

## ***Interactive comment on “Oxygen minimum zone of the open Arabian Sea: variability of oxygen and nitrite from daily to decadal time scales” by K. Banse et al.***

**K. Banse et al.**

banse@ocean.washington.edu

Received and published: 17 January 2014

We thank the Referee for his constructive comments. Our point-to-point response is as follows. Please note that the comment identifier "15472:12" denotes "page 15472, Line 12"

p. C6562. Thanks for the compliments and the comments. C6562. Regarding the bottom of the page: To be too close to the subject matter is a common, recurrent fault of authors although we tried to avoid adding irrelevant information. Being concerned about the length of the paper, we might have failed to elaborate at some places to establish the context. To help putative readers, however, we will open involved sections

C7982

with one or two sentences, taken from the concluding part of the section, that present the results

15456:7-10, '... out of the blue' – this is an abstract but not running text! To establish context, however, we expand the lines to '... processes. While we report on historic O<sub>2</sub> observations, the very low O<sub>2</sub> values subsequently obtained from the STOX sensor in the eastern tropical South Pacific probably characterize also the Arabian Sea OMZ. Currently, however, there is no apparent reason why the temporal trends of the historic data should not hold.'

15456:11. The sentence has been changed to '...O<sub>2</sub>, NO<sub>2</sub><sup>-</sup>, temperature and salinity made between ...'

15456:26-27. We regret there was an error. The sentence has now been changed to '...but an opposing trend of an increase in O<sub>2</sub> near 21°N is observed'

15457:1. We replace 'reconstitution of the decrease' by 'replenishment of O<sub>2</sub>'.

15457:7-9. We have changed the text as follows: 'Going by the distribution of NO<sub>2</sub><sup>-</sup>, taken as an indicator of active denitrification, there is no trend in the redox environment for a quarter of a century at a GEOSECS station near 20°N. In the entire OMZ the slopes on year within seasons for the quite variable NO<sub>2</sub> do not show a clear pattern.'

15457:19-20. We change to '... water column of the world ocean. According to Naqvi et al. (2005: Table 9) the contribution of the Arabian Sea to the global marine pelagic denitrification lies between 8 and 21%.'

15459:1: We insert 'albeit non-sulfidic' after anoxic.

15459:6-11. We move the entire paragraph to the present p. 15460: after Line29.

15459:21. We drop the last sentence ['Thus ... AMZ.']

15460:6. We insert 'and Ulloa et al. (2012)' after 'Thamdrup et al. (2012)'

C7983

15460: 7-9. We moved to p. 15461:1 and rephrased.

15460:7-10. We rephrase: '... South Pacific. The answer is No. The OMZ of the Arabian Sea as a whole is not a non-sulfidic Anoxic Marine one (AMZ) as envisaged in 2012 by Ulloa et al. and Thamdrup et al. Metazoan (animal) ...' [note: the authors' order is deliberately inverted].

15460:15. We replace 'reconstitute' by 'replenishes'.

15460: 21-22. We rephrase '... 3.2.5). Thus, enough O<sub>2</sub> was present to prevent the onset of NO<sub>3</sub><sup>-</sup> reduction. In contrast ...'

15460:30. We insert here lines 6-11 of p. 15459.

15461:1 We drop the first  $1\frac{1}{2}$  lines, as well as the last sentence (lines 4-5) beginning with 'Therefore' and rephrase (starting a new paragraph): 'The detection limit of the titration endpoint in our data collation is about 0.04 mL L<sup>-1</sup> ( $\sim 2\ \mu\text{M}$ ) above the  $\sim 0.01$  mL L<sup>-1</sup> of modern automated titration methods (see Suppl. Sect. 2). Measurements in the OMZs with the recently developed STOX sensor have yielded even lower values (by at least an order of magnitude; see Sect. 1). However, in spite of these uncertainties associated with O<sub>2</sub> measurements at vanishingly low concentrations, we believe that the temporal trends being reported here remain valid. Were it not so ...' [continue from present 15461:2].

15462:21-24. We drop the sentence starting with 'In turn' and ending with 'new era'. Instead, we write on without starting a new paragraph ['For our boxes ...'].

15470:5. We drop the entire subsection except of moving the last sentence of the first paragraph into the next section.

15471:26. We drop 'the already referred map of'.

15472:11. We correct a mistake, 'As stated, 21% of 707 samples ...'

15472: 18-20. We drop the sentence.

C7984

15472-15474, Section 3.2.6: We disagree with the referee. The purpose of this section is to argue for a steady supply of O<sub>2</sub> to the OMZ. Therefore, we have retained it.

15474:11. We make the sentence clearer by replacing 'that of NO<sub>2</sub><sup>-</sup>' by 'the NO<sub>2</sub>-maximum'.

15475:3. We drop subsection 3.2.8 with regrets. It was to provide scope for workers on, e.g., plankton or satellite-derived chlorophyll, who are unlikely to run into this literature on their own.

15477:12 and Fig. 3. The connect to the latitudes is the box designation (e.g., 'D' for 15oN). To help a tired reader, we insert on 14576: 18: 'see also Fig. 1' in the parenthesis after 'Fig. 3'.

15479:6-7. We replace 'on only two cruises' by 'on two cruises during successive years (Naqvi et al., 1990), three cruises during two years (de Sousa et al., 1996), or several cruises during one year (Morrison et al., 1998). They could not distinguish ...'

1548:4. We insert a new subsection (5.2.1)

'5.2.1 Oxygen, nitrite, nitrate, and metazoan plankton We noted that titration-based O<sub>2</sub> values and NO<sub>2</sub><sup>-</sup> co-occur temporally, and since NO<sub>3</sub><sup>-</sup> where determined is always present, free S is not found in the OMZ. Also, 21% of 707 discrete OMZ samples analyzed for O<sub>2</sub> were without NO<sub>2</sub><sup>-</sup>. Following Thamdrup et al. (2011), these would have contained > 0.002 mL L<sup>-1</sup> ( $\sim 0.1\ \mu\text{M}$ ) O<sub>2</sub>, which is well below the detection limit of the conventional O<sub>2</sub> methods (the value marks onset of NO<sub>3</sub><sup>-</sup> reduction). In section 3.2.5 and Suppl. S.3 we review that the OMZ of the Arabian Sea with its pronounced secondary NO<sub>2</sub>-maximum harbors resident metazoan plankton throughout, but the plankton observations all come from net hauls of > 50 m vertical intervals. The NO<sub>2</sub><sup>-</sup> was usually observed at standard depths, which in the OMZ are vertically widely spaced. It is unknown anywhere in the open sea whether metazooplankton actually co-occurs with NO<sub>2</sub><sup>-</sup> as residents living day and night at < 0.002 mL L<sup>-1</sup>. It would be physiologi-

C7985

cally extraordinary (cf. Childress and Seibel, 1998). For tying NO<sub>2</sub><sup>-</sup>, O<sub>2</sub>, and metazoan occurrence together, we suggest in future to collect the animals with large water bottles (e.g., the Russian 100- to 140-liter samplers, Vinogradov et al., 1987), from which samples for NO<sub>2</sub><sup>-</sup> are also drawn. While the elaborate STOX sensor could measure the actual O<sub>2</sub> levels, routine determination of NO<sub>2</sub><sup>-</sup> as a simple substitute would provide a limit to the O<sub>2</sub> capacity of animal plankton. Using such large water bottles, R/V Dimitriy Mendeleev in mid-March 1978 at ~15°S along a section off Peru reported 1-100 mg (a few samples with 100-250) mg m<sup>-3</sup> wet weight of mesozooplankton (calculated from the species counts) at 10-m vertical intervals to 150 m depth, and at 175 and 200 m, with 3-8 μM NO<sub>2</sub><sup>-</sup> and > 12 μM NO<sub>3</sub><sup>-</sup> at six stations (Bordovskiy et al., 1980: figs. 14a, b; Semenova et al., 1980: Fig. 10). Because sampling during day light hours dominated, however, biomass of daily migrators cannot be excluded. We suggest new night-time collections, which presumably will catch only resident animals.'

15488:5. We drop '(total)'. (Thanks.)

15488:19. We replace 'mention' with 'cite'.

15489: 11. For 'these estimates' we substitute 'the estimates by Stramma et al. (2010) and Resplandy et al. (2012)'.

Table 3. Mean values of variables are named at the start (first columns) of the lines.

Table 4. We add to the first footnote, 'e.g., D1 200 m, SWM, median 0.12, 8 samples vs. SI, median 0.00, 3 samples'.

Table 7. We add to the footnote, 'see first footnote of Table 4'. Fig. 1 (p. 15510). The first line of the caption said it: 'Distribution of boxes, (left series, "1", right series, "2") with ...'

Supplement

L 9. We insert 'sigma-t' after density.

C7986

L 13. We replace 'Note' by 'Recall'.

L 19. We drop 'apparent', but retain it on lines 21 and 28.

---

Interactive comment on Biogeosciences Discuss., 10, 15455, 2013.

C7987