incoming shortwave radiation measured at four OOI surface moorings showing the daily cycle of sunlight; the total solar eclipse happens a little after 10 a.m. local time on August 21, 2017. (bottom) Echogram of acoustic backscatter at 200 kHz measured from the OOI Oregon Offshore midwater platform. The bioacoustic sensor is mounted on the 200 m deep midwater platform looking up; the dark red line is the acoustic return from the sea surface; other red and bright green returns are scattering off zooplankton that undergo diel vertical migration. Times of sunset and sunrise are noted by black vertical lines. The total solar eclipse is indicated by a black dashed line. The faint straight red lines traveling diagonally from top to bottom are acoustic returns off the Cabled Shallow Profiler that samples the water column nine times per day.

SUMMARY

With the examples described above, we demonstrated the utility of the OOI Endurance Array to capture oceanographic events lasting from hours to years. This OOI Endurance Array, the Cabled Array, and the Station Papa Array are all parts of a larger Northeast Pacific observing network that allows the spatial connections and the propagation of events to be studied from formation to impact. The sensors deployed on the array simultaneously measure physical, biological, and chemical parameters, allowing the study and modeling of linked physical-biogeochemical processes. The examples above provide but a glimpse of the capabilities of the OOI Endurance Array.

Further analysis and modeling of the arrival and the impact of the "warm blob" on Pacific Northwest waters can make use of the large number of moored and mobile assets on the OOI platforms in the region as well as measurements made by Ocean Networks Canada and the NOAA-supported Station Papa mooring and NANOOS instruments. Such an analysis would join and benefit from the in-depth analysis of the warm water anomalies conducted farther south in the California Current using a variety of observational platforms (e.g., Zaba and Rudnick, 2016; Cavole et al., 2016). Better yet, as the OOI time series grows over the anticipated 25–30 year life of the program, we expect to sample more interdecadal changes and add to the historic time series in the area that will allow us to better discern long-term change in the context of interdecadal variability.

The hypoxia event observed in July 2017 provides a glimpse of the strong changes driven both by the "event-scale" (2–10 days) changes in the wind and by biogeochemical processes. Variability in all ocean parameters is strong at this timescale, and the OOI Endurance Array is set up to capture this variability. Further insight and even predictive capability is possible by combining the many air-sea interface, water-column, and seafloor measurements across the OOI arrays. These data should also be used to verify and challenge our ever-improving numerical ocean circulation and biogeochemical modeling capability.

The Endurance Array was not designed for measuring the August 21, 2017, eclipse, but its sensor diversity and large footprint over the continental shelf sets it up well to measure events in unique ways. While the anticipated zooplankton migration was observed in previous eclipses, what is new and different about OOI's eclipse sampling is synoptic coverage from multiple bioacoustic sonars as well as measurements from all of the other potentially relevant Endurance Array sensors. We look forward to a more complete analysis of this event and welcome others to dig in to these data.

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