

1 **The flow field of the upper hypoxic eastern tropical North Atlantic**
2 **oxygen minimum zone**

3
4 **L. Stramma¹, R. Czeschel¹, T. Tanhua¹, P. Brandt^{1,2}, M. Visbeck^{1,2}, and B.S.**
5 **Giese³**

6 [1]{GEOMAR Helmholtz Centre for Ocean Research Kiel, Düsternbrooker Weg 20, 24105
7 Kiel, Germany}

8 [2]{Kiel University, Christian-Albrechts-Platz 4, 24118 Kiel, Germany}

9 [3]{Department of Oceanography, Texas A&M University, College Station, Texas, USA}

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12 Reply to reviewer #2

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14 Reviewer #2:

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16 This paper is a valuable contribution to knowledge of the phenomenology of the eastern tropical
17 North Atlantic, especially as it relates to the supply of oxygen to the oxygen minimum zone. The
18 authors gather an impressive collection of data from satellite altimetry, ADCP/hydrography
19 sections, float trajectories and a tracer release. The paper describes the circulation as revealed by
20 these methods over the past decade or so. A very significant result of the work is the report on the
21 long term decline of oxygen in the oxygen minimum zone over the past several decades. This
22 trend seems to be well documented.

23 The paper is mostly descriptive of the circulation as revealed by the methods mentioned above.
24 This circulation, including transport by mesoscale eddies, is no doubt a dominant player in
25 resupply of oxygen to the oxygen minimum zone (OMZ), the other potential player being
26 diapycnal mixing. A disappointing aspect of the whole paper in its present form, however, is that
27 it does not address the authors' estimates or even speculations about how oxygen is fed into the
28 OMZ. Was this answered by earlier papers by the same research group? If so the results could be
29 summarized here. If not, what work is in process to address this important question?
30 Some more minor or detailed comments are as follows, in the order in which material appears in
31 the manuscript.

32
33 Answer to reviewer 2:

34
35 We thank both reviewers for the helpful comments, which helped to improve the manuscript
36 during the revision.

37 The present knowledge how oxygen is fed into the OMZ was summarized in Brandt et al.
38 (2015). As proposed we summarize now this information in the introduction:

1 “The structure of the OMZ is a consequence of the balance between the supply of oxygen
2 through ventilation and circulation, oxygen production by photosynthesis and oxygen
3 consumption by remineralization of sinking organic matter. Brandt et al. (2015) summarize
4 the oxygen supply by energetic equatorial current bands as well as the present knowledge on
5 vertical and lateral mixing, advection and consumption within the OMZ. Oxygen variability
6 might be related to changes in the strength of latitudinally stacked zonal jets as derived by
7 Brandt et al. (2010) which result in changes in the advective pathways to the ETNA OMZ,
8 with likely the strongest impact in the upper 300-400 m of the water column (Hahn et al.,
9 2014). The importance of the equatorial current system for the mean oxygen distribution is
10 also revealed by high-resolution model simulations showing the oxygen supply at the equator
11 in case of more realistic representation of the circulation compared to coarser resolution
12 models (Duteil et al. 2014). “

13
14 We modified the manuscript as explained below for the more minor or detailed comments.

15
16 Reviewer #2:

17
18 For the abstract:

19 Mixing the discussion of the surface flow with the flow at the level of the OMZ is awkward and
20 distracting from the OMZ flow, the way it is presented. I would leave out mention of the surface
21 flow in the abstract.

22
23 Answer to reviewer 2:

24
25 The information that the circulation in the OMZ mirrors the surface circulation is one of the main
26 results and we kept it in the abstract. However, we removed the information about the seasonal
27 signal at the surface seen in the floats, as the results are not connected to the OMZ flow field.
28

29 Reviewer #2:

30
31 What is meant by “northward shift” in the abstract?

32
33 Answer to reviewer 2:

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35 The northward shift was meant to describe the drift of float f350. As also the cyclonic circulation
36 was stronger the sentence was modified to: “The northward drift of a float into the upper OMZ
37 and a stronger cyclonic flow around the Guinea Dome.....”.

38
39 Reviewer #2:

40
41 What is meant by “expands into the OMZ layer” in the abstract?

42
43 Answer to reviewer 2:

44
45 “Expands into the OMZ layer” is modified to “Reaches down into the OMZ layer”
46

47 Reviewer #2:

48

1 The phrase “the OMZs” seems like it should be “the OMZ” or just “OMZs” in the abstract.
2 Another distracting and awkward facet of the paper is the inclusion, with little context, of the
3 Pacific OMZ, or of OMZs in general.

4
5 Answer to reviewer 2:
6

7 In this context we meant all OMZs, hence we removed “the”. It was quite surprising, that the
8 eddies in the eastern tropical North Atlantic are weak and less energetic than in the eastern
9 tropical South Pacific, hence we like to keep the information in the abstract.

10

11 Reviewer #2:

12

13 The abstract would read more smoothly if the sentence bringing up the performance of the oxygen
14 sensor came before the sentence starting with “Mesoscale eddies ...”

15

16 Answer to reviewer 2:

17

18 Right, a modified order reads more smoothly and we shifted the sentence “oxygen sensors on the
19 floats...” up and it comes now before the sentence starting with “Mesoscale eddies...”

20

21 Reviewer #2:

22

23 The presentation of the tracer data together with the ADCP data in the figures is novel and
24 economical. However, interpreting them together is naïve, since the ADCP surveys give a
25 snapshot influenced by eddies and internal waves, while the distribution of the tracer is the result
26 of the advection field over the previous many months. This fact is acknowledged only in the
27 discussion section; it should be acknowledged when it first comes up. Comparison of the tracer
28 distribution with the float trajectories, or the float displacements at parking depth, with the surface
29 displacement removed, seems a bit more relevant. Most relevant is the comparison of the apparent
30 tracer movement with the mean of many ADCP sections. So I recommend reversing the order,
31 and the emphasis of the comparisons of current measurements and the distribution of the tracer.

32

33 Answer to reviewer 2:

34

35 The different time scales represented by ADCP, float and tracer measurements is now mentioned
36 for the first time at the end of the introduction. At the beginning of the paragraph 3.3 Tracer
37 spreading the following text is included, to make these differences clear right at the beginning of
38 this paragraph:

39 “The tracer distribution and float paths represent an integral effect of the velocity field since
40 deployment, while ADCP surveys yield velocity snapshots influenced by eddies, tides and
41 internal waves. Nevertheless it is interesting to investigate how different results obtained by
42 the different methods might be.”

43 Comparisons to the mean 23°W section were added to the discussion as you mentioned that
44 they are more relevant than the ADCP snapshots of a single cruise.

45 Reviewer #2:

46

47 I’m not sure what is meant by the sentence:

1 “Our three floats may underestimate the mean eastward spreading of the tracer during
2 periods of westward recirculation”

3 Do you mean that the floats were biased because of the time they were deployed?
4

5 Answer to reviewer 2:
6

7 The floats were deployed together with the tracer, hence the bias should not be related to the
8 deployment time. We think that the flow reversal and the deeper depth of the floats compared to
9 the tracer deployment depth could lead to an underestimation and we modified the text to:

10 “Our three floats may underestimate the mean eastward spreading of the tracer during periods
11 of westward flow component. One reason could be that the floats drift at a greater depth than
12 the mean tracer maximum depth at 314 m.”
13

14 Reviewer #2:
15

16 Again, it does not seem justified to use ADCP snapshots to give the general circulation, as in the
17 following sentence. Indeed the impression I get from the ADCP velocity maps is mainly one of a
18 field of eddies that may be transitory.
19

20 “To the south of the deployment location large tracer signals are found at about 6°N
21 where the ADCP velocities are directed westward and indicate recirculation of the lower
22 part of the NECC or the nNECC to the west”
23

24 Answer to reviewer 2:
25

26 Eddies are rare south of 10°N in the eastern Atlantic, but maybe there was influence of waves. We
27 modified the text and specified explicitly that the observation is only true for
28 November/December 2009:

29 “To the south of the deployment location large tracer signals are found at about 6°N where the
30 ADCP velocities are directed westward and indicate recirculation of the lower part of the
31 NECC or the nNECC to the west or the influence of waves in November/December 2009.”
32

33 Reviewer #2:
34

35 Here is another example of assigning too much permanence to the ADCP data. The tracer may
36 have been moving westward at the moment of the ADCP profile, but the main point should be
37 that the tracer has moved west over many months from the release location:

38 “At 6 to 7.5°N the floats have a westward drift and the tracer signal in December 2009 is large
39 and directed westward”
40

41 Answer to reviewer 2:
42

43 We modified the text (below) to make sure that it is not a general agreement but one which agrees
44 at the time of the ADCP measurements:

45 “At 6 to 7°N the floats have a westward drift and the tracer signal is large. The ADCP flow
46 field at 6 to 7°N in December 2009 is directed southwestward, hence the flow field in
47 December 2009 agrees with the long-term signal of the tracer spreading.”
48

49 Reviewer #2:

1
2 In the sentence containing the following, I would say “appeared to be” rather than “was”. The
3 tracer may have moved equatorward and been swept out of the region of the survey.
4 “the tracer signal is almost zero, hence there was no exchange between
5 the NECC and the equatorial region”
6

7 Answer to reviewer 2:

8
9 Thanks, we replaced “was” by “appeared to be”.
10

11 Reviewer #2:

12
13 The following sentence starts with the tracer signal and ends with the float. Was “tracer” meant
14 where it says “float” near the end:
15 “The tracer signal between the Cape Verde Island and Africa along 15_N is near zero
16 except for a weak signal at 21 to 22_W, indicating a weak northward flow component which
17 might have shifted the float to the north of the Cape Verde Islands.”
18

19 Answer to reviewer 2:

20
21 No, not tracer was meant but the related northward flow of float f350 and the ADCP flow in
22 October/November 2010. The text is modified to read:
23 “The tracer signal between the Cape Verde Islands and Africa along 15°N is near zero except
24 for a weak signal at 21 to 22°W, indicating a weak northward flow component just east of the
25 Cape Verde Islands. Such a northward flow component is consistent with the northward drift
26 of the float f350 and the flow field in October/November 2010.”
27

28 Reviewer #2:

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30 It seems that the section on the tracer should have started with the following paragraph and figure,
31 rather than ending with it, since it is the start of the tracer story. Also, the floats are hard to find in
32 the figure (I can find two of them with a lot of searching):
33 ¹⁵In November/December 2008, just seven months after the deployment the tracer was
34 located closer to the deployment region and the ship survey was carried out in a smaller
35 region near the deployment site (Fig. S5). The maximum tracer concentration seven
36 months after the deployment in November 2008 are up to 230 fmkg₁, much larger than
37 the maximum tracer values of 6.5 fmkg₁ in November/December 2009 or 3.9 fmkg₁
38 ²⁰in October/November 2010. The strongest tracer values were observed northeast of
39 the deployment site with the highest values at about 9_N, 20_W and the float f350
40 shifted also to this region. The two other floats shifted toward the southeast and in this
41 region a westward recirculation with enhanced tracer values is present. Some of the
42 tracer shifted around the Guinea Dome and spread westward at 11_N.
43

44 Answer to reviewer 2:

45
46 Right, the figure for November/December is the start of the tracer story. However, we think that
47 there is not much new information as the tracer is close to the deployment region seven months
48 after the deployment. As it does not contribute much to the main goal to investigate the flow field
49 of the OMZ we prefer to keep the information at the end of the tracer paragraph and show the
50 figure for November/December only in the supplement.

1
2 In figure 8 the float paths of the floats are plotted, however it is not possible to compare it
3 with the related velocity and tracer signals in figures 10 and 11. Hence we tried to make the
4 float trajectories better visible in figures 10 and 11. We use now similar colors for the floats
5 as in figure 8 and the flow paths are much better visible in figures 10 and 11. As proposed by
6 reviewer 1 some arrows are added to figures 10 and 11 to indicate the main flow features.
7

8 Reviewer #2:

9
10 A note on English usage: The phrase “up to” or the word “through” would be better than “until” in
11 sentences like the following.

12 The shipboard oxygen observations in 2008, 2009 and 2010 augmented by 4 other
13 oxygen cruise measurements are used to determine the deoxygenation trend near the
14 Guinea Dome in the upper OMZ until the year 2014
15

16 Answer to reviewer 2:

17
18 “Until” was replaced here and at all other locations in the text by “up to” or “through”.
19

20 Reviewer #2:

21
22 “Until” carries a strong implication that something different happened afterwards. “up to” might
23 also, but it is a weaker implication. “through” has very little of such an implication.
24

25 Answer to reviewer 2:

26
27 Thanks, as mentioned above, “until” was replaced at all locations in the text by “up to” or
28 “through”.
29

30 Reviewer #2:

31
32 Again, regarding eddies as they are mentioned in the discussion, eddies do seem to affect the
33 ADCP patterns shown, as I already mentioned, - the circulation argued for seems blurred by
34 eddies. The Guinea Dome anticyclone is not always clear. "Recirculations" seem to be invoked
35 for westward flow where eastward is expected, but maybe cases of unexpected westward flow are
36 merely due to transient eddies.
37

38 Answer to reviewer 2:

39
40 We included this information in the text and modified the sentence on eddies (see below): We
41 replaced “recirculation” to “cyclonic flow” for the Guinea Dome and replaced recirculation at two
42 other locations.

43 “Some indication of eddy activity is seen in the float time series and eddies seem to affect and
44 blur the ADCP flow fields, however the signal is not as strong and not as deep-reaching as in
45 eddies of the eastern Pacific off Peru (Stramma et al., 2013).”
46

47 Reviewer #2:

48

1 The following sentence needs to be reworked, though I think I understand it and agree with it. The
2 word "variability" is used 4 times! Plus mesoscale variability should be acknowledged much
3 earlier, as I have already suggested, when comparing ADCP, float and tracer measurements.
4 "In snapshots of the horizontal distribution of current vectors combined with oxygen
5 and tracer measurements (Figs. 6 and 11) the mean large-scale circulation signal is
6 obscured by meridional variability in the flow components as observed in the ship surveys
7 and in the SODA velocity field and is overlain by circulation variability caused by
8 climate related variability such as the AMM and mesoscale variability"
9

10 Answer to reviewer 2:

11
12 The sentence was split into two sentences and 2 times variability was replaced:
13 "In vector plots of snapshots of the horizontal flow field combined with oxygen and tracer
14 measurements (Figs. 6, 10 and 11) the mean large-scale circulation signal is obscured by the
15 meridional variability in the current bands as observed in the ship surveys and in the SODA
16 velocity field. It is further overlain by circulation changes caused by climate modes such as
17 the AMM and mesoscale variability."
18

19 As mentioned above the variability in ADCP snapshots is now mentioned in the added text at
20 the beginning of paragraph 3.3.
21

22 Reviewer #2:

23
24 The paper ends with the following rather weak statement about the circulation. Is the reader
25 supposed to infer the relevance to supply of oxygen to the OMZ? Again, the paper should address
26 this issue to the extent possible, since it seems to be the main issue motivating the research.
27 "Nevertheless, the different measurements used and combined here demonstrate that the
28 circulation of the upper OMZ widely mirrors the near-surface circulation (Fig. 12) except for
29 the weak 200 to 400m flow below the NECC and an enhanced westward excursion of the
30 200 to 400m flow north of the Guinea Dome at about 12°N."
31

32 Answer to reviewer 2:

33
34 As mentioned above, the supply of oxygen was investigated in earlier papers and summarized in
35 Brandt et al. (2015) and is now mentioned in the introduction. The main focus was to better
36 determine the flow field of the OMZ. We modified the former last sentence of the chapter 4 (now
37 a statement on needed data for a better description of the three-dimensional flow field follows as
38 requested by reviewer 1) and we think that it is no longer a weak statement:
39 "Despite the large variability in the snapshots of the ADCP-derived flow field the different
40 measurements used and combined here demonstrate that the circulation of the upper OMZ widely
41 mirrors the near-surface circulation (Fig. 12). Exceptional cases are the weak 200 to 400 m flow
42 below the NECC and an enhanced westward excursion of the 200 to 400 m flow north of the
43 Guinea Dome at about 12°N."
44