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Interactive comment on "On the role of circulation and mixing in the ventilation of oxygen minimum zones with a focus on the eastern tropical North Atlantic" *by* P. Brandt et al.

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Reviewer #1: This article largely reviews recent results from the SFB 754 program designed to investigate the climate and biogeochemistry interactions in the oxygen minimum zones (OMZs) of the tropical oceans. It is very well written and gives a thorough and complete overview of the major results to date. Since it is primarily a review/progress article, it is difficult to find fault with any of the results since the article mainly reports and synthesizes the results rather than (re)interpret these results or present new results. So, consequently this review provides (hopefully) constructive comments rather than a scientific critique of the published record. I very much liked the layout of the paper, and the discussion of the individual components of the oxygen budget and the main mechanisms that influence this budget in the eastern tropical Atlantic. An excellent approach. However I think in general there could have been more discussion of the error bars of the budget, particularly in the individual sections that discuss the processes. Most sections lacked any error bars on the estimates, other than to note that the mechanisms might be poorly constrained (a good reason to show or explicitly discuss the error bars and how they are comprised). Or perhaps error bars were presented in the accompanying figures (e.g. Figure 12, 13 showing the effect of diapycnal mixing) but there was little discussion of how these error bars were computed.

Answer to reviewer #1: We included more discussion on how the error bars were obtained particularly for diapycnal and lateral diffusive fluxes. The calculation of deep diapycnal mixing including error bars was repeated using more deep microstructure profiles that are now available. This leads to changes in Figures 11 to 13, and 21. We included in section 4.1 “Error estimates are reported as 95% confidence limits and are based on standard errors of the mean of individual K_rho and oxygen gradient profiles for each subregion. Subsequent error estimates for the mean total K_rho profile (Fig. 12), flux profiles, and the mean supply profile (Fig. 13) were obtained from Gaussian error propagation (Ferrari and Polzin, 2005;Schafstall et al., 2010).” Furthermore we included in section 4.2 the sentence “Hahn et al. (2014) estimated a meridional eddy diffusivity profile for the upper 1000 m with the range of uncertainty assumed as large as a factor 2 following Ferrari and Polzin (2005).” And “The corresponding error (i.e. of the eddy-driven meridional oxygen supply) was derived both from the error of the curvature of the meridional oxygen distribution (95% confidence) and the error of the eddy diffusivity (factor 2 assumed following Ferrari and Polzin (2005)).” In section 6.3 we included: “Within this region, the diapycnal flux of oxygen from the mixed layer into the stratified ocean is 73 mmol/mˆ2/d, with an upper and lower 95% confidence limit determined from Gaussian error propagation (Ferrari and Polzin, 2005;Schafstall et al., 2010) being 105 mmol/mˆ2/d and 44 mmol/mˆ2/d, respectively.”

Reviewer #1: In the section 4.3 Advection I kept wondering why there was no actual quantification of this component. It was not until the conclusions that it was reported that this component is so poorly resolved that it is actually represented as a (large!) residual in the budget. This information needs to be reported much earlier.

Answer to reviewer #1: Already in the last version of the manuscript, we stated right at the beginning of section 4.3 that "we are only able to quantify this term as a residual". We now include an explanation at the beginning of section 4.3 "A rigorous determination of the advection term would require mean sections around a closed box to fulfil mass balance within the box. This cannot be achieved with the present observing system. However, our measurements along 23° W confirm that the advection term is a major player in the ventilation of the OMZ, especially above 400 m depth."

Reviewer #1: The reason this component cannot be resolved is because there are insufficient and/or inadequate measurements available to determine this component. This raises another issue. Given the disparate and large number of measurements collected as part of the SFB 754 program, it might also be worthwhile discussing what measurements might still be required and at what resolution. In other words, it is an ideal time to determine what legacy measurements might remain and what additional measurements (e.g. multiple glider transects crossing the deep tropical jets instrumented with O2 sensors etc?) might be needed for monitoring the changes in the OMZ and the processes that lead to these changes.

Answer to reviewer #1: Thank you very much for this comment. Besides the difficulties of quantifying the mean advection, we now changed the wording and add sentences regarding the requirements for future observing systems. In the summary and discussion we included: "Dedicated process studies using mooring arrays, shipboard and multiple glider observations may help to elucidate the role of different processes in the eastern boundary oxygen budget." and we clarified: "Oxygen data from shipboard repeat hydrography and moored observations show substantial interannual variability (Fig. 8) and trend-like changes (Fig. 19). The continuation of such measurements is

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essential to be able to test different hypotheses for the driving mechanisms of oxygen changes in the ocean."

Reviewer #1: Finally, given the length of the paper, I think that it's probably best to only focus on the OMZ in the eastern tropical Atlantic Ocean and carve out the comparison with the Pacific for another paper later. It really is a very meaty paper already and there is a lot to digest!

Answer to reviewer #1 (same as answer to reviewer #2): Although removing the ETSP part would shorten the text and keep the focus on the ETNA, we like to keep the comparison of the ETNA OMZ with the ETSP OMZ in the text. The motivation here is similar as for the SFB 754 to compare a hypoxic system, i.e. the ETNA OMZ, with a suboxic system, i.e. the ETSP OMZ. Particularly the observed deoxygenation trend in the hypoxic ETNA OMZ might lead to a shift of the ETNA OMZ to suboxic conditions and hence the comparison of the two systems will lead to a better understanding of differences and similarities of both systems finally to investigate possible consequences of such a possible regime shift in the future. This was not made clear in the earlier text and will be clarified in the revised manuscript. We included in the introduction: "The Atlantic and Pacific OMZs have many similarities particularly regarding OMZ shape and circulation pattern. The ETNA and the eastern tropical South Pacific (ETSP) OMZs (Figs. 1, 2) are both located in the shadow zones of the ventilated thermocline and are ventilated by lateral and vertical mixing as well as by zonal advection in the equatorial band. However, the striking difference between both OMZs is that the ETNA OMZ is hypoxic (oxygen below ~60 to 120 μmol/kg) and the ETSP is suboxic (oxygen below about 10 μmol/kg). Karstensen et al. (2008) concluded that this difference is the result of reduced oxygen levels in the eastward current bands of the Pacific OMZs compared to the Atlantic OMZs, which they argue can be traced back to the larger ratio of the total volume of OMZ layer to the renewal or subduction rate in the Pacific compared to the Atlantic." and "The ETSP OMZ has been studied as well using a reduced observational program. However, the comparison between the hypoxic ETNA and the suboxic

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ETSP is of particular interest here, as the observed deoxygenation in the ETNA, or future climate change, might lead to a shift from hypoxic to suboxic conditions." At beginning of section 8 we included: "A continuation of the observed deoxygenation in the ETNA would turn the ETNA OMZ suboxic within a century, hence it is worth to look at differences and similarities of the ETNA and the ETSP with regard to a possible shift of a hypoxic system to a suboxic system." In the summary and discussion we included: "The relative importance of the different terms affecting the oxygen budgets of the ETNA und ETSP OMZs appear to be similar. For both OMZs the eastward advection of oxygen-rich waters from the well-ventilated western boundary was found to be a dominant ventilation process. As the zonal currents are of similar strength in the tropical Pacific and Atlantic, the difference in the basin width of both oceans consequently results in lower oxygen concentrations and larger water mass ages in the eastern tropical Pacific (Fig. 20) compared to the eastern tropical Atlantic (Fig. 6)."

Minor Comments by reviewer #1:

1. Page 12075: Is there any seasonal variation of the shallow OMZ?

Answer to reviewer #1: We expect that there is a seasonal variation of the shallow OMZ. Unfortunately we don't have a good seasonal coverage of oxygen data in the eastern boundary upwelling region of Mauretania and Senegal and cannot give a clear statement.

2. Page 12077, line 6: I could not wrap my head around this first sentence of this paragraph. Is there a simpler way to write this?

Answer to reviewer #1: We split the sentence into two: "The 23° W section (Fig. 6) cuts through the ETNA OMZ, which can be identified by low oxygen levels as well as by the high age of the water masses. The gradual change of salinity on density surfaces along this section defines the transition between low- and high-saline water masses of southern and northern origin, respectively."

3. Page 12081: How good is the assumption that meridional advection is negligible? What about the possible significance of cross-equatorial exchanges via thermocline convergence, upwelling and Ekman divergence?

Answer to reviewer #1: The thermocline convergence, upwelling and Ekman divergence describes the flow within the subtropical cell (STC). The water masses subducted in the eastern subtropics have to follow equatorward and westward pathways without a mean meridional flow into the OMZs, which is described by the ventilated thermocline theory (Luyten et al., 1983b) and observed geostrophic water mass pathways (Zhang et al., 2003). This is described in Sect. 3. So far there is no evidence of a significant mean meridional flow in the core of the open ocean OMZ.

4. Figure 3 caption needs more information about how these oxygen concentration estimates were determined.

Answer to reviewer #1: We changed caption of Fig. 3: "Minimum oxygen concentration below 200 m (representing the deep oxygen minimum) as obtained from CTD station data taken during the period 2006 to 2013. Oxygen concentration at the deep oxygen minimum below 40 μmol/kg is marked by purple dots."

5. Figure 17. What causes the big spike at sigma-theta 26.1 in the AOUR values determined for the North Atlantic basin mean (black dots?)

Answer to reviewer #1: The apparent "spike" that is seen for the density range 26.1 to 26.2 originates from the comparably young reservoir age of this density range (related to enhanced subduction rates). We added a statement to the text (also with a reference to the Figure 9 in Karstensen et al. 2008 which nicely shows the enhanced subduction within the given density range).

Interactive comment on Biogeosciences Discuss., 11, 12069, 2014.