An expanding observatory to monitor hypoxia in the Northern California Current System

John A. Barth[1], R. Kipp Shearman[1], Francis Chan[2], Stephen D. Pierce[1], Anatoli Y. Erofeev[1], Justin Brodersen[1], Murray D. Levine[1], Kim Page-Albins[2], Craig Risien[1], Laura Rubiano-Gomez[1], and B. Walton Waldorf[1]

[1]College of Oceanic and Atmospheric Sciences, Oregon State University, 104 COAS Admin Bldg, Corvallis, Oregon, 97331-5503, U.S.A.
E-mail: barth@coas.oregonstate.edu
[2]Department of Zoology, Oregon State University, 3029 Cordley Hall, Corvallis, Oregon, 97331, U.S.A.

Abstract

Near-bottom waters over the inner shelf (< 50 m water depth) off central Oregon, U. S. A., have been increasingly hypoxic (dissolved oxygen < 1.4 ml/l) over the last 8 years, including the appearance of anoxia in summer 2006. The appearance of near-bottom, inner-shelf hypoxia is driven by upwelling of low-oxygen and nutrient-rich sourcewater onto the continental shelf, followed by the decay of organic matter raining down from surface phytoplankton blooms. Through a combination of ship sampling, moorings and autonomous underwater vehicle gliders, we have been measuring dissolved oxygen with increasing temporal and spatial coverage. For longer term context, we use historical observations along the Newport Hydrographic Line sampled since the 1960s. The mooring array spans the inner shelf (15 m isobath) along 60 km of Oregon coastline and includes two mid-shelf (70-80 m isobath) moorings. Two of these moorings return near-bottom dissolved oxygen, as well as temperature and salinity, in near real-time. Since April 2006, we have occupied the Newport Hydrographic Line nearly continuously using two Webb Research Corporation 200-m Slocum electric gliders and a 1000-m Seaglider. In total, gliders have been at sea for 1,253 days (3.4 years), sampled over 400 cross-shelf sections, collected in excess of 110,000 vertical profiles and traveled over 28,000 km. We analyze data from this observatory to show how the severity of inner-shelf hypoxia varies year-to-year due to changes in upwelling sourcewater properties and the characteristics of wind-driven upwelling.

Near-bottom waters over the inner shelf (< 50 m water depth) off central Oregon, U. S. A., have been increasingly hypoxic (dissolved oxygen < 1.4 ml/l) over the last 8 years, including the appearance of anoxia in summer 2006 (Grantham et al., 2004; Chan et al., 2008). The appearance of near-bottom, inner-shelf hypoxia is driven by upwelling of low-oxygen and nutrient-rich sourcewater onto the continental shelf, followed by the decay of organic matter raining down from surface phytoplankton blooms. Hypoxia in this region is not driven by input of nutrients from freshwater runoff.

Through a combination of ship sampling, moorings and autonomous underwater vehicle gliders, we have been measuring dissolved oxygen with increasing temporal and spatial coverage. For longer term context, we use historical observations along the Newport Hydrographic Line sampled since the 1960s. The mooring array spans the inner shelf (15 m isobath) along 60 km of Oregon coastline and includes two mid-shelf (70-80 m isobath) moorings. Two of these moorings return near-bottom dissolved oxygen, as well as temperature and salinity, in near real-time.

Beginning in April 2006, we have used autonomous underwater vehicle gliders to sample a cross-shelf transect along the Newport Hydrographic Line off central Oregon (44 39.1'N) (**Fig. 1**). This cross-shelf section is in the middle of the mooring array and runs from the 20-m isobath out about 90 km, and takes 3-7 days to complete. The glider undulates from the surface to 3-5 m above the bottom with an along-track resolution ranging from 100 m in shallow water to 400 m in deep water. Position and oceanographic data are relayed to shore every 6 hours via Iridium cell phone. The glider is equipped with a conductivity-temperature-depth instrument and several optical instruments (chlorophyll fluorescence, colored dissolved organic matter fluorescence, light backscatter for a measure of particles, dissolved oxygen). Near real-time data are posted on the web (http://gliderfs.coas.oregonstate.edu/gliderweb).

Since April 2006, we have occupied the Newport Hydrographic Line nearly continuously using two Webb Research Corporation 200-m Slocum electric gliders and a 1000-m Seaglider (**Fig. 1**). In total, gliders have been at sea for 1,253 days (3.4 years), sampled over 400 cross-shelf sections, collected in excess of 110,000 vertical profiles and traveled over 28,000 km. A vertical section of dissolved oxygen from July 2006 shows hypoxic waters over the mid to inner shelf and occupying over half the water column in some places (**Fig. 2**).

We are coordinating the measurement of dissolved oxygen from annual National Oceanic and Atmospheric Administration (NOAA) groundfish and hake surveys which allows us to greatly expand the spatial footprint of our sampling. Recent maps of near-bottom dissolved oxygen show a ribbon of hypoxic water extending along the Pacific Northwest coast. Accurate knowledge of the subsurface dissolved oxygen distribution provides the context for sampling to assess the impact of low oxygen on marine organisms, for example on larval and adult fish and invertebrates (Keller et al., 2009).

The severity of inner-shelf hypoxia varies year-to-year due to changes in upwelling sourcewater properties and the characteristics of wind-driven upwelling. We use a regression model to link observed inner-shelf, near-bottom oxygen levels with offshore sourcewater dissolved oxygen levels and two measures of wind forcing (Barth et al., 2009). Wind forcing is represented as both the cumulative seasonal upwelling and an exponentially weighted sum of winds over the last 30 days. The model shows that 94% of the variability of inner-shelf, near-bottom dissolved oxygen levels is explained by a nearly equal combination of changes in sourcewater dissolved oxygen and wind forcing. Long-term records of dissolved oxygen in upwelling source waters off central Oregon show a decrease consistent with other recent estimates of oxygen declines in the eastern North Pacific (Whitney et al., 200X; Bograd et al., 2008).

Sustained, near real-time observations and further understanding of coupled physical and biological processes can inform ecosystem approaches to management and help assess the efficacy of marine protected areas. Anticipated advances in bio-chemical sensors, payload capacity, battery duration, and ease-of-use will expand the ability to use gliders to monitor boundary current scale bio-physical processes and their response to climate variability.

Acknowledgments

Support for our glider observations comes primarily from the U. S. National Science Foundation, with additional contributions from the Gordon and Betty Moore Foundation (GBMF), and the U. S. National Oceanic and Atmospheric Association through the Northwest Association of Networked Ocean Observatories (NANOOS), the Pacific Northwest regional association of the U. S. Integrated Ocean Observing System (IOOS). Support for our mooring observations comes from the David and Lucile Packard Foundation, GBMF and NANOOS.

References

Barth, J. A., R. K Shearman, A. Y. Erofeev, S.D. Pierce, F. Chan, J. Brodersen and L.Rubiano-Gomez, 2009: The evolution of seasonal hypoxia off the central Oregon coast. *Limnol. Oceanogr*., in preparation.

Bograd, S. J., C. G. Castro, E. Di Lorenzo, D. M. Palacios, H. Bailey, W. Gilly and F. P. Chavez, 2008. Oxygen declines and the shoaling of the hypoxic boundary in the California Current. *Geophys. Res. Lett*., **35**, L12607, doi:10.1029/2008GL034185.

Chan, F., J. A. Barth, J. Lubchenco, A. Kirincich, H. Weeks, W. T. Peterson, and B. A. Menge, 2008. Novel emergence of anoxia in the California Current System. *Science*, **319**, 920.

Grantham, B. A., F. Chan, K. J. Nielsen, D. S. Fox, J. A. Barth, A. Huyer, J. Lubchenco and B. A. Menge, 2004. Upwelling-driven nearshore hypoxia signals ecosystem and oceanographic changes in the northeast Pacific. *Nature*, **429**, 749-754.

Keller, A., V. Simon, F. Chan, W. W. Wakefield, M. E. Clarke, D. Kamikawa, E. L. Fruh and J. A. Barth, 2009. Demersal fish and invertebrate biomass in relation to an offshore hypoxic zone along the U.S. West Coast. *Fisheries Oceanography*, in press.

Whitney, F. A., H. J. Freeland and M. Robert, 2007. Persistently declining oxygen levels in the interior waters of the eastern subarctic Pacific. *Prog. Oceanogr*., **75**, 179-199.

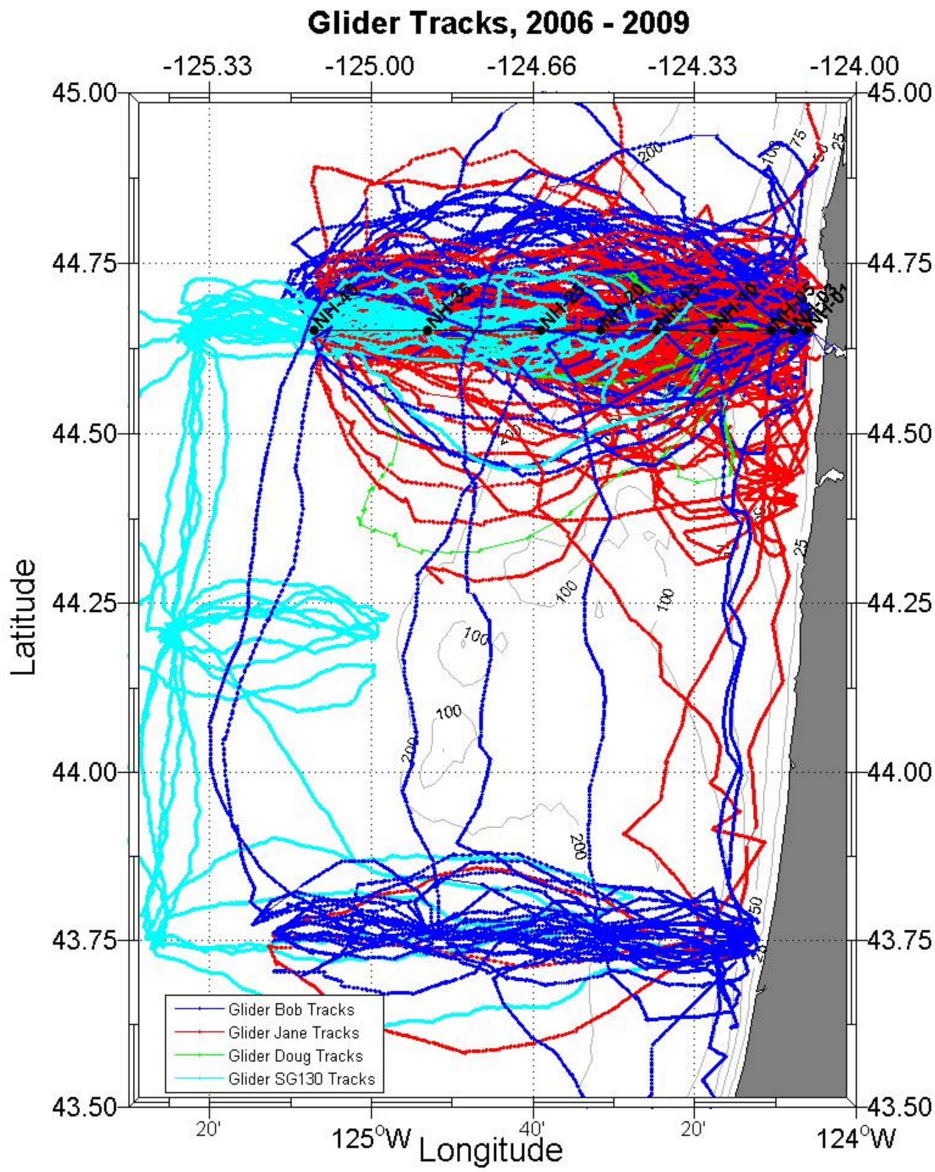

Figure 1: Track lines occupied by autonomous underwater gliders off central Oregon from April 2006 to August 2009. Red and blue lines are occupied by Webb Research Corporation 200-m Slocum electric gliders; cyan lines are occupied by a 1000-m Seaglider; green curves are from a Webb Slocum glider equipped with an experimental turbulence sensing package.

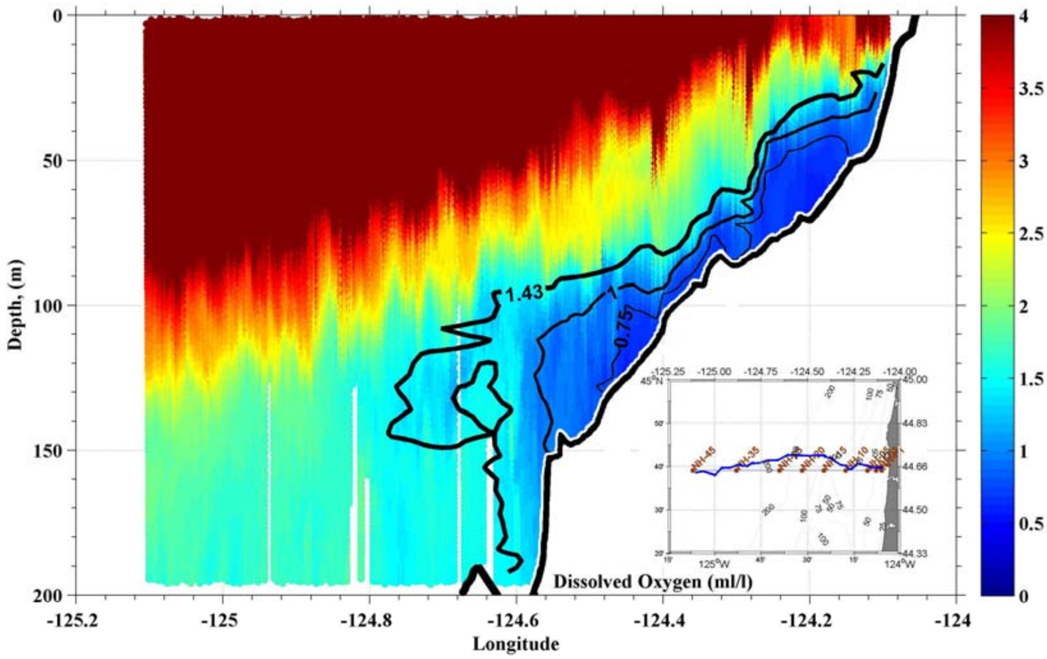

Figure 2: Dissolved oxygen (ml/l) sampled with an autonomous underwater glider off Newport, Oregon (44 39' N) during July 2006. Contours are for 0.75, 1.0 and 1.43 (hypoxia boundary) ml/l.