

Interactive comment on “On the role of mesoscale eddies for the biological productivity and biogeochemistry in the eastern tropical Pacific Ocean off Peru” by L. Stramma et al.

L. Stramma et al.

lstramma@geomar.de

Received and published: 10 September 2013

Enclosed is our reply to the reviewer 2 for ms BG-2013-255: Reply: We thank reviewer 2 for the helpful comments. Our reply to the reviewer's comments is following after each reviewer's comment.

This manuscript addresses two themes of considerable topical interest in recent years, the impact of mesoscale physics on biogeochemistry and the dynamics of oxygen minimum zones. Diverse biogeochemical analyses of 3 eddies in the eastern tropical Pacific provide a basis for a conclusion that eddies exert a significant control on the dynamics of the region. There is much here of interest but I feel that the manuscript could

C4921

be significantly strengthened if a more thorough interpretation of results were carried out. In addition to minor technical comments that I list below I have a number of more significant general comments that I hope will be of use in revising the manuscript. A key component of the manuscript is comparison: of one eddy to another and of an eddy to background values. Although some of the evidence for differences is already compelling there are some important ways that I think this should be strengthened.

First, the authors choose to use profiles immediately outside eddies as background reference. Where an eddy ends is a difficult thing to judge and there are instances where it looks like the 'background' profile is not outside e.g. for eddy C in Fig 8. In order to have confidence in the background 'baseline' that the authors are using for comparison I recommend the use of a common background profile for all eddies. More specifically, there should be a single figure of property versus depth for all profiles currently used in the paper for 'background'. If they are truly background, they should all be similar and an average of them constitutes a more robust background for comparison to eddy profiles. If a hitherto used background profile differs significantly from others then it is an indication that it may not be sufficiently outside the eddy to be used for comparison. If there is evidence that the background profile changes across the region e.g. from coast to open ocean, then there are many profiles not currently used in the manuscript, judging from Fig 1, and these should be used to construct a more robust background for each eddy's immediate location.

Answer: Our aim was to describe the changes in eddies from observations. Therefore we had to rely on the available data to define the boundaries. Satellite data show jumps in strength and size probably due to the interpolation scheme used to create complete images from the satellite paths with available data and hence are not good to define the boundaries. E.g. the SSHA in figure 1b based on the delayed time images differs in the location of the core of the eddy from observations, while the near real-time data for the same day showed the eddy core further to the west fitting better the real measurements. Nevertheless, the satellite data show that there are large variations

C4922

which can be seen also in the sections from our own data. We tried to construct a mean background profile from our own measurements, but due to the eddy variability and the general gradients the background profiles differed in the core as well as on outside stations.

As the ETSP is covered by cyclonic and anticyclonic features (Fig. 1b of the ms), it is difficult to derive a mean background field. Nevertheless, a comparison of our sections with the mean climatology of the World Ocean Database showed small salinity deviations in the region, where we defined the boundaries of our eddies. Figure R1 shows the difference in salinity at 16°45'S from Meteor 90 and from the World ocean data base at 16°30'S across the eddy B. It shows the zero contour line close to the boundaries used for eddy B (left and right end of the figure) below about 200 m. In the upper ocean the higher differences are related to seasonal changes. A comparison of the salinity profiles in the center of the eddies at rim profiles in a new figure 9 showed the deviations in the eddy centers and a close relation of the anticyclonic eddies to the Peru Chile Undercurrent region.

(Figure R1 (at the end) Comparison of salinity difference across eddy B between M90 data and World Ocean Data Base)

Second, when comparing the two mode water eddies an assumption is made that B is an older 'version' of A. While this seems a sensible hypothesis, little is done to justify it despite the fact that the conclusion of decreased activity with age rests upon it. On the simplest level this simply requires a quantitative discussion of things such as salinity of core and the density surface that the anomaly resides on to demonstrate they are consistent. However, I also have some concern over the analysis of eddy A. The velocity components shown in Fig 2 do not seem to be consistent with the flow around an eddy. For an eddy, the peak velocity in the along-transect component should be at the eddy core (assuming no transect will ever perfectly go through the eddy centre). However, both components demonstrate a dipole structure, flipping from positive to negative either side of the core. This is more consistent with a jet than an eddy. Only

C4923

one velocity field is shown for B.

Answer: We made a film of daily satellite SSHA data and followed the eddies A and C back to their formation location and time. However, eddy B could be followed backward in time only for 5 months and 1 week when it originated from two anticyclonic eddies located to the northeast and southwest and the formation time and location stays unclear. Nevertheless, it can be shown, that the open ocean eddy B was at least 5 months old while eddy A was 2 months and 1 week old when measured. Hence eddy B was older than A, but as we could not trace eddy B back to the formation location the salinity and temperature of the eddy might differ based on the location and season of formation. With the new figure 9 (mentioned above) we were able to show Similarities and deviations of the anticyclonic eddies and the rim stations with the Peru Chile Undercurrent region. We think the velocity component shown in Figure 2 should fit an eddy. In case the velocity field of the eddy is centered a little closer to the eddy core than shown in the near real time SSHA figure for 21 November 2012 (shown at comment I) north of the eddy core should be the strongest southward and westward component and south of the core strong eastward and weak northward flow. Both velocity components for the other sections are now shown.

Third, particularly given the comment above about the velocity structure of eddy A, more care needs to be exercised extrapolating general results from studies of just 2 mode water eddies. Without knowing how much variability is seen in the biogeochemistry and physics of the mode water eddies in the area, comments inferring changes due to ageing need to be balanced with a discussion of the uncertainties. As part of this, greater use of the literature would be helpful. The popular eddy-pumping hypothesis is used already but eddies can influence local biogeochemistry in many more ways: see for example work by Amala Mahadevan, Marina Levy and Leif Thomas in addition to other work by Dennis McGillicuddy and Patrice Klein. Furthermore, there is currently no discussion of how conclusions may have been affected by the transects not passing through the centre of the eddy, which could bias the estimate of properties associated

C4924

with it.

Answer: Papers by Mahadevan, Levy, Lapeyre and Thomas are now mentioned in the revised text. It is now explained that the differences might be biased low if the section does not cross the center, however as AHA and ASA are high compared to the mean values the sections used are expected to be located close to the center.

Technical comments: a. there should be consistency in the figures presented for the 3 eddies. Figs 2, 7, and 8 should show all the same fields (as Fig 2 preferably) or have reasons given for why the data weren't available.

Answer: Some fields were not very informative and provided the same information as other components. For consistency we tried now to present always the some parameters except for eddy B, where only one pH profile was taken on the section used here.

b. 3rd paragraph of introduction would be clearer if it was broken up into shorter sentences.

Answer: The order of the paragraphs in the introduction was rearranged following reviewer's 1 request and the sentences in the former third paragraph were modified/shortened.

c. a definition/description of a 'typical mode water eddy' would be useful as context e.g. for p9182, lines 19-20

Answer: The order of the introduction was rearranged based on a request by reviewer 1. In the first paragraph we describe now better what is typical for mode water eddies.

d. dates need to be given for each of the transects presented

Answer: The dates for the sections are included now in the data paragraph and in the figure legends of the section figures.

e. p9185, lines 23-24: a brief description of the method is still needed here e.g. is extent of eddy determined from density or velocity structure?

C4925

Answer: For figure 3 the difference between the mean of the defined outside stations and the station in the center is plotted to show the amplitude of changes. For AHA and ASA the maximum of swirl velocity from the ADCP was defined on both sides of the eddy for each depth and then temperature and salinity were interpolated on an equidistant grid between these boundaries from all existing profiles along the section and the gridded field was used for the AHA and ASA computation, now explained in the text.

f. it would be useful to also have bathymetry on Fig.1

Answer: We added the 200 m and the 2000 m contour to figure 1a. We tried with 1000 m contours, but the topography is too busy close to shelf to show the complete bathymetry.

g. p9188, lines 3-4: what is the justification for this definition of eddy extent? Why should an eddy be considered 'shorter' just because it is moving? More generally, is swirl velocity a reliable indicator of the size of a mode water eddy. If there is a barotropic mode then the swirl will go much deeper than the displacement of isopycnals and the latter are more closely linked to properties such as heat and tracer anomalies.

Answer: As described in Chaigneau et al. 2011 the underlying assumption is that mesoscale eddies are sufficiently nonlinear so that the anomalies are trapped inside their core, down to the trapping depth defined by the Flierl (1981) criterion. We used the same approach to do our computations similar to Chaigneau et al. 2011.

h. a little more explanation is needed when comparing observations to the Chagneau et al. 2011 paper. In the latter velocities are determined from geostrophy. In this manuscript they are observed directly using ADCP and will include other contributions in addition to the geostrophic component. As a further comment, the argument put forward on p9192 lines 5-9 does not explain all of the discrepancy.

Answer: The difference components in geostrophic computations relative to a depth

C4926

layer and the velocities measured by the ADCP is now explained in the text.

i. p9193, lines 11-15: the definition used for the eddy extent of $U/c > 1$ is also the criteria for an eddy to trap its contents. Hence, according to the standard interpretation of 'eddy-pumping' there should be no continued supply of nutrients to the euphotic zone within the eddy. Instead, the decaying signal would be due to the original trapped nutrient supply being consumed (if other dynamical process were ignored).

Answer: The sentence was modified.

j. p9193, lines 19-20: this statement needs quantification to support it. What is the primary production within eddies and what is that for the area?

Answer: The statement about the 'significant contribution' of eddies to the productivity was modified.

k. p9190, line 22: Fig 3 does not seem to support the claim about silicate anomalies.

Answer: The comparison with anticyclone A was modified, no longer stating that the silicate anomalies are of similar strength.

l. Fig 1 would seem to imply that transect A1 missed the eddy core by some margin

Answer: The SSHA figures show different eddy core locations for near real time data and delayed time processing. The near real time data for 21 November 2012 showed the eddy core west of 76°W (see figure R2 below) different to figure 1b and the SSHA fields can't be used for determining the exact eddy core.

(Fig. R2 (at the end) SSHA for 21 November 2012 from the near real-time data.)

m. the depth of the oxygen anomaly for eddy B seems difficult to reconcile between Figs 3 and 7.

Answer: We separated the scale for oxygen changes in figure 3 above and below 300 m depth to make the deeper changes better visible compared to the large gradient in

C4927

the upper ocean.

n. Fig. 3: more tick marks needed on x-axes. Also need to state which transects/CTD casts were used to calculate these anomalies.

Answer: More tick marks are added and the CTD profiles used are now stated in the figure legend.

o. Fig.4 would benefit from having density contours added.

Answer: Density contours were added to figure 4 which is a really helpful addition.

p. Fig.6: the left hand panels suggest that the eddy is centred at $\sim 76.6\text{W}$ with edge of core at 76W . This would mean that the right hand panels are almost all outside the eddy core.

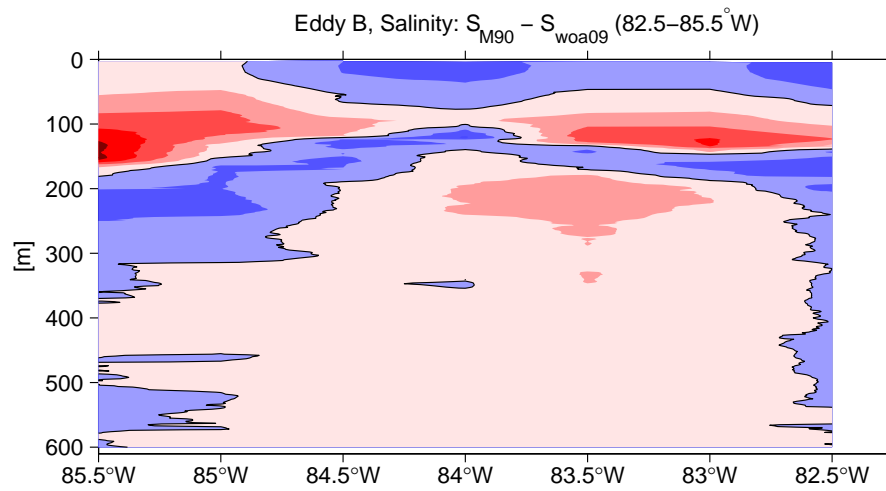
Answer: Correct, we used the right hand panel to describe the near-shelf parameter distribution e.g. at the Peru Chile Undercurrent which could have influenced the water masses of the eddy when the eddy formed. The text was modified and we think it is clearer now, that the right hand panel is presented to describe the near-shelf parameter distribution. In a new figure 9 salinity profiles are shown to describe that the anticyclonic eddies A and B contain water from the Peru Chile Undercurrent.

q. Fig.7: velocity structure seems noisy and not very coherent. Has the transect missed the core?

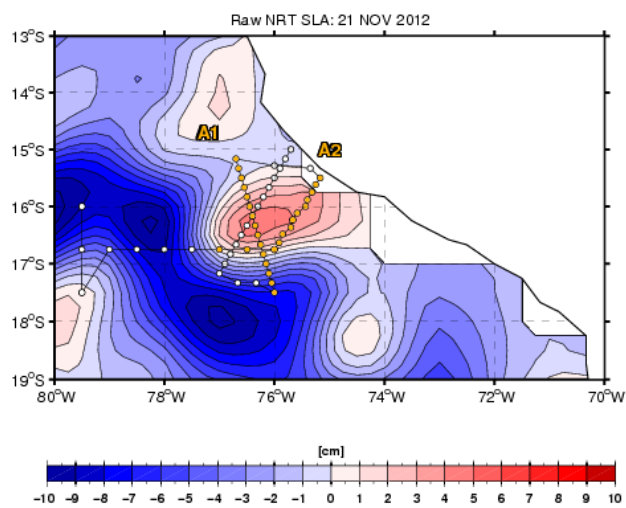
Answer: As can be seen from Figure 1b a weak anticyclonic feature was located just west of eddy B leading to a broader southward component on the western side.

Interactive comment on Biogeosciences Discuss., 10, 9179, 2013.

C4928



C4929



(Fig. R2 SSHA for 21 November 2012 from the near real-time data.)

C4930