Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2020-75-AC1, 2020

Biogeosciences
Discussions

Interactive comment on “Characterizing deep-water oxygen variability and seafloor community responses using a novel autonomous lander” *by* Natalya D. Gallo et al.

Natalya D. Gallo et al.

ndgallo@ucsd.edu

Received and published: 23 May 2020

We are very grateful to the reviewer for his thorough review of our manuscript, and for the concrete suggestions on how to further improve this study. We respond to each comment below.

1) What is the bottom topography around the Nanolanders? Table 1 well summarizes the seven deployments including information on deployment location and depth. But, ‘Scripps Coastal Reserve’, ‘Del Mar Steeples Reef’ with latitudes/longitudes and bottom depth are not enough information for readers (particularly someone who is not familiar to the region) to figure out local bathymetric features, where outer shelf

and upper slope are located/ranged/shaped, seafloor area exposed to different oxygen conditions, and so on. It is important to give details of the bathymetry around the deployment sites highlighting the key information as mentioned above. This would also be helpful for better discussing physical drivers of the oxygen variability. Thus, I would like to suggest to add one figure (or incorporated into Figure 1) showing compact and easy to understand map of the local bathymetry along with the deployment locations.

RESPONSE: Thank you for highlighting this omission. We have created a new figure (called New Figure 3) which clearly shows the deployment locations (green diamonds) in relationship to local bathymetric features. Despite relatively close spatial proximity between the Scripps Reserve and Del Mar deployment sites (∼10 km), there are important bathymetric differences. The Scripps Coastal Reserve deployment sites are positioned close to a submarine canyon feature (the La Jolla canyon), while the Del Mar Steeples Reef deployment sites are on a gradually sloping margin. Additionally, we have added the locations of nearby CalCOFI stations (93.3 26.7 and 93.3 30) (black circles) and have included data from CalCOFI station 93.3 30 to provide additional context regarding variability over longer timescales.

2) There is no summary/concluding remarks/conclusion in the manuscript. Substantial conclusions are reached but they are not presented as a separate section. Thus, I would like to suggest to add Section 5 to conclude or summarize the materials.

RESPONSE: Thank you for this suggestion. We have modified what was previously section 4.3 of the discussion, titled “A global array of deep sea landers”, added additional content summarizing the findings of the study, and titled this section: "Section 5: Concluding remarks". This section now reads:

“5.0 Concluding remarks

Ocean deoxygenation is a global concern, with changes in oxygen conditions potentially impairing the productivity of continental shelves and margins that support important ecosystem services and fisheries. Nanolanders provide a powerful tool to examine short-term, fine-scale fluctuations in nearshore dissolved oxygen and other environmental parameters, and associated ecological responses that are rarely recorded otherwise. Oxygen variability was strongly linked to tidal processes, and contrary to expectation, oxygen variability did not decline linearly with depth. Depths of 200 and 400 m showed especially high oxygen variability which may buffer communities at these depths to deoxygenation stress by exposing them to periods of relatively high oxygen conditions across short timescales (daily and weekly). Despite experiencing high oxygen variability, seafloor communities showed limited responses to changing conditions at these short time-scales. However, our deployments did not capture any large acute changes in environmental conditions, that may elicit stronger community responses; future studies using this platform could allow for such observations.

Nanolanders provide a cost-effective and easily deployable tool for studying local conditions throughout the world. Many of the areas where large decreases in oxygen have been observed occur in developing countries, such as along the western and eastern coast of Africa (Schmidtko et al. 2017). Large oxygen losses have also been observed in the Arctic (Schmidtko et al. 2017), where the seafloor habitat is understudied. Due to their compact design, small landers such as DOV BEEBE can provide easy access to nearshore, deep-sea ecosystems and could expand the capacity of developed and developing countries to monitor and study environmental changes along their coastlines. We found that the Nanolander performed well and reliably over the course of the deployments, and allowed us to study seafloor community responses within the context of short-term environmental forcing. For continental margins and seafloor habitats, a global array of Nanolanders, similar in scope to the Argo program, could be envisioned. These would provide coupled physical, biogeochemical, and ecological measurements, which would greatly expand our understanding of temporal and spatial heterogeneity in nearshore deep-sea ecosystems and seafloor community sensitivity to environmental change. ”

3) To give proper credit to related work, I would like to suggest to use ‘13CW’, name

of specific water mass linked to the deoxygenated water, instead of its locally defined water types, Pacific Equatorial Water (PEW) although previous works used the terms PEW. Based on recent work (Zachary et al., 2020; “The role of water masses in shaping the distribution of redox active compounds in the Eastern Tropical North Pacific oxygen deficient zone and influencing low oxygen concentrations in the eastern Pacific Ocean” published in Limnology and Oceanography as of 06 February 2020), two water masses – 13CW and deeper North Equatorial Pacific Intermediate Water (NEPIW) act as the two Pacific Equatorial source waters to the California Current System corresponding to upper and lower PEW at isopycnals of 26.2-26.8 kg m-3 when defined locally. Here, the relevant water mass seems to be 13CW (upper PEW), and not NEPIW (lower PEW).

RESPONSE: Thank you for drawing our attention to this new reference. We have added the following clarification in the manuscript. In Section 2.2: “Previous studies have found that changes in oxygen and pH in the Southern California Bight are associated with changes in the volume of Pacific Equatorial Water (PEW) transported in the California Undercurrent (Bograd et al. 2015, Nam et al. 2015). PEW is characterized by low oxygen, warm, high salinity conditions, and is composed of two watermasses, the 13°C water mass (13CW) and the deeper Northern Equatorial Pacific Intermediate Water Mass (NEPIW) (Evans et al. 2020).”

Further, in the discussion, we have updated our reference to PEW to 13CW and included the appropriate citation: “Input of 13°C water (13CW), which is brought up by the California Undercurrent (Evans et al. 2020), is key to determining near-seafloor oxygen conditions at ∼200 m, and in the spring, 13CW upwells to 100 m leading to lower oxygen conditions. In contrast, at deeper depths (∼300 and 400 m), added input of 13CW increases oxygen conditions.”

In Section 4.1, we have also updated the text to read, “We note that 300 m is an interesting depth which may be at an important boundary between two different water masses. The correlation between spiciness and oxygen concentration is negative at 200 m (indicative of high input of 13CW, which is a component of Pacific Equatorial

Water), and then positive at 300 m (Fig. 3)."

To maintain consistency with the nomenclature in the reference, we have kept the use of "PEW" in cases where it directly refers to the results of a study. For example, "Previous studies have found that changes in oxygen and pH in the Southern California Bight are associated with changes in the volume of Pacific Equatorial Water (PEW) transported in the California Undercurrent (Bograd et al. 2015, Nam et al. 2015)."

4) The observed oxygen variability over short time scales was compared with multi-decade-long deoxygenation or long-term trends/shifts reported in Bograd et al. (2008) and McClatchie et al. (2010). However, it was not discussed in comparison to interannual oxygen variability in the region. Does the period of data collection from August 2017 to March 2018 correspond to normal or more likely abnormal (El Niño/La Niña) year? My suggestion is to provide discussions on the observational results in terms of significant local interannual oxygen variability in association with such large-scale condition presented in Nam et al. (2011; "Amplification of hypoxia and acidic events by La Niña conditions on the continental shelf off California" published in Geophysical Research Letters as of 23 November 2011).

RESPONSE: Thank you for this suggestion. Indeed, we were interested in comparing how short-term variability compares to longer-term variability driven both by interannual and multidecadal changes as one of the objectives of this research. Between August 2017 and March 2018, the conditions in the Eastern Pacific were more consistent with La Niña conditions; associated with being lower in oxygen and pH on average (as shown in Nam et al. 2011). The monthly Niño-3.4 index was always negative during the period of our data collection and ranged from -0.21 to -1.04 (https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/detrend.nino34.asci However, these conditions were much weaker than the La Niña time-period (Jul 2010-Jan 2011) described in Nam et al. (2011) during which the monthly Niño-3.4 index ranged between -1.04 to -1.73.

To compare our high-frequency measurements to a longer-term dataset, we incorporated data from a nearby CalCOFI station to provide additional context to our results. We relied on data from CalCOFI Station 93.3 28 since it was the closest station to our deployments which sampled the full upper water column down to 500 m. CalCOFI Station 93.3 26.7 was too shallow for our comparison; but both stations are provided in the new map figure with deployment sites (New Figure 3). We then used all available CTD casts for Station 93.3 28, which represented data from 65 CalCOFI cruises during the time-period between July 2003 and November 2019, and looked at how the overall variability in environmental conditions across this longer (∼16 year) time-period, compares to the overall variability in environmental conditions across our shorter (∼3-week deployments). These results are presented in a new figure labeled New Figure 7. This figure shows how the mean, variance (indicated using +/- 1SD and +/- 2SD), and coefficient of variation (CV) for temperature and oxygen change across the upper 500m of the water column at Station 93.3 28 (Panels A-D). This figure also selects data from specific depths that relate to our targeted deployment depths (100, 200, 300, and 400 m), and shows how the variance distribution in temperature and oxygen across our ∼3 week deployments compares to the observed variance at these depths over ∼16 years of CalCOFI cruise measurements (Panels E-H). Additionally, we have looked for evidence of linear changes in temperature or oxygen at our targeted deployment depths (100, 200, 300, and 400 m) at CalCOFI Station 93.3 28 (Panels I-J) as additional context for longer-term change. We hope that this added analysis helps frame our results regarding variability over short timescales within the context of variability over interannual and multidecadal timescales.

5) What are depths of thermocline/oxycline (any strong vertical temperature/oxygen gradient close to 200 m?) and their sectional structures across the shelf-slope? It would be helpful to check the cross-sectional structures of water temperature and dissolved oxygen across the shelf and slope at a given time, e.g., see Figure 2 of Nam et al. (2011) but focusing on the deeper area (over the slope). Both mean and standard deviation to the mean, thus the CV of the temperature/oxygen can be partly explained

from its vertical (and horizontal) gradient. My question is whether relatively high CV is due to strong vertical (or horizontal) gradient of temperature and oxygen (thermocline and oxycline depths). Also, how the structures are different from spring (D100-DM-Spr) vs. fall (DM100-DM-Fall)? It would also be relevant to high turbidity condition around 300 m as the internal waves/internal tides break and enhance the mixing (to resuspend the sediment) when and where the isopycnals (isotherms) touch the bottom (see the comments #6 below for details).

RESPONSE: To look at patterns in cross-sectional structures of water temperature and dissolved oxygen across the shelf and slope, and to look at how these spatial patterns change seasonally, we extracted data from CalCOFI stations 93.3 28, 93.3 30, 93.3 35, and 93.3 40 and examined the CTD profiles for these stations during the deployment period. Four cruises were relevant to examine, however, cruise 1802SH was shortened due to the government shutdown and therefore only one of the four stations (93.3 30) was sampled. As such, we focused this additional analysis on just the three cruises (1708SR – August 2017, 1711SR – November 2017, and 1804SH – April 2018). In the new supplementary figure (attached, and titled New Supplementary 1), we show the temperature and oxygen profiles for these four stations across the three relevant cruises. From these profiles, we see that in the spring (April 2018), there is no onshore-offshore gradient, whereas in summer (August 2017) and to a lesser degree in late fall (November 2017), spatial differences in onshore (93.3 28 and 93.3 30) and offshore (93.3 35 and 93.3 40) environmental profiles are evident. These spatial differences are most pronounced in late summer (August 2017). Additionally, in August 2017 there is evidence of some unusual vertical structure in the oxygen profile around $\sim$200 m; both at station 93.3 28 and 93.3 30. Our first deployment (D200-LJ-1) was conducted in late August, so may have captured part of this feature. However, this cannot fully explain the higher variability we observed at 200 m, because our later deployment (D200-DM) was done in mid November, when there is no evidence of unusual vertical structure in the oxygen profile at 200 m for 93.3 28 or 93.3 30. These supplementary profiles, as well as the profiles in New Figure 7 do show that the thermocline is steeper and

shallower, overall, than the oxycline. We hope these additional datapoints help shed light on the sources of observed variability in our short-term deployments.

6) As described in Abstract, the high-frequency oxygen variability was strongly linked to tidal processes. But, I do not understand why it is contrary to expectation. As described in Section 1 (Lines 54-57), Section 3 (Lines 308-313), Section 4 (Lines 449-450 and 479-480), and Supplements, diurnal and semidiurnal oxygen variability is noticeable. This is not something unexpected but consistent with previous works reporting oxygen variability in a shallower zone, e.g., Frieder et al. (2012). Importance of tidal processes may also be confirmed from spring-neap cycles or modulations of semidiurnal/diurnal oxygen fluctuations. I could see such a spring (neap) amplification (reduction), for example, from time series plot of D10 - 98 m or D100-DM-Spr in Supplement 1B. Amplitudes of semidiurnal oxygen fluctuations reach up to larger than 20 μmol kg-1 for Days 0-3 and 10-13 (presumably corresponding to spring tide) while smaller than 10 μmol kg-1 for Days 5-8 and 17-20 (presumably corresponding to neap tide). What are CVs for periods of spring vs neap tides? I believed and continue to believe that such high-frequency oxygen variability is relevant to internal tides generated and shoaled at a specific phase of the surface tide in a sloping bottom (even up to the zone as shallow as 15 m) as reported in the region by Nam and Send (2011) and others. It is generally known that the isotherms (so iso-oxygen surfaces) move up and down at high-frequency due to propagation and evolution internal tides and associated shorter period nonlinear internal waves (also termed internal solitary waves). When they shoal and break, turbulent mixing is markedly enhanced often forming bottom nepheloid layer that may account for suspended sediments and the high turbidity condition around 300 m. The bottom nepheloid layer has been presented since McPhee-Shaw (2006; “Boundary-interior exchange: Reviewing the idea that internal-wave mixing enhances lateral dispersal near continental margins” published in Deep Sea Research II: Topical studies in Oceanography as of 20 February 2006), e.g., Boegman and Stastna (2019; “Sediment resuspension and transport by internal solitary waves” published in Annual Reviews of Fluid Mechanics as of 15 August 2018).

RESPONSE: Thank you for raising these points. One of the objectives of this study was to place rates of anthropogenic change within the context of short-term variability that nearshore deep-sea communities are exposed to. These results show that tidally-driven variability is an important source of high-frequency variability to consider, that could either exacerbate or buffer deep-sea communities from changes in mean conditions with climate change. Contrary to the idea that the deep-sea is a stable environment, these results show a substantial amount of environmental variability occurring at short timescales on the upper margin.

As suggested by the reviewer, we examined the CVs for the two spring and neap periods captured during D100-DM-Spr. The CVs for the two time periods corresponding to the spring tide (Days 0-3 and Days 10-13) were 5.02% and 4.76%, respectively, while the CVs for the two time periods corresponding to neap tide (Days 5-8 and 17-20) were 2.66% and 2.69%, respectively.

Additionally, we have added the following information in the discussion in section 4.1: “The high turbidity observed at this depth may be due to shoaling and breaking nonlinear internal waves that can form bottom nepheloid layers (McPhee-Shaw 2006, Boegman and Stastna 2019). High turbidity conditions have also been observed during two separate ROV dives at $\sim$340 m off Point Loma (unpublished, NDGallo), suggesting high turbidity conditions may be the norm at these depths on the upper slope in the SCB.”

7) Not being a biologist, I do not know in detail how the seafloor communities respond to short-period (mostly diurnal) changes in environmental conditions, but it is convincing that longer time series data are vital for addressing the science issue. My question is why camera sample should be less frequent for longer-term deployment. Is it limited by battery or memory? There would be several technical ways to overcome battery or memory limit. Why not trying new technologies that allow longer-term deployment keeping the same camera (as well as other sensors) sampling frequency.

RESPONSE: Ideally, we would like to maintain both the high-resolution sampling frequency (20 second video samples every 20 minutes) and extend the deployment length. In this study, the main technological limitation we ran into was limited battery capacity to power the LED lights; all other elements would have allowed for longer sampling (camera battery and memory, SBE MicroCAT battery and memory). The basic Nanolander itself can stay in situ for periods of 2 years, perhaps longer. However, we were only able to provide sufficient power to the LED lights for a maximum period of 14 days at the selected sampling frequency.

As we see the advantages of even longer time series, we are looking at the limitations of our initial technology choices. Some of these were made on the basis of cost and availability, others because of familiarity. We have looked specifically at ways to improve the power capacity to the LED lights, which can be done by using new camera controllers, solid-state relays, and high efficacy LEDs. Additional batteries to power the LED lights can also be added by integrating them into newly devised side pods that attach to the Nanolander. Using low light cameras, such as the Sony α7S II, would also reduce the amount of LED light required, reducing power drain, and would increase the depth of field. These options are all currently being explored as ways to extend future deployment lengths, while maintaining the high-resolution sampling frequency.

Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2020-75, 2020.

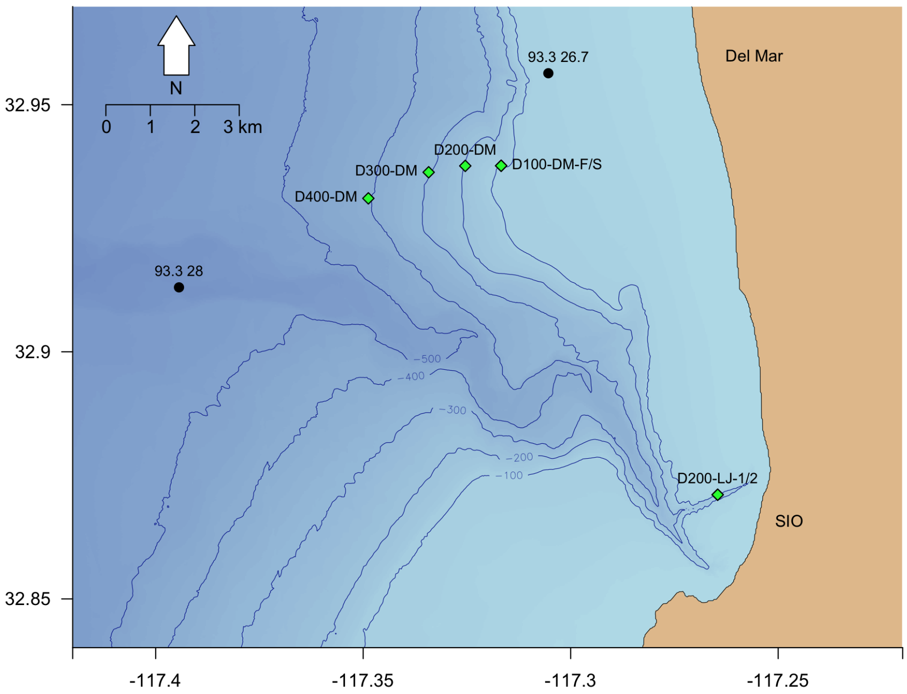

Fig. 1. New Figure 3

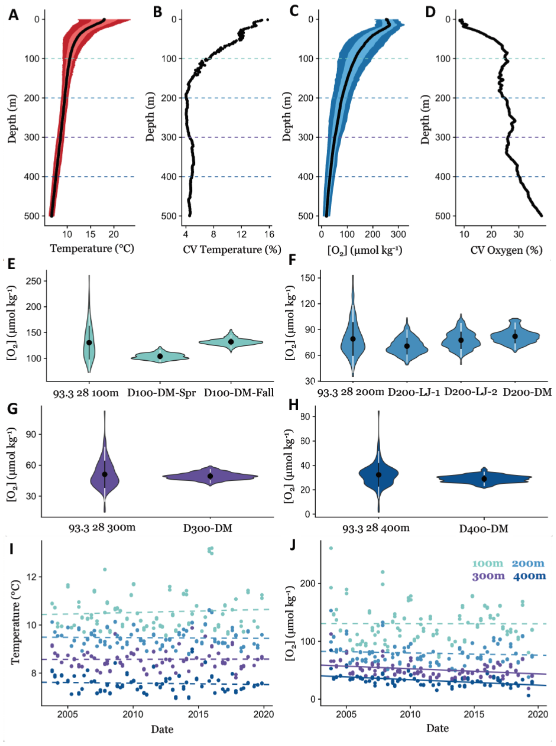

Fig. 2. New Figure 7

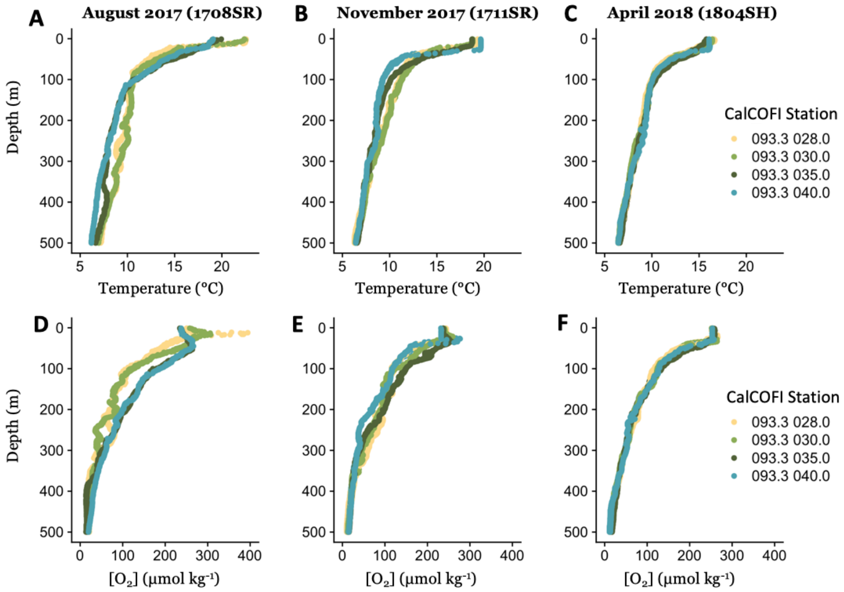

Fig. 3. New Supplementary 1