Circulation, eddies, oxygen and nutrient changes in the eastern tropical South Pacific Ocean

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Reply to reviewer #1

Reviewer #1:
Main comment: This paper presents a set of observations collected during an oceanographic cruise off Peru in November-December 2012. The zonal circulation in the south eastern Pacific has been measured, as well as the alongshore flow off the Peru coast. The trajectories and properties measured by drifting floats launched in the area are also described in detail. In the end of the paper, circulation trends are estimated by comparing the data with those of previous cruises (Feb 1993). Nutrient and oxygen trends are also inferred from the present and previous measurements. This paper is following a suite of several papers presenting invaluable observations recently collected off Peru during a series of oceanographic cruises. The data certainly deserves to be published as there has not been many papers presenting recent observations in this upwelling region which has peculiarities because of its very intense oxygen minimum zone. However, the present paper is mainly a repetition of a previous paper by Czeschel et al. (JGR, 2011, doi:10.1029/2010JC006565.) which presented data from a previous cruise with quasi similar transects. It was structured similarly, described current sections, floats trajectories, etc.. Despite the similarities between the two papers, there is almost no discussion of the new results in the light of the previous findings of Czeschel et al. (2011). Moreover, while the quality of the figures is good, the text is extremely difficult to read. It lacks structure, there are lots of repetitions, there are no transitions between the paragraphs, parts of the manuscript are really unclear. A lot of it deserves rewriting (see my detailed comments below). Therefore I believe that the paper could be significantly improved by (i) introducing a more developed section with a detailed discussion of the previous findings of Czeschel, (ii) careful rewriting of several paragraphs. Thus, I am in favour of a major revision.

Answer to reviewer 1: We thank the reviewer for the good comments, which helped to improve the manuscript considerably during the revision. As these general comments are specified in the detailed comments, we list our replies and changes made below.

We modified the manuscript considerably as explained below in the reply to the detailed comments.

Detailed comments:

Reviewer #1:
Detailed comments: p2207,L4-5Â˘ a: There are a number of studies and measurements of the EUC near 95_W. Cite other references please, not only the most recent one of Stramma et al. Also, I think that some context should be provided for the OMZ (why is it important to study them, etc..).

Answer to reviewer 1: A second reference to the EUC Karnauskas et al. 2010 was listed in the sentence below. In addition we added now an early reference by Lukas 1986 and Collins et al. 2013, the latter was listed already in the first version later in the manuscript. A paragraph on the importance of oxygen is added at the beginning of the introduction and the lst paragraph of the introduction was slightly modified.

We added two references by Lukas 1986 and Collins et al. 2013 at the text location mentioned by the reviewer. With regard to the importance of oxygen we added at the beginning of the introduction: ‘In all tropical oceans low oxygen layers exist at subsurface layers in about 200 to 700 m depth. In most of these oxygen minimum zones (OMZ) a decrease of oxygen was observed but in few areas also an increase in oxygen (e.g. Keeling et al., 2010; Stramma et al. 2010a). Should observed decreases in oxygen continue this could lead to habitat compression, shifts in animal distribution and loss of biodiversity with impact on fisheries and economics. To understand the ongoing changes in OMZ’s it is necessary to understand the circulation and its changes in the open ocean. In the eastern tropical South Pacific a strong OMZ is located, however the information on subsurface circulation changes and possible drivers for the oxygen changes are sparse. ‘

Reviewer #1:
p2207: The description of the current system is quite dense and hard to follow. This paragraph would be easier with a figure summarizing the current knowledge of the equatorial current system and also by being more general without citations of shortterm observations during recent oceanographic campaigns (e.g. in November 2003,

in February 2009,..) which provide information on the variability, not on the mean circulation.

Answer to reviewer 1: We included the current bands in figure 1. We did not remove the observation from November 2003 as this is the reference for the EUC east of the Galapagos Islands, however the sentence to February 2009 was removed.

We included the current bands now in Figure 1 and removed the discussion of the February 2009 observation.

Reviewer #1:
L26: “the coastal geometry”: I am not convinced that the coastal geometry plays a role here, please be more specific.

Answer to reviewer 1: The sentence on coastal geometry was removed and instead the connection of the equatorial and coastal upwelling by the current bands is mentioned.

We removed the sentence on the coastal geometry and write instead: ‘The regions of equatorial upwelling and coastal upwelling are connected by the subsurface Peru-Chile Undercurrent (PCUC) and the surface Peru-Chile Countercurrent; both are in part fed by the EUC.’

Reviewer #1:
p2208, L14: do you mean that there are three types of eddies in general or in particular in this region?

Answer to reviewer 1: Based on several comments on eddies by reviewer 2 we modified the introduction of eddies in the text. A fourth type (‘cyclonic thinnies’; McGillicuddy (2015)) is mentioned and the common use of ITE’s = Intrathermocline Eddies (Hormazabal et al. 2013) is included. As McGillicuddy 2015 described the eddies as observed throughout the world ocean, we mention the eddies now as global features.

We modified the text and mention the eddies now as observed throughout the world ocean.

Reviewer #1:
p2208, L6-24: This paragraph needs rewriting. It appears more like a list of previous

findings on eddies in the region than a bibliographical review. There are eddies, but why is that important?

Answer to reviewer 1: The paragraph was modified and details on the different eddy types added before some detailed findings from observations are listed.

We modified the paragraph and added information on the different types of eddies. For the importance of eddies we extended the former description to: ‘During the last two decades eddies have been recognized to play an important role in the vertical and horizontal transport of momentum, heat, mass and the chemical constituents of seawater, such as oxygen and nutrients (e.g. Klein and Lapeyre, 2009) which might be especially important in regions with low oxygen layers.’

Reviewer #1:
p2208, L25: No transition there, this needs rewriting! Please provide some context for the study of oxygen trends.

Answer to reviewer 1: As mentioned before we included at the beginning a paragraph with regard to the importance of oxygen. Therefore we added here only a related statement that the floats can be used to extend oxygen time series.

We modified the sentence to: ‘Profiling floats are ideal tools for continuous sampling of the ocean instead of short-time measurements from ships. Besides CTD profiles, additional parameters can be measured on floats, including oxygen to extend oxygen time series.’

Reviewer #1:
p2209,L16-20Â˘ a: sentence is too long and clumsy, please rephrase.

Answer to reviewer 1: We modified the text and split the sentence.

We write now: ‘The aim of this investigation is to better understand the flow field, its variability on different time-scales and changes caused by eddies. This will help to better understand the existing shape of the OMZ in the eastern tropical South Pacific and its changes with time.’

Reviewer #1:
p2211Â˘ a: What is the parking depth of the floats equipped with Seabird sensorsÂ˘a? It would be nice to visualize where the floats were deployed in Figure 1. This would provide a better understanding of the sampling strategy.

Answer to reviewer 1: The parking depth of the floats was 1000 m. The deployment locations of the three floats presented in the manuscript are now shown in figure 1 and for a better overview float details are given in an additional table.

We added the information on the 1000 m parking depth in the text. Added the deployment locations to figure 1 and added also a table with float details for a better overview.

Reviewer #1:
p2213Â˘ a: I find the discussion about the EUCs and EUCd unclear. Here we see only one branch of the EUC in Figure 2, why not label them EUCs or EUCd as described in the text? Also, I do not understand what the SECC stands for in Figure 2. It looks to me as a third SSCC, as it is located at depth. Could you explain that more precisely in the text?

Answer to reviewer 1: We included EUCs and EUCd in figure 2. The description of the EUC was revised (see details in comment below). SECC was removed from the figure as SECC should be small in the eastern Pacific and the text with regard to SECC was modified.

We included EUCs and EUCd in figure 2 and the text with regard to the EUC was rearranged (see below). SECC was removed from figure 2 and the text with regard to SECC modified to: ‘The strong subsurface eastward flow at about 12.5°S is located in the region of possible SECC flow, however as this current has a subsurface core it might not be the SECC but could be caused by the cyclonic feature located in this region in November 2012 (Fig. 1).’

Reviewer #1:
p2213, L16-20Â˘ a: avoid repetition of EUC flux Â´nÂ˘abetween 2_N and 2_S and 200m depth”. Also, in this paragraph, information on the transport and on the depth of the EUC are mingled, which is rather confusing. The end of the paragraph is unclear. Is the data presented here consistent with previous observations, or is it consistent with the model results? Please rephrase, this is quite difficult to follow.

Answer to reviewer 1: Right, due to the inclusion of changes south of 15°S and additional information on the connection of the EUC with the SICC, it was difficult to follow the EUC transport discussion. We modified now the information by shifting the information on the region south of 15°S and on the connection to the EUC (see below), removed repetition of the upper 200 m layer information from the text and we think that the transport information should be now clear. The comparison with the model results was rewritten and should be much better understandable.

We moved two paragraphs and connected the transport description parts, one in front of the EUC transport section and one behind the EUC transport section, hence it should be now clear which differences were observed. The comparison with the model was rewritten and focusing on the depth of the seasonal cycle.

Reviewer #1:
Figs 3b-c-d: the oxygen concentration encountered near 16_S-24_S, 87W-85W is much lower (in dark blue: 0- 10 _M) than the climatology (100-200 _M) at 200m depth. How do you explain this? Could there be a problem in the data? This is not mentioned in the text.

Answer to reviewer 1: As mentioned in the figure legend, ADCP measurements with no accompanying CTD oxygen measurements were shown in black. Unfortunately the black arrows were difficult to differentiate from the dark blue arrows. Therefore, we change the color of the black arrows to white arrows, hence it should be visible now, that there are no low oxygen values.

We changed the figure to show white instead of black arrows for velocities without oxygen measurements and the impression of very low oxygen values should no longer appear.

Reviewer #1:
Fig3: It would be helpful to add some arrows to show the location of the EUC, NICC, SICC on these Figures.

Answer to reviewer 1: EUC, NICC and SICC are now shown in the modified figure.

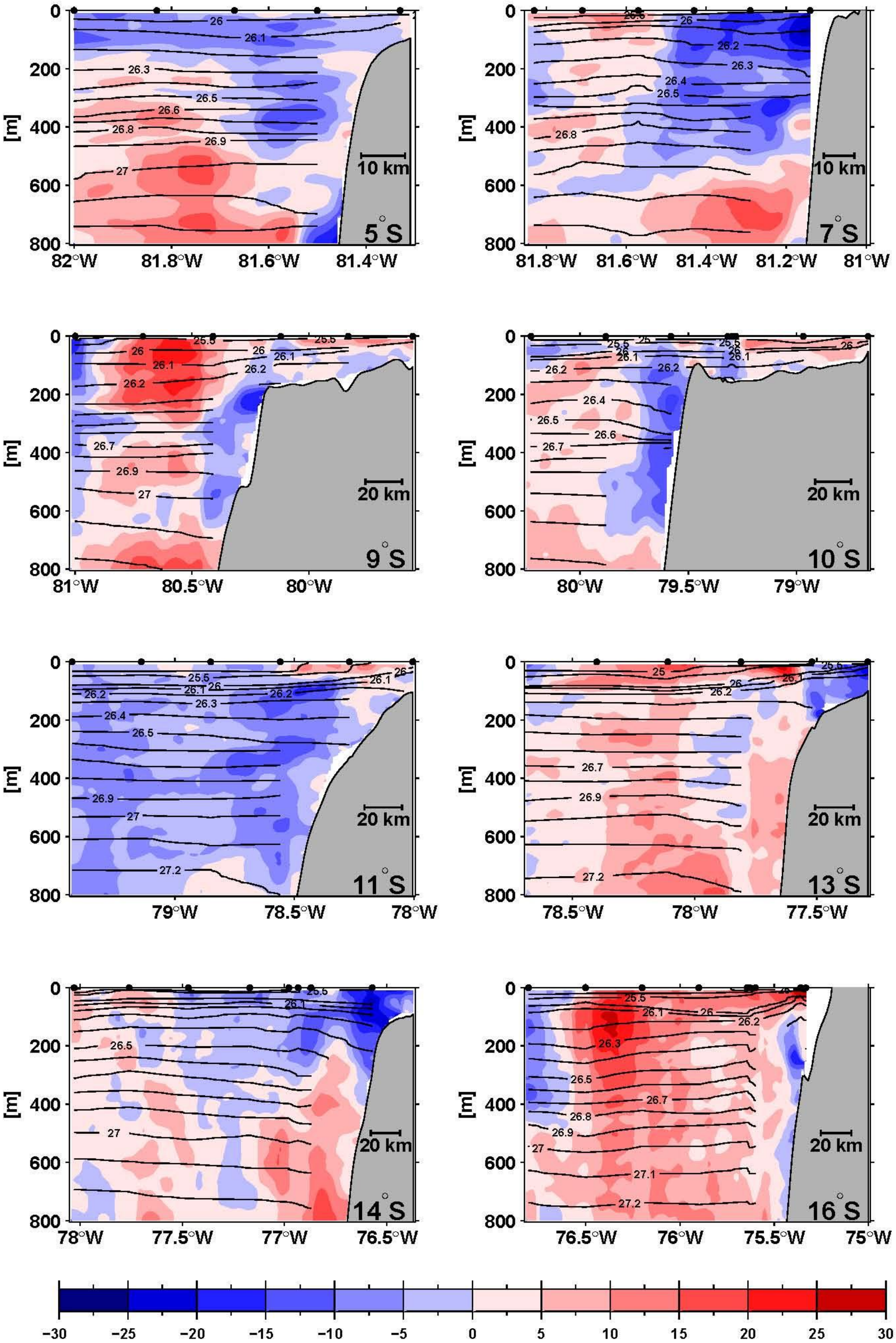
We modified the figure and included EUC, NICC and SICC as proposed.

Reviewer #1:
p 2215, L16Â˘ a: the shelf can not be seen in Figure 4 for the section at 7_S. How can the pCUC be “attached to the shelf”? For the section at 11_S, I do not think that the

poleward flow west of _79_Wcan be counted as the PCUC. Not taking this flow into account would certainly reduce the transport of the so-called PCUC in this latitude range, and make it more consistent with the poleward transport at other latitudes. It would also be interested and possibly useful to smooth these current sections and overlay with density or salinity as to identify the water masses transported by the so-called PCUC. In any case, it might help separate the actual PCUC which transports waters of equatorial origin from other poleward flow. At 16_S, the section might miss part of the poleward flow while at 14_S the current might be compared to the glider-derived velocity sections from Pietri et al. 2013, 2014, in this section or in the discussion section. Refs: Pietri et al., 2013: Finescale Vertical Structure of the Upwelling System off Southern Peru as Observed from Glider Data.Â˘aJ. Phys. Oceanogr.,Â ˘a43, 631–646. doi:Â˘ahttp://dx.doi.org/10.1175/JPO-D-12-035.1 Pietri et al., 2014. Impact of a coastaltrapped wave on the near-coastal circulation of the Peru upwelling system from glider data,J. Geophys. Res. Oceans,Â˘a119,Â˘a2109–2120, doi:10.1002/2013JC009270.

Answer to reviewer 1: Please see the changes made at the ms below.

We modified Figure 4 to show the shelf at the 7°S section. At 11°S only the transport east of 79°W was computed which reduced the transport to -2.5 Sv. The data were smoothed and a few transport values changed by 0.1 Sv. The reduction of PCUC flow caused by the northern component of the subtropical gyre is now mentioned. The density or salinity contours (Figures below) did not show much structure and is not shown in the revised ms. However, oxygen gives good information on the changes in oxygen along the flow path and on the eddy influencing the 16°S section and oxygen contours are now added to figure 4.


[m]
10 km
5°S
82°W
81.8°W
81.6°W
81.4°W
7°S
81.8°W
81.6°W
81.4°W
81.2°W
81°W
20 km
9°S
81°W
80.5°W
80°W
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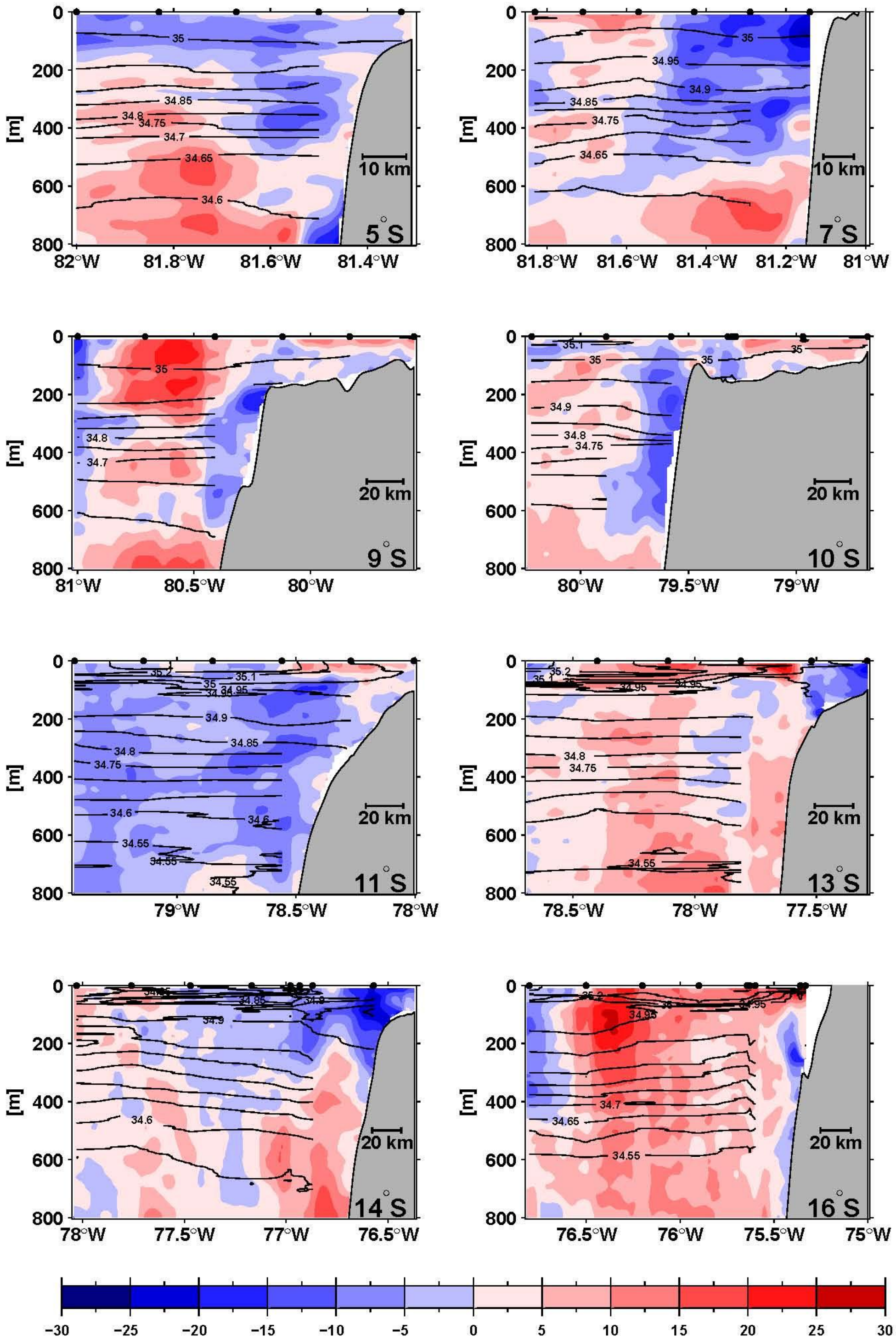

We added a text with regard to a reference to Pietri et al. 2014: 'The northward transport of the Chile-Peru Deep Coastal Current east of 77.3°W above 800 m depth is 2.6 Sv in good agreement with glider measurements in April-May 2010 at 14°S of 2.5 Sv (Pietri et al., 2014).

These glider measurements of ~-2.5 SV for the PCUC agree again well with our transport of -2.4 Sv at 14°S'.

Reviewer #1:
p 2216,L28Â˘ a: why do the cyclonic loops lead to a shoaling of the oxyclineÂ˘a? Do you mean that it is because the float is trapped in a cyclonic eddy? Please rephrase.

Answer to reviewer 1: Right, we rewrote the text and mention that the float is trapped in the eddy and the shoaling of the oxycline should be clear from the new discussion on eddies in the introduction.

We rewrote: 'A float with oxygen sensor (float 3900715) deployed on October 26 2008 at 20.1°S, 85.6°W had a lifetime of only 1.5 years. This float stayed for more than half a year in a cyclonic eddy (Fig. 6). The float path shows two cyclonic loops (Fig. 6a) while trapped in the cyclonic eddy, which lead to an up-rise of the low oxygen layer in the upper ocean (Fig. 6b).'

Reviewer #1:
p 2217, L10Â˘ a: the movie is a supplementary figure. I do not think you should compare the movie and the Figure here, it sounds clumsy.

Answer to reviewer 1: We modified the text and reference figure 6a when the figure is discussed and refer to the supplementary movie only when describing the westward drift of the eddy.

We changed the text to: 'At the beginning of the float mission the float crosses a regular anticyclonic eddy before it completes two full loops around the strong cyclonic eddy (Fig. 6a). The cyclonic eddy moves westward and the cyclonic loops during the westward shift are well visible in the supplementary movie.'

Reviewer #1:
p2217, L11-13: Avoid repetition here. You have already said that the cyclonic structure generates an upwelling of the oxycline, thus a decrease of oxygen.

Answer to reviewer 1: The sentence was removed and the related information on the parameters at 300 m depth added to the description of the related figure in the text.

The modified text reads now: ‘The strongest oxygen anomaly is located at about 300 m depth and the potential density anomaly, salinity, potential temperature and oxygen time series were plotted at 300 m depth and show an increase in the potential density anomaly and the salinity, a potential temperature decrease as well an oxygen decrease at 300 m depth (Fig. 6d-g).’

Reviewer #1:
p2217, L16: “an anticyclonic eddy in October 2009, visible in the low oxygen layer located at 350m depthÂ˘aÂ˙z. I do not understand the end of the sentence. Which Figure is there a reference to? Please explain how (on which Figure) you identify the anticlonic eddy.

Answer to reviewer 1: The text was modified to explain how and in which figure the anticyclonic eddy can be seen.

We modified the text: ‘The flow path at the end of the cyclonic eddy influence looks like an anticyclonic movement, however inspection of the satellite data showed that the float moved southward at the boundary of the cyclonic eddy before it was entering an anticyclonic eddy in October 2009. This is visible in the low oxygen layer located at 350 m depth (Fig. 6b) as well as in the oxygen at 300 m depth (Fig. 6g).’

Reviewer #1:
p2217,L22: The relation between oxygen changes at depth and anticyclonic eddies needs to be explained more clearly.

Answer to reviewer 1: The relation between oxygen changes at depth in cyclonic and anticyclonic eddies is now explained in the introduction chapter.

We describe now the relation between oxygen changes at depth in cyclonic and anticyclonic eddies in the revised part on eddies in the introduction.

Reviewer #1:

p2118, L3-10: The link between the region of study and other regions of the Pacific (Hawaii, South pacific gyre) is not clear at all. Please rephrase, this is confusing.

Answer to reviewer 1: As our float is located about 20 to 30°further east than the South Pacific float used by Riser and Johnson (2008) it is worth to compare the results to look for zonal changes.

We included: ‘With a profiling float available in the eastern South Pacific about 20 to 30° east of the float used by Riser and Johnson (2008) it is worth to check how NCP differs in the South Pacific zonally.’

Reviewer #1:
p2118, L10: “Net community production (NCP), which is equal to primary production minus respiration at all trophic levels, is difficult to measure”: this sentence is rather useless..what do you mean by “difficult”? The statement “Here we use the same method..” is misplaced. After it, you do not mention NCP but the annual cycles of other properties from Figure 8. This paragraph needs to be rephrased. The paragraph on the mixed layer oxygen should be better introduced. There is no transition and no thread in the paper! Overall the paper should be better structured (an independent section for NCP maybe).

Answer to reviewer 1: For a better structure the net community production text is now a separate section. The sentence with ‘difficult to measure’ was taken from the Riser and Johnson (2008) paper. We rewrote the text, (see below) and write that we apply the same method as Riser and Johnson (2008).

The net community production text is now an own section: ‘**3.3 Net community production estimates’**

The text was modified to: ‘Primary production in the subtropical gyres is episodic and thus difficult to observe. Net community production (NCP), is equal to primary production minus respiration at all trophic levels. Oxygen increases below the mixed layer at a nearly constant rate is similar to independent measures of NCP (Riser and Johnson, 2008) and oxygen sensors on profiling floats can be used to examine the balance of oxygen production and consumption. The oxygen measurements on floats led to highest NCP of about 15 mmol C m^{-3} yr^{-1} near Hawaii and about 7 mmol C m^{-3} yr^{-1} in the South Pacific gyre (Riser and Johnson, 2008). With a profiling float available in the eastern South Pacific about 20 to 30° east of the float used by Riser and Johnson (2008) it is worth to check how NCP differs in the South Pacific zonally.

Here we apply the method as described by Riser and Johnson (2008) to derive the NCP from a float track located in the eastern South Pacific.'

Reviewer #1:
P2118: from line 5 to the end, the text needs to be better structured. This is very difficult to follow. Several depth ranges are mentioned, there is repetition of the method used for NCP (slope from the oxygen data), there are some very unclear sentences (e.g. line 29). A rewriting effort is needed.

Answer to reviewer 1: We rearranged the text, moved a paragraph and added information about the estimation of the NCP with more explanations on the several depth ranges. We modified Fig. 10b by including a fit (red dots) showing the oxygen decrease and accordingly modified the figure caption.

We write now: 'Generally, oxygen changes can be caused by changes in mixing, solubility and biological production. Oxygen anomaly (oxygen saturation minus oxygen concentration, Fig. 9f) gives information about oxygen changes which are independent from solubility changes. The mean annual cycle over five years of oxygen concentration shows a continuous increase with time in the shallow oxygen maximum layer between about 40 to 80 m depth from mid-May to early April (Fig. 8e). Here we show the mean annual cycle of mixed layer depth, potential density anomaly, salinity, potential temperature, oxygen concentration, oxygen saturation, and oxygen anomaly (Fig. 9) in an example for 64 m depth which is the depth of the highest NCP only below the mixed layer depth (Fig. 10c).

Between mid-May and mid-November oxygen increase takes place above the seasonal thermocline and is primarily caused by solubility changes in the mixed layer (Fig. 9a, e) reflecting a decrease in salinity and potential temperature (Fig. 9c, d). Increase of oxygen concentration below the seasonal thermocline between mid-November and early April (Fig. 9a, e) cannot be driven by changes in oxygen saturation, which show in fact a decrease during that period (Fig. 9e) associated with an increase in salinity and potential temperature (Fig. 9c, d). As the float moves horizontally with the water parcels and the horizontal oxygen gradient is negligible the oxygen increase must be caused by biological oxygen production.

The rate of oxygen production at a particular depth was determined after Riser and Johnson (2008) from the slope of a straight line that fits the oxygen data best in a least square sense against time for the whole period of oxygen increase from mid-May to early April (about 320 days, Fig. 10a). The time interval is determined from the maximum slope of oxygen concentration against time for depth of 40 to 80 m, where oxygen accumulates below the pycnocline (Fig. 8e). The increase of oxygen from the slope of the time series is then converted into carbon uptake with the modified Redfield ratio (150 mol of O_2 produced per 106 mol of CO_2 fixed, Anderson, 1995) for all depths. The daily increase is extrapolated to an annual rate of the NCP which is highest in 58 m depth with a rate of 16.7 ± 6 mmol C m^{-3} yr^{-1} (Fig. 10c). NCP estimates above 58 m depth are derived from the slope of oxygen anomaly (oxygen minus oxygen solubility) against time to determine the oxygen increase that is independent from solubility changes in the mixed layer with the highest NCP value of 12.6 ± 4.9 mmol C m^{-3} yr^{-1} in 48 m depth (Fig. 10c).

For comparison: NCP estimates from a float in the South Pacific gyre (Riser and Johnson, 2008) determined from the slope of the annual cycle of oxygen against time for the period from June to May show highest values of 8.5 ± 5 mmol C m^{-3} yr^{-1} in 87 m depth (Fig. 10c) which is smaller than the value calculated from the data of the float propagating along the OMZ boundary. The NCP from the slope of oxygen anomaly against time within the mixed layer in the South Pacific also shows smaller rates with a maximum of 10 ± 1.3 in mmol C m^{-3} yr^{-1} in 87 m depth.

NCP rates determined from the slope of oxygen concentration time series against time in depth levels above the pycnocline can be imprecise due to oxygen loss to the atmosphere by gas exchange. Therefore the rate of oxygen production is determined from the slope of oxygen concentration increase against time for every depth level strictly below the mixed layer to avoid oxygen changes due to solubility variations. The time intervals depend on the maximum slope of oxygen concentration and must be deeper than the mixed-layer depth (Fig. 10b). The NCP is highest in 64 m depth with a rate of 7.7 ±3.2 mmol C m^{-3} yr^{-1} (Fig. 10c) depending on a strong oxygen increase between end of November to early April. However, oxygen concentration in 64 m decreases in the time interval from November 2009 to early April 2010. Due to oxygen loss below the mixed layer the NCP calculation for the period November 2009 to April 2010 was skipped (Fig. 10b).’

Reviewer #1:
Fig11: I think it would be interesting to compare the oxygen change on isopycnals. Maybe a section with density as the vertical coordinate could help. This might help for the interpretation of the observed changes. Besides, it is not clear to me how the El Niño cold phase might affect oxygen concentrations at 86_W. Is it by offshore transport? What are the dynamical processes responsible for these changes?

Answer to reviewer 1: We prepared a figure (shown below) for the section with the density distribution, however, it shows the same changes except for a shifted scale due to the non-linear density changes. Therefore, we did not include the figure in the revised manuscript. The text is now modified to explain both the oxygen decrease in the upper ocean and the increase in the OMZ layer in the La Niña phase. Both causes for the deep layer, the heave of the relatively oxygen-rich Antarctic Intermediate Water and its spreading on shallower isopycnals is now mentioned.

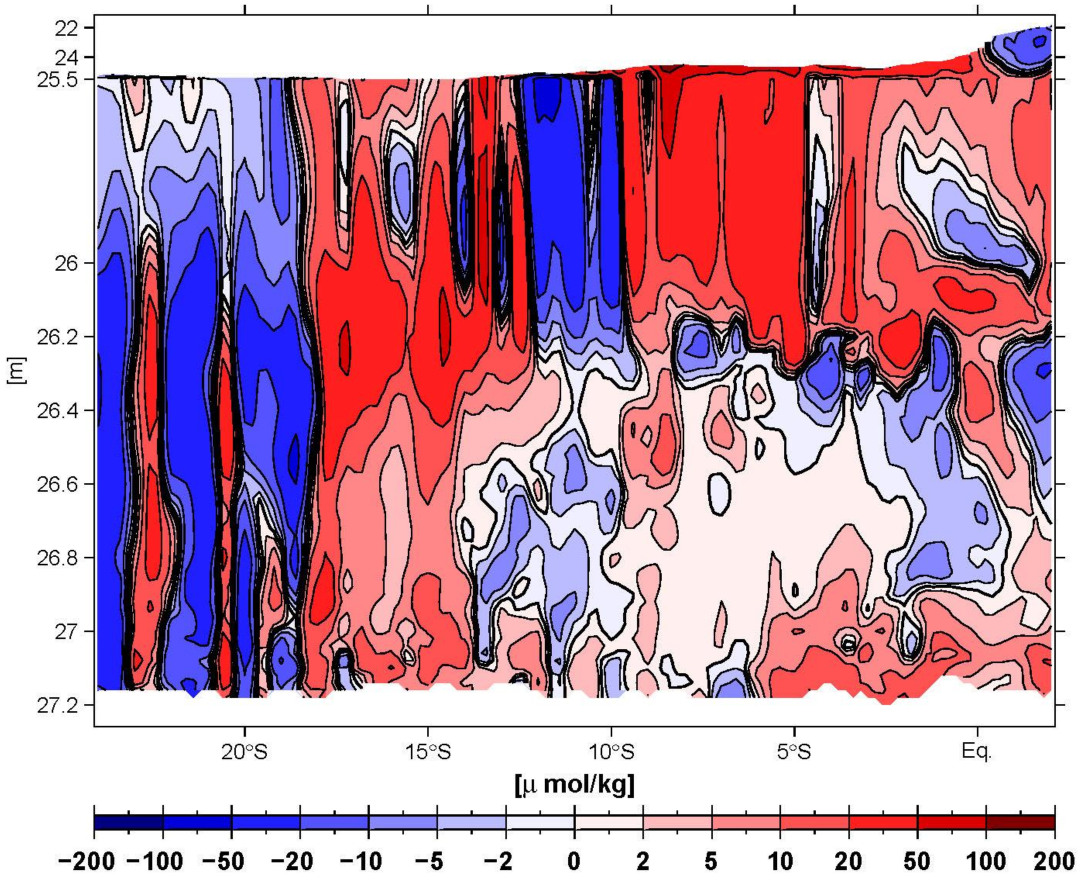

Fig. Oxygen differences along the section at about 86°W between November 2012 and March 1993 versus density.

We modified the text: ‘As the upper 400 m in the eastern equatorial Pacific experience an oxygen increase during El Niño periods (e.g. Czeschel et al., 2012), the decreased oxygen in the upper ocean seems to be caused by the El Niño status. A comparison with an extended optimum multi-parameter analysis between the sections in March 1993 and February 2009 showed that during a cold phase the heave of relatively oxygen-rich Antarctic Intermediate

Water into the depth range 150 to 500 m and the flow of AAIW at shallower depths leads to higher oxygen values in the upper OMZ (Llanillo et al., 2013). As the Niño1+2 index shows an even larger cold phase for November 2012 compared to February 2009, the oxygen increase north of 18°S below 400 m seems to be caused also by the El Niño phase differences.'

Reviewer #1:

p2221: L5: "southern hemisphere pacific.." : rephrase

Answer to reviewer 1: Actually this sentence was from a general description of the IPO from Chris Folland from the Hadley Center. Nevertheless we changed the text to a more descriptive version (see below).

We changed the text to: 'The Interdecadal Pacific Oscillation (IPO; Power et al., 1999) is almost the Pacific-wide manifestation of the Pacific Decadal Oscillation with strong variability in the Southern Hemisphere as well as in the Northern Hemisphere.'

Reviewer #1:

L7-9: I do not understand this sentence. Is this really useful for the purpose of the paper? Please clarify or suppress it. Overall the IPO paragraph should be simplified and clearer.

Answer to reviewer 1: The sentence was removed as proposed. Several other parts of the text were modified and the IPO paragraph should be clearer now.

We removed the sentence as proposed and modified the text.

Reviewer #1:

L18-24: I do not understand the link between the transport of the EUC and the two other sentences. It is hard to follow the logic between these three sentences which seem to contradict one another: "however", "But", "Hence.."!

Answer to reviewer 1: This part was modified. One sentence was deleted and the text rewritten without 'however', 'But' and 'hence'.

We removed one sentence and modified the text to: ‘Measurements in late March 2009 resulted in a EUC flow of 7-11 Sv (Collins et al., 2013), less than the 16.3 Sv for late March 1993. The fact that the velocity difference between February 2009 and March 1993 (Fig. 12b) is not only restricted to the EUC but also to the region north of 5°S points to a larger-scale decrease in the velocity field.’

Reviewer #1:
L26: What is the relation with the warming hiatus here? Why do you need to invoke it? This is confusing.

Answer to reviewer 1: We removed the part of the sentence with regard to the warming hiatus.

We removed ‘and the ongoing warming hiatus’.

Reviewer #1:
L27: After giving an explanation of the large scale structure, there is no need to describe the mesoscale structure at the end of the paragraph, this only blurs the message.

Answer to reviewer 1: ok, we removed the description of this mesoscale structure to make the message on the large scale changes better visible.

We removed the sentence.

Reviewer #1:
p2222, L1-11Â˘ a: This paragraph on Redfield ratio is rather lame as linear trends, not Redflied ratios, are shown in Fig. 13 and table 1. How do you make the link between the region of study (87_W-84_W,2_S-5_S) and the subartic Pacific Ocean (cf the reference to Whitney et al., 2013) (L12 and p2223, L5)? Besides, how does he change of migratory habitat affect the nutrient distribution? Please clarify.

Answer to reviewer 1:

The part on the Redfield ratios was reduced to introduce only that oxygen will decrease when nitrate, phosphate and silicate go up. The part with regard to findings by Peng and Broecker (1987) and Ishizu and Richards (2013) was removed.

In the subarctic Pacific and in the California Current (Reference to Bograd et al. (2015) now added), trends in nutrients were observed and we investigate, whether such a signal exists in the tropical Pacific, which makes the link now to the different Pacific regions. Migratory habitat affects the nutrient distribution via changes in productivity (Whitney et al. 2013), now mentioned in the text. In addition we added estimates of nutrient measurement accuracies to show that the trends are larger than possible measurement errors.

The paragraph on Redfield ratios was strongly reduced.

We write now with regard to the connection with the work in the subarctic Pacific: ‘In the subarctic Pacific Ocean, nutrient enrichment in nitrate, phosphate and silicate has been observed since the mid-1980s while oxygen decreased (Whitney et al., 2013). Similar trends were described for the California Current (Bograd et al., 2015) and the question comes up, whether such nutrient trends exist also in the eastern tropical Pacific.’