Ocean Sci. Discuss.,
https://doi.org/10.5194/os-2020-123-AC1, 2021

Ocean Science Discussions
Open Access
EGU

Interactive comment on "Oxygen and nutrient trends in the Tropical Oceans" *by* Lothar Stramma and Sunke Schmidtko

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Received and published: 21 April 2021

Our replies are added to the reviewer's comment. A more structured pdf-version is added as supplement.

We thank both reviewers for their comments, which helped to improve the revised manuscript.

Reviewer(s)' Comments to Author:

Reviewer: 1

Abstract: The abstract begins with a reference to the "vertical expansion of the intermediate-depth low-oxygen zones", a topic developed in the earlier Stramma et

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al. (2008) paper. The present manuscript does not really discuss “vertical expansion” and I suggest modifying this introductory abstract sentence so that it focuses on the present paper.

Thanks, good remark. The first sentence focusses now on the oxygen decrease instead of the vertical expansion.

Methods: I am not a specialist with the statistical methodology (a limitation discussed in advance by email with the editor). However, many readers of this paper are likely to also be non-specialists in this regard. In order to make this paper more comprehensible to the broader global change community, a simple non-technical summary paragraph of how the data were chosen and assembled to get a single point representing 1 year per depth zone and area, and the limitations of the dataset and methodology, would be valuable and would prevent mis-interpretation. Although I read the referenced methods in Schmidtko et al. (2017), I still have questions (and most general readers would probably not refer back to that reference).

We added a more non-technical summary paragraph in the Data and methods chapter on page 5. With regard to limitation of the method also the text in the Discussion and Summary chapter was modified and more details added that are easier to comprehend the steps taken in this manuscript and in the references. See also our answer below.

Some methodological questions that could be addressed in a summary paragraph include: Were only individual bottle sample data used or were data from continuous electronic sensors from the last few decades included (vertical profiles from the many oceanographic instruments that include CTD sensors)? If electronic profiles were used, how were they condensed into 1 value for that depth interval? Were any data from Argo floats used since temporal and geographic coverage is expanding (although extended geographical oxygen coverage is only just beginning with the Biogeochemical Argo floats)? If these various electronic profilers were not used, a major source of modern data was ignored, and this limitation should be acknowledged. The discussion could

include suggestions about how these continuous profiles might be applied to future trend calculations.

In the additional paragraph in the Data and methods section it is now described that bottle and CTD data are used and that float data were not included as measurements from our own floats showed drifts probably due to biological activity at the sensors which would lead to erroneous trends. The possibility to use float data in future once drifts can be removed is mentioned in the Discussion and Summery section. The main focus of this manuscript is to compare the extended time period with the Stramma et al. (2008) results, this paper is even today highly cited. Therefore, we used the similar methods to make the results comparable (mentioned now in the additional paragraph in the data and Methods chapter). CTD data are available in 1 dbar steps. We used only the CTD values 5 dbar apart to reduce the amount of data, as also the vertical gridding was made on 5 dbar steps. This information is now included in the supplement text. Using an objective mapping scheme described in the manuscript the available data were mapped on 5 dbar steps and then the mean value and standard deviation for the two depth intervals 50 to 300 m and 300 to 700 m was computed. This in now explained in the text.

How many individual data points (or specific CTD casts) were included for each year? This is especially important for interpreting the earliest records. Could this be included in a supplementary table?

The data points and CTD profiles vary for each year in each area. A table with the numbers of data points would not show how large the bias of the computed mean oxygen value is. However, we mention now the possible influence of the fewer data point within a selected depth layer in the additional paragraph in “Data and methods”.

The authors do discuss how they accounted for chemical measurement improvements over this time period. However, since the 1950’s, there have also been substantial improvements in location (satellite-based) and depth (electronic sensor) data. Was there

any consideration for those sampling changes and uncertainty of those parameters in earlier data? That should at least be mentioned.

We mention now in the Data and methods paragraph the uncertainty caused by less accurate depth measurements from bottle data with CTD-depth measurements. As all measurements within each area independent from the geographical location were used, the better satellite derived location should not influence the results presented here.

The authors mention standard vertical depth levels (line 126). What are the depths and how were they used? As someone who deals with the small-scale vertical and temporal variability of oxygen through some of these depth strata, I remain confused about how that single value was derived, what it represents, and how robust that calculated value is. Is this supposed to be an indicator of the concentration of oxygen in the OMZ? Small changes in depth (and location and time) within their indicated depth zones can have quite different oxygen concentrations, as we now know from continuous profiling sensors and short-term replicated profiles. Since many of the long-term trends are slight, small changes in this value (for example from bottles offset by < 10 m or taken a few hrs apart) could have large consequences for the calculated trends. In the discussion, the authors should include more about the uncertainty associated with these issues, how to account for that, and how to improve future predictions.

In the revised version more information is presented with regard to uncertainties. The reviewer is correct that time of measurements and vertical resolution play a role for uncertainties of the trends. Never-the-less on the larger scale, due to internal waves, depth uncertainties and other factors we can assume these errors to be noise the no systematic bias over time. Thus, any trends derived will be less certain though not biased in decline or increase of the parameter analyzed. Furthermore as mentioned above we use the same methods as in Stramma et al. 2008 to make the results comparable. With CTD oxygen measurements on 1 dbar steps the uncertainties between years will be much less than in comparison to bottle oxygen measurements in earlier

years. Nutrient trend computations could be improved if future nutrient measurements are made on defined standard depth levels to make the results better comparable. This is now explained in the Data and method section as well as in the supplementary file.

Results and Figures Tables 1 and 2. It would be helpful to have more space between items or some other font indicator (bold?). It took several readings to notice the year listing since this blended in with the other numbers.

The years in Tables 1 and 2 are now bold, hence it should be well recognizable what are the trends and what are the time periods.

Fig. 2 and 3. The plots should be labelled A, B, C etc. There should be bigger tick marks for the decadal divisions on the x axis so those are visually differentiated from the climate index modal divisions. The caption should include a sentence noting that the X's in the plots represent an annual value (one X per year). There should also be a sentence to point out that the Y axes for oxygen (and nitrate in Fig. 4) differ in each plot.

In Ocean Science subsets of figures are labelled a, b, c (not A, B, C)

Bigger tick marks now show the decadal divisions on the x-axis.

The (x) is included in the figure legends and a sentence added to point out that the y-axes changes.

Fig 5. First line of the caption should delete "oxygen" and its units since this figure shows different variables in each graph.

Thanks, "oxygen" was replaced by "parameter" and the units were deleted in the first line of Fig. 5 caption.

It would be very interesting to see all the overall trend lines for a particular variable (oxygen in the two depth zones, nitrate) plotted on a single graph (one graph for each variable) with a single Y axis range. This would allow a visual comparison of the ge-

ographic variability in the strength of these trend lines. This could be a supplemental figure.

As supplementary figures the trends for both oxygen layers and the nitrate trends are presented.

Discussion This paper provides strong support for the trend of increasing deoxygenation worldwide at mid ocean depths. Many interesting possibilities are discussed to explain the trends in the different ocean areas and the interactions of different variables with regional physical oceanography, the climate modes, and each other. However, this also becomes confusing with details. It would be helpful to have some summary conclusions, perhaps a numbered list by geographic area. I would also like to see more discussion about the broader implications of these trends especially for ocean biology and human impacts. The authors could also bring in some mention of how their results could contribute in the future to some of the major climate change discussions and documents (IPCC report, UN Ocean Decade, etc.)

We included near the end of the manuscript a paragraph listing the observations by ocean basins. The implication of oxygen trends for biology and human impacts quite large and a lot of literature exist. All aspects of oxygen trends are discussed in the different chapters of the IUCN report (2019) and this is now mentioned and referenced at the end of the summary.

Minor wording comments: Line 47: sinking, transport, and subduction into the deep ocean (the biological pump includes more processes than sinking) Line 73: extent Line 74: biologically Line 97: despite the fact that the low Line 434: nutrients Line 441: agrees with Line 443: sentence? Line 452: adding Line 463: trend-line; Line 478: areas. Hence, Line 484: appear Line 485: ocean; therefore, Line 495: inverse Line 496: observed; however, Line 519: fisheries

Thanks for pointing to the correct writing, all proposed changes were done in the modified manuscript.

Please also note the supplement to this comment:
https://os.copernicus.org/preprints/os-2020-123/os-2020-123-AC1-supplement.pdf

Interactive comment on Ocean Sci. Discuss., https://doi.org/10.5194/os-2020-123, 2020.

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