Final Author Comments

"Characterization of "dead-zone" eddies in the tropical Northeast Atlantic Ocean"

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Dear Editor, dear Reviewer,

We would like to thank you for the positive evaluation of our manuscript. The constructive criticism, the corrections and suggestions surely helped to improve the manuscript. In the following we address the remarks of the Reviewer #2 in detail and how we intend to address his/her concerns in the manuscript. The comments by the reviewer are shown in *italic* and our responses in normal text.

Anonymous Referee #2

Main Comments

Based on a set of data from different platforms, the authors analyze the impact of mesoscale eddies in the formation of the shallow oxygen minimum in the eastern tropical North Atlantic (which differs from the deepest minimum located below 400 m, that characterize the oxygen minimum zone of that region). Another central idea of the work is that the shallow oxygen minimum (~ 80 m depth) observed in some kind of eddies, is not due to the transport of waters with low oxygen carried by the eddies from the coastal regions, but is generated by the internal dynamics, particularly in cyclonic and subsurface anticyclonic eddies (or anticyclone modewater eddies). Within both types of eddies, the shallow isopycnal surfaces (located about 70-100 m depth) rise, favoring biological productivity near the surface (documented by positive chlorophyll anomalies estimated from satellite observations). The export of organic matter back into the subsurface would, thus, result in a relatively high rate of respiration leading to the formation of a shallow minimum of dissolved oxygen. Eddies effectively may *"accumulate" this effect by transporting the water as they move.*

I think the paper is an important contribution to the understanding of the dynamics of the biogeochemistry in the study region and highlights the effects of a special class of eddies (ACME), which is possibly relevant to other regions where the presence of subsurface anticyclonic eddies is frequent. The work is fairly well structured and in general, the argument is consistent and can be followed easily. It seems that the authors have done a good job and in my opinion is an important contribution to understanding the hydrography and the biogeochemistry in that region, and it is also a contribution on the role of mesoscale eddies in the ocean. However, there are two issues that seem to me that should be discussed:

- Thank you very much for this positive evaluation.

(1) Subsurface anticiclonic eddies may not have a proper manifestation in satellite altimetry. For example, contrasting Figure 5a for the cyclonic eddy and that for the ACME (Figure 5b), the latter has very small speed anomalies near the surface, and thus the sea level (and geostrophic velocity) anomalies should be small. This should be a relatively major problem if geostrophic velocities, based on altimetry, are used to identify, define the contours of these eddies and to position oxygen profiles.

- It is correct that ACMEs have a weak surface signature, which makes them more difficult to be detected and tracked by satellite altimetry compared to normal anticyclonic/cyclonic eddies. In the present analysis only eddies detected with a common Sea Level Anomaly (SLA) threshold are followed with the tracking algorithms. Resulting eddy composites of SLA, Sea Surface Temperature (SST) and Seas Surface Salinity (SSS) are shown in Figure 1. The weaker anomaly of ACMEs compared to the other types of eddies is apparent. However, as there should exist also ACMEs with weak or even no SLA signature, we expect that the frequency of occurrence of ACMEs is underestimated. We included a corresponding statement in the text.

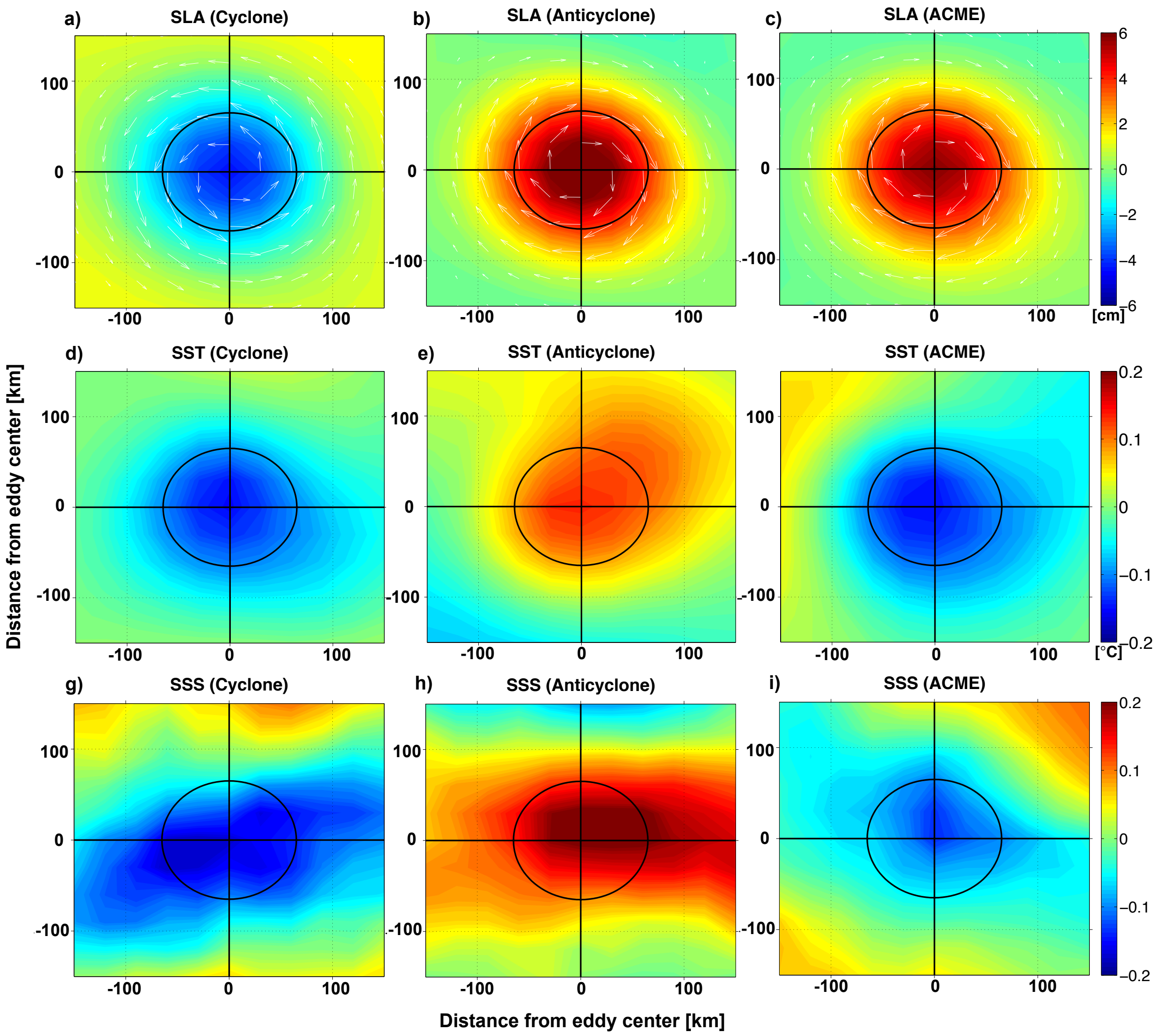

Figure 1: Sea Level Anomaly (SLA), Sea Surface Temperature (SST) and Sea Surface Salinity anomalies of the composite cyclone, anticyclone and ACME in the tropical Atlantic off northwest Africa. SLA (color) and the associated geostrophic velocity (white arrows) are shown for each eddy type in **a)**, **b)** and **c)**; SST anomaly in **d)**, **e)** and **f)**; and SSS anomaly in **g)**, **h)** and **i)**, respectively. The circles mark the mean eddy radius. Taken from Schütte et al. (2016).

We now added a sentence on page 10 line 23 that point out the weakness in the statistic assessment:

"As discussed in Schütte et al. (2016) we expect that the number of ACMEs is underestimated because of the possible existence of ACMEs with a weak surface signature in SLA data."

(2) The authors argue that the water remains fairly isolated within eddies. Although several

studies (based on observation, numerical modeling and theoretical models) have shown that this phenomenon is correct, this is generally true for high latitude or subtropical eddies. Eddies ability to trap and transport water could be lower in the more linear equatorial region. This should be an issue to consider, at least for the southern part of the study area, located south of 12 ° N.

- Thank you for the comment, this is a very interesting point. In general we where surprised to detect long lived low oxygen eddies in the region south of 12°N. At this stage we simply have to accept the fact that the low oxygen levels are present in these eddies and, as we see from the T/S characteristics, the water seems not to originate from the eastern boundary region as it is the case for eddies found further north. Following the trajectories it seems that the ACMEs are generated in the open ocean somewhere in the region between 5°N and 7°N. However, the eddies seem to be isolated long enough (and respiration is intense enough) to generate an oxygen depleted core during their westward propagation. Clearly, further studies on their generation mechanism and their characteristics are required.

We added one sentence to discuss less isolation in lower latitudes at page 10 line 17-19:

"The occurrence of oxygen depleted eddies south of 12°N is rather astonishing, as due to the smaller Coriolis parameter closer to the equator the southern eddies should be more short-lived and less isolated compared to eddies further north."

Another (positive) comment is that given the extensive data set used in the study, the authors present quantitative information and in some cases, allows them to estimate statistical errors based on the standard deviation. In general, dissolved oxygen data is relatively scarce in large areas of the open ocean, this work is undoubtedly also a contribution in this regard.

- As mentioned right by the reviewer the dissolved oxygen data is relatively scare and flawed with large errors (Argo-floats) in wide areas of the open ocean. Due to the combination of the shipboard, mooring, glider and Argo measurements a satisfying dataset in the eastern tropical Atlantic could be obtained. But this could only be done due to the extensive observation of the eastern tropical north Atlantic in the recent years (25 research cruises, 1 longtime mooring and several glider deployments).

Other minor comments

In the first paragraph of the introduction, the references to support some general sentences do not seem to me the most appropriate (for example, lines 6, 7 and 8). I do not mean that the argument is fallacious (magister dixit), but I think there are other studies that might have greater authority to support what is mentioned.

- That is correct. We include other references at page 2 line 6, 7 and 8:

Line 6:

“In particular, the eastern boundary current system close to the Northwest African coast is a region where northeasterly trade winds force coastal upwelling of cold, nutrient rich waters, resulting in high productivity (Bakun et al., 1990; Pauly and Christensen, 1995; Messié et al., 2009; Lachkar and Gruber, 2012) “

Line 7, 8:

”The ETNA region is characterized by a weak large-scale circulation (Mittelstaedt, 1991; Brandt et al., 2015), but pronounced mesoscale variability (here referred to as eddies) acting as a major transport process between coastal waters and the open ocean (Marchesiello et al., 2003; Correa-Ramirez et al., 2007; Capet et al., 2008a; Schütte et al., 2015; Thomsen et al., 2015; Nagai et al. 2015).”

P4. L 1-6. Time lag for optode sensors is rather long given important differences between glider dives and climbs. How were the optode data from gliders corrected. Page 4 lines 14-15 and 22-23. Aanderaa optodes were really calibrated (I mean to change the calibration constants) using CTD cast or the casts were used to estimate the accuracy of the optodes.

- We added more information on the time constant problem on page 4 line 23-24:

“All four autonomous gliders were equipped with Aanderaa optodes (3830) installed in the aft section of the devices. A recalibration of the Optode calibration coefficients were determined on dedicated CTD casts following the procedures of Hahn et al. (2014). These procedures also estimates and correct the delays caused by the slow optode response time (more detailed information can be found in Hahn et al. 2014; Thomsen et al., 2015).”

- The CTD casts are used to change the calibration constants of the Aanderaa optodes. We add one sentence at page 4 line 16 to give that information:

"Optode calibration coefficients were determined on dedicated CTD casts and additional calibrated in the laboratory with water featuring 0% air saturation before deployment and after recovery following the procedures described by Hahn et al. (2014): "

P7. L24 (and 16). Salinity in the core of ACME is mentioned as an important variable, why did you decided not to show it.

- That is right. We changed figure 5 and substitute the temperature with salinity (see figure 2).

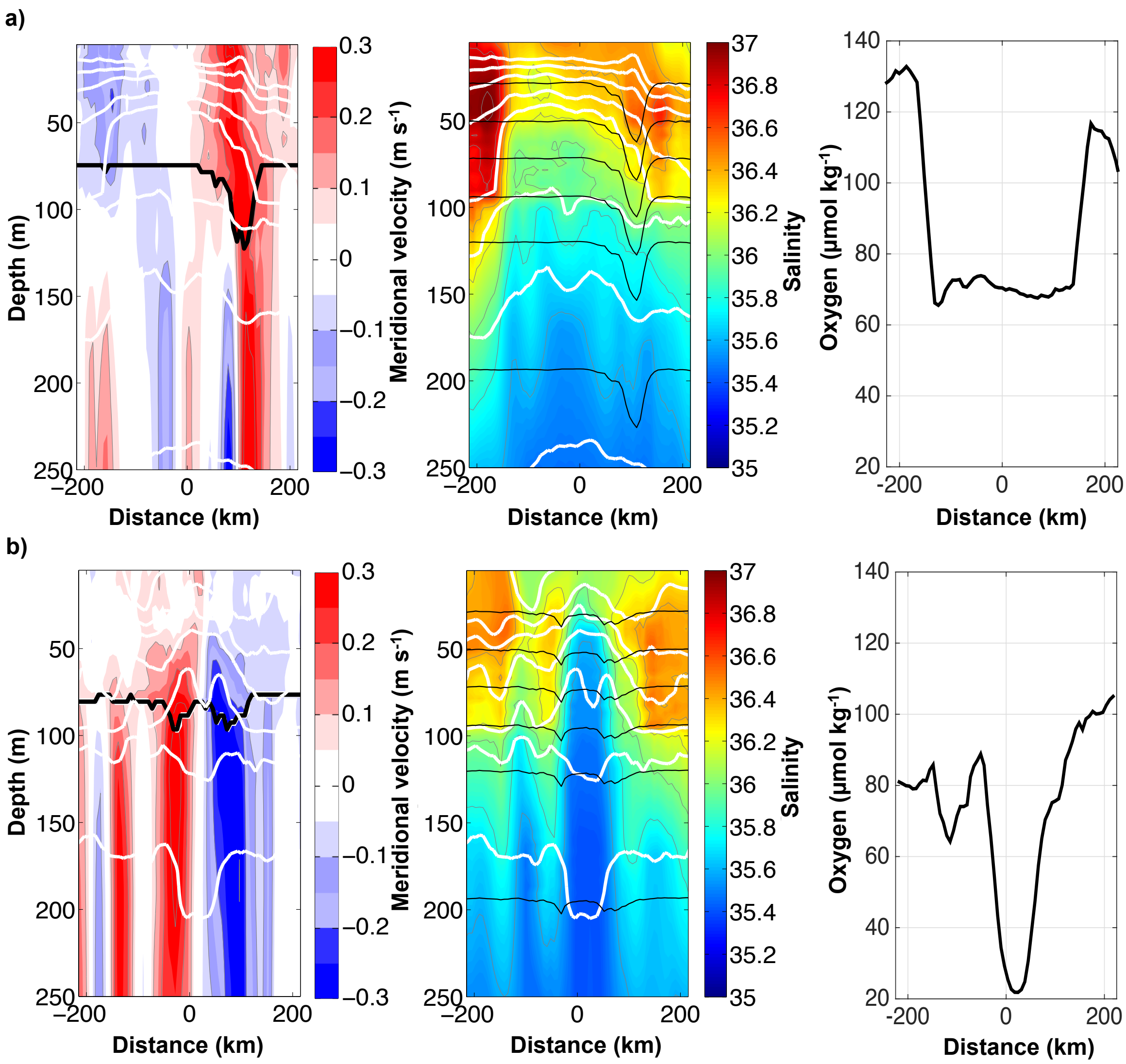

Figure 2: Meridional velocity, salinity and oxygen of an exemplary **a)** CE and **b)** ACME at the CVOO mooring. Both eddies passed the CVOO on a westward trajectory with the eddy

center north of the mooring position (CE 20 km, ACME 13 km). The CE passed the CVOO from October to December 2006 and the ACME between January and March 2007. The thick black lines in the velocity plots indicate the position of an upward looking ADCP. Below that depth calculated geostrophic velocity is shown. The white lines represent density surfaces inside the eddies and the thin grey lines isolines of salinity. Thin black lines in the salinity plot mark the vertical position of the measuring devices. On the right time series of oxygen is shown from one sensor available at nominal 120 m depth.

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