Innovative Nitrogen Sensor Maps the North Pacific Oxygen Minimum Zone

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Oxygen minimum zones (OMZs) play important roles in regulating the ocean's global carbon and nitrogen cycles. In these functionally anoxic waters, denitrifying and anammox (short for anaerobic ammonium oxidation) microbes remove nitrogenous nutrients from the biosphere by transformation to biologically unavailable nitrogen gas (N_2). A newly developed sensor can detect this "excess" N_2 in OMZ regions in order to quantify these nitrogen-loss processes. The near-term goal is to explore OMZs and collect high-quality excess N_2 data to document their baseline inventories. The long-term objective is to determine if excess N_2 inventories in OMZs are increasing as a result of ocean deoxygenation (Stramma et al., 2008; Schmidtko et al., 2017).

N_2 Sensor. Although this new gas tension device (GTD; McNeil et al., 2006) was designed as a low cost, fast response profiling sensor for NOAA Ship *Okeanos Explorer*'s CTD, it could easily be deployed on AUVs, wire crawlers, and gliders. Concentration of N_2 in anoxic waters is derived from gas tension using Henry's Law and expressed as excess N_2, or ΔN_2, relative to atmospheric equilibrium. A standard dissolved oxygen probe compensates the GTD signal for O_2 in hypoxic waters. Biogenic production of N_2 is evidenced by $\Delta N_2 > 0$.

Sensor tests were performed on *Okeanos Explorer* in October 2017 while the ship transited the eastern tropical North Pacific OMZ during a multibeam bathymetry survey (Figure 1). This is the first instance of an OER Federal Funding Opportunity project that leverages *Okeanos Explorer's* capabilities.

Preliminary Results. With the ship on station and the new sensor mounted, the CTD was lowered to a depth of 600 m to soak for 10 minutes to equilibrate heat and gases with the surrounding seawater. After Niskin bottles were triggered, the CTD was raised to the next sampling depth. Repeating this procedure approximately 10 times during the same cast created accurate vertical profiles of dissolved O_2 and N_2. Ten casts during the cruise provided approximately 100 samples.

The measurements (Figure 2) show strong vertical and longitudinal variability. Several layers of waters with different properties are indicated, including: (1) a warmer, fresher, aerated and well-mixed near surface layer; (2) a subsurface layer at 80–200 m depth with minimum salinity; and (3) a weakly stratified deeper layer at 300–600 m depth with low O_2. High ΔN_2 was found in the upper layer of the low O_2 waters, consistent with organic matter export from the sea surface fueling microbial denitrification there. Strong longitudinal variability in O_2 was observed with generally lower O_2 and shallower oxycline toward the east, and minimum O_2 in the OMZ core region. Peak ΔN_2 was found in the OMZ core region at 60–300 dbar. Further analysis will consider mixing effects and the source water supply of ΔN_2 to the region.

The new sensor appears to have worked well and allowed real-time measurement of ΔN_2 on the ship. During post-cruise analysis, these ΔN_2 measurements will be compared to independent estimates derived from N_2/Ar ratios by mass spectrometry and biogenic N_2 using nutrient data.

Figure 1. Map showing 10 CTD stations (red markers) along the cruise track of NOAA Ship *Okeanos Explorer* between Hawai'i and Panama that crosses the eastern tropical North Pacific oxygen minimum zone where loss of nitrogen-based nutrients to N_2 gas occurs (approximate location of high N_2 regions indicated by the shaded gray region. *Image credit: Google Earth overlay with high N_2 regions taken from Figure 1 in Deutsch et al. (2014)*

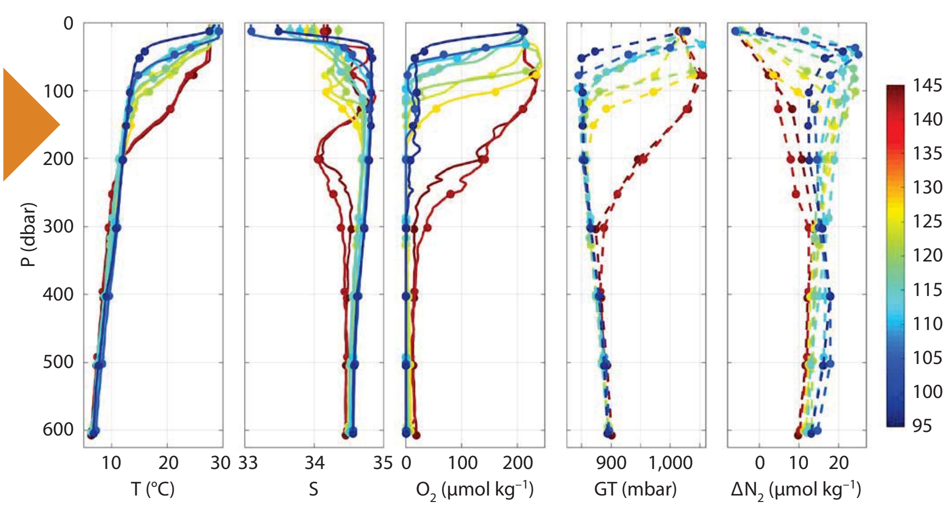

Figure 2. Preliminary data collected at 10 CTD stations (refer to map in Figure 1) showing vertical profiles (plotted to hydrostatic pressure P) of seawater temperature (T), salinity (S), and dissolved oxygen concentration (O_2) collected by an SBE 43 electrochemical sensor; gas tension (GT) measured by the new sensor described here; and derived excess nitrogen concentration (ΔN_2). Data are color coded by longitude (see color bar). Solid lines indicate depth binned (5 m) CTD data and dashed lines linear interpolation between equilibrated data points (colored dots). Intercalibrations and data quality control will be performed during post-cruise analysis.