Detailed response to referee #2

We are thankful to referee #2 for her/his comments and suggestions. The tuning of the biogeochemical parameter has substantially improved the simulation results presented in the now-revised version of the manuscript. In addition, the analyses of advective fluxes have allowed for a better interpretation of the processes involved in nutrient variations within the selected eddies.

Eddies play an important role in modulating the physical and biogeochemical environments in eastern boundary upwelling systems. The authors analyze two simulated eddies in the Humbolt upwelling system. They argue that horizontal entrainment instead of biogeochemical dynamics governs biogeochemical properties inside eddies. While the mechanism is plausible, it is not sufficiently supported by the presented analysis.

Major comments:

1. Description of models is too brief. This study employs the BioEBUS model, citing a relatively recent paper [Gutknecht et al. 2013]. I don't think many readers is familiar with the model and the paper. I would suggest the authors to describe the model and the parameters in an appendix or in supplementary materials.

Agreed. We added the respective information in a supplement.

Addition to the supplementary information, section 1:

1. Biogeochemical model

BioEBUS is a nitrogen-based model, developed from the $N_2P_2Z_2D_2$ by Koné et al. 2009. This model contains 12 compartments (Gutknecht et al. 2013). As described in Gutknecht et al. 2013, marine biota are represented by four compartments and comprise the first trophic level of the food web, small (nano/ picophytoplankton and microzooplankton) and large (diatoms and mesozooplankton) organisms. The phytoplankton growth is limited only by the availability of fixed nitrogen in the water column. The nitrogen cycling includes denitrification, nitrification and anammox processes, as well as uptake by phytoplankton in the sun-lit surface layer and subsequent cycling and re-cycling by the planktonic ecosystem,. The model also represents dissolved oxygen, allowing a separation of respiration processes occurring under oxic and suboxic conditions.

1.1. Model parameters

To simulate the biogeochemical dynamics of the ETSP, we essentially used the same parameters as in previous studies (Koné et al. 2009, Gutknecht et al. 2013, Montes et al. 2014). Some parameters are adjusted, in order to obtain a better agreement with the observed dynamics of the ETSP (Table 1). These parameters include the half saturation constant for nutrient (ammonium, nitrate and nitrite) uptake by both small and large phytoplankton classes, zooplankton (including small and large classes) feeding preferences, half saturation constant for zooplankton (including small and large classes) ingestion. The constants for nutrient uptake by phytoplankton and the zooplankton ingestion are adjusted to the values presented in Koné et al. 2009. The rate of first and second stage of nitrification consist of parameter values used in Gutknecht et al. 2013 and in Montes et al. 2014, respectively.

Table 1. Adjusted parameter used in the biogeochemical model.

Half saturation constant for NH4 uptake by large phytoplankton	mmol N m^{-3}	0.7
Half saturation constant for NO2+NO3 uptake by small phytoplankton	mmol N m^{-3}	1
Preference of small zooplankton to small phytoplankton	mmol N m^{-3}	0.75
Preference of small zooplankton to large phytoplankton	mmol N m^{-3}	0.25
Preference of large zooplankton to large phytoplankton	mmol N m^{-3}	0.5
Preference of large zooplankton to small zooplankton	mmol N m^{-3}	0.24
Half saturation constant for ingestion by small zooplankton	mmol N m^{-3}	1
Half saturation constant for ingestion by large zooplankton	mmol N m^{-3}	2
Rate of first stage of nitrification	d^{-1}	0.9
Rate of second stage of nitrification	d^{-1}	0.25

The adjustment of the phytoplankton nutrient uptake and the zooplankton dynamics constants led to a reduction of both phytoplankton and zooplankton production, and consequently export production, and an improved agreement with vertical nutrient and oxygen profiles. Adjustments of the rates of nitrification allowed a better reproduction of nitrite and nitrate distributions in our model configuration.

2. Suggest adding a figure to show the domain extent.

The domain extent is now added in the supplementary information.

Addition to the supplementary information, section 2:

2. Model domain

Figure SI-1 shows the extension of the model domain used in the 2 way-nesting procedure to simulate the high-resolution bio-physical dynamics of the Eastern Tropical South Pacific (ETSP). As the ETSP is strongly influenced by equatorial dynamics (Montes et al. 2010), a larger model domain with a coarser grid, covering the relevant current systems of the ETPS, is used to force the high-resolution model centered on the oxygen minimum zone off Peru.

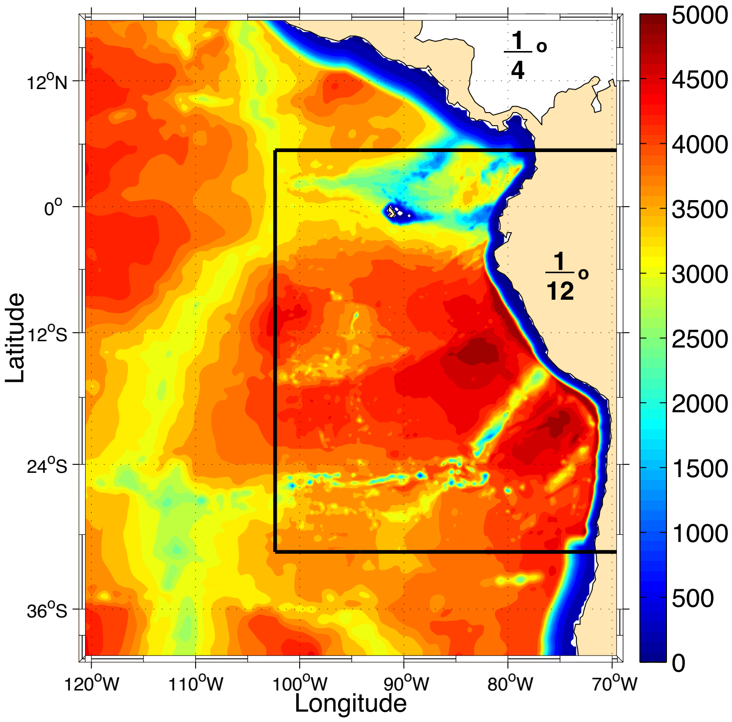

Figure SI-1: Model bathymetry of the Eastern Tropical South Pacific. The black square denotes the zoom into the eastern tropical south Pacific oxygen minimum zone. The color denotes depth in meters. The topography is derived from the GEBCO 1’ data set.

The model is insufficiently validated:

– In figs. 2(a) and (b), the model seems to capture the chlorophyll pattern correctly, but underestimate nearshore chlorophyll and overestimate offshore chlorophyll. I think this can be fixed by adjusting parameters in the biogeochemical model.

Indeed, the model overestimates the offshore chlorophyll concentration. This issue, which is still recurrent in the new simulation, might be related to the model formulation. The model formulation only accounts for the phytoplankton growth limitation by nitrogen, even though growth off Peru is known to be limited by iron (Hutchins et al. 2002).

Addition to the new version of the manuscript, section 2.1, page 3, lines 29-33:
Although the representation of patterns of surface chlorophyll is generally good, there are biases offshore where simulated concentrations exceed the observations. We speculate that this model deficiency is related to iron limitation (c.f. Hutchins et al. 2002), which we do not explicitly account for in our current model.

– In Figs. 2(c) and (d), the strength of the OMZ is indistinguishable due to the choice of colorbar and color scale.

The colorbar and color scale are changed in the new version of the manuscript.

– The left and middle panels of Fig. 3 suggest that the model overestimates mixed layer depth.

The simulated mixed layer depth appears comparable with the observations (Fig. 1). However, in the revised version we changed some of the biogeochemical parameters (see Table 1) such that now the vertical profiles of nitrate and oxygen are more realistic (Fig. 2).

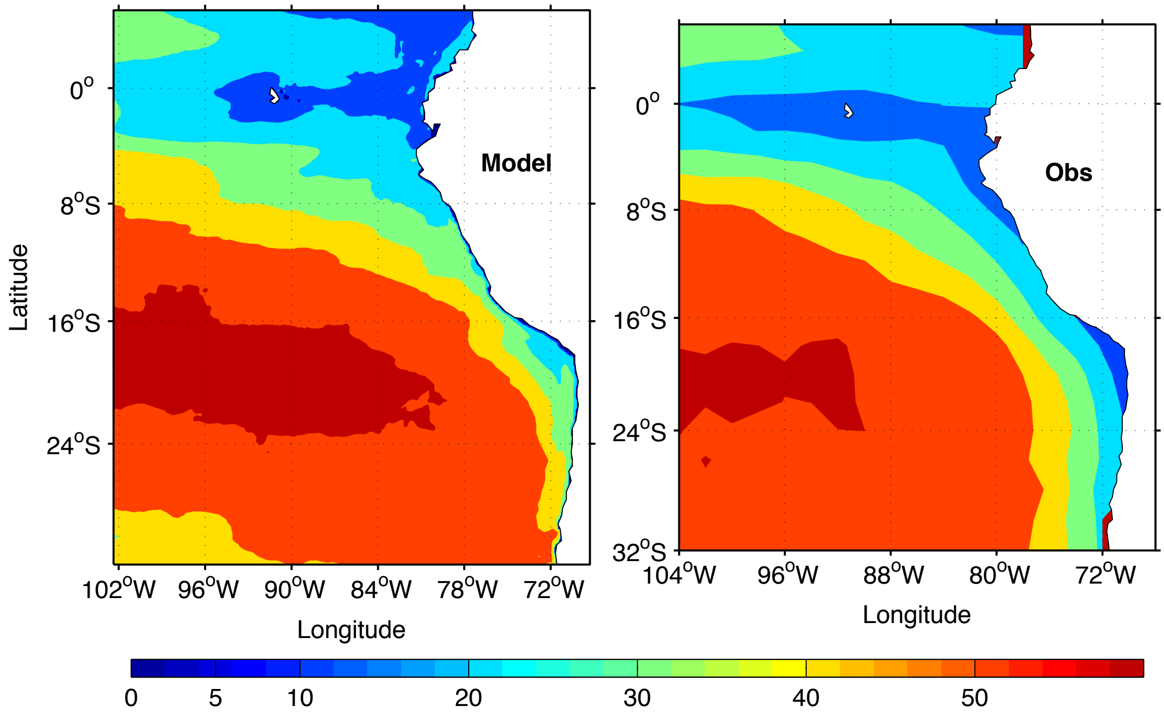

Figure 1. Simulated (left) and observed (right) climatological annual-mean surface mixed layer depth from Montégut et al. (2004).

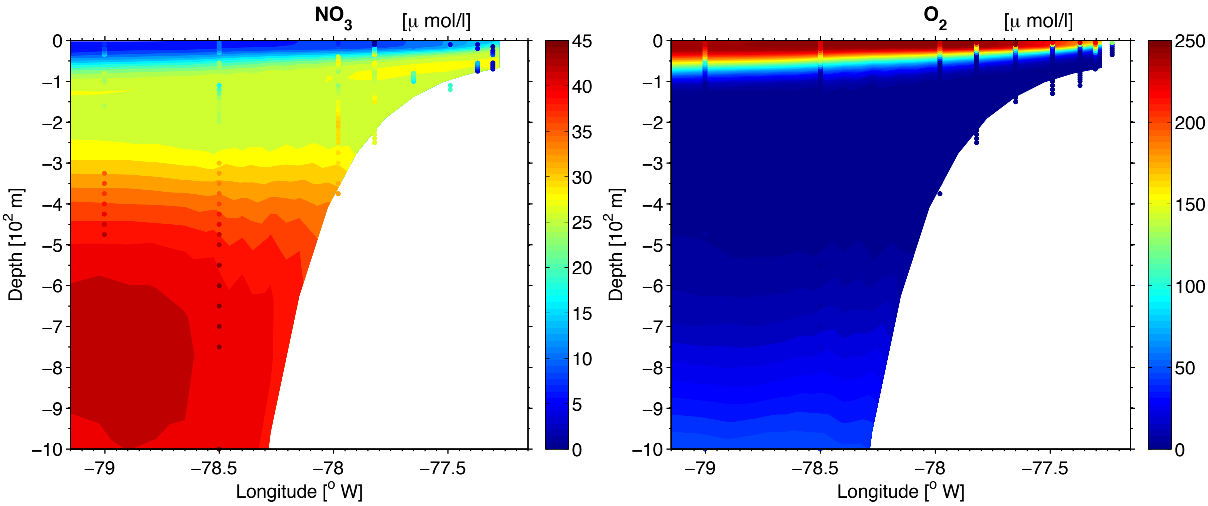

Figure 2. Zonal section of nitrate [μ mol /l] and oxygen [μ mol /l] along 12°S. Simulated concentrations correspond to climatological December. The observed concentrations shown by colored dots are from measurements taken on the cruise M91, December 2012.

– In the right panel of Fig. 3, the model does not capture the high NO_2 concentration in the OMZ. The authors argue that benthic process is the cause for the discrepancy. The claim is not convincing as 78.5W is quite away from any ocean bottom.

I suspect the authors could adjust model parameters for oxygen-dependent nitrification/

denitrification and get a better agreement.

A new simulation with adjusted parameters (see Table 1) has indeed allowed for a better agreement between observed and simulated NO_2 (Fig. 3).

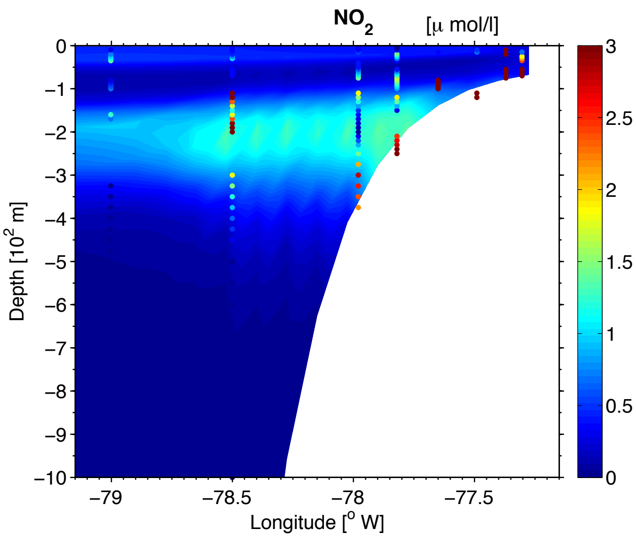

Figure 3. Zonal section of nitrite [μ mol /l] along 12°S. Simulated concentrations correspond to climatological December. The observed concentrations shown by colored dots are measurements taken on the cruise M91, December 2012.

4. In Figs. 7 and 9, averages over the upper 400 meters are presented while the difference in NO3 and NO2 between the two eddies are between 100 to 200 m. Could the authors also carry out an analysis for fluxes and concentrations between 100m and 200m?

The fluxes and concentrations are now calculated for depth range 100-200 m.

5. While the authors claim advection is the dominant process for NO3 and NO2 concentration within eddies, there is no estimate of the advective flux. I would suggest the authors to add results for advective fluxes.

The advective fluxes are now added in the revised manuscript.

Addition to the text, section 3.2, page 7 and page 8:

…. To investigate the origin of water masses present in the selected eddies, we analyse the advective transports of both nitrate and nitrite into the eddy during the eddy's lifetime (Fig. 10 and Fig. 12). The water mass properties within the structure are also analysed and compared with the surrounding environment during different instants of the eddy's lifetime (Fig. 11 and Fig. 13). Figure 10 illustrates the nitrate and nitrite fluxes into the eddy $A_{sim.}$ It shows a strong injection of nutrients from the lateral margins of the eddy. This nutrient injection is elevated in the first months following the eddy formation.

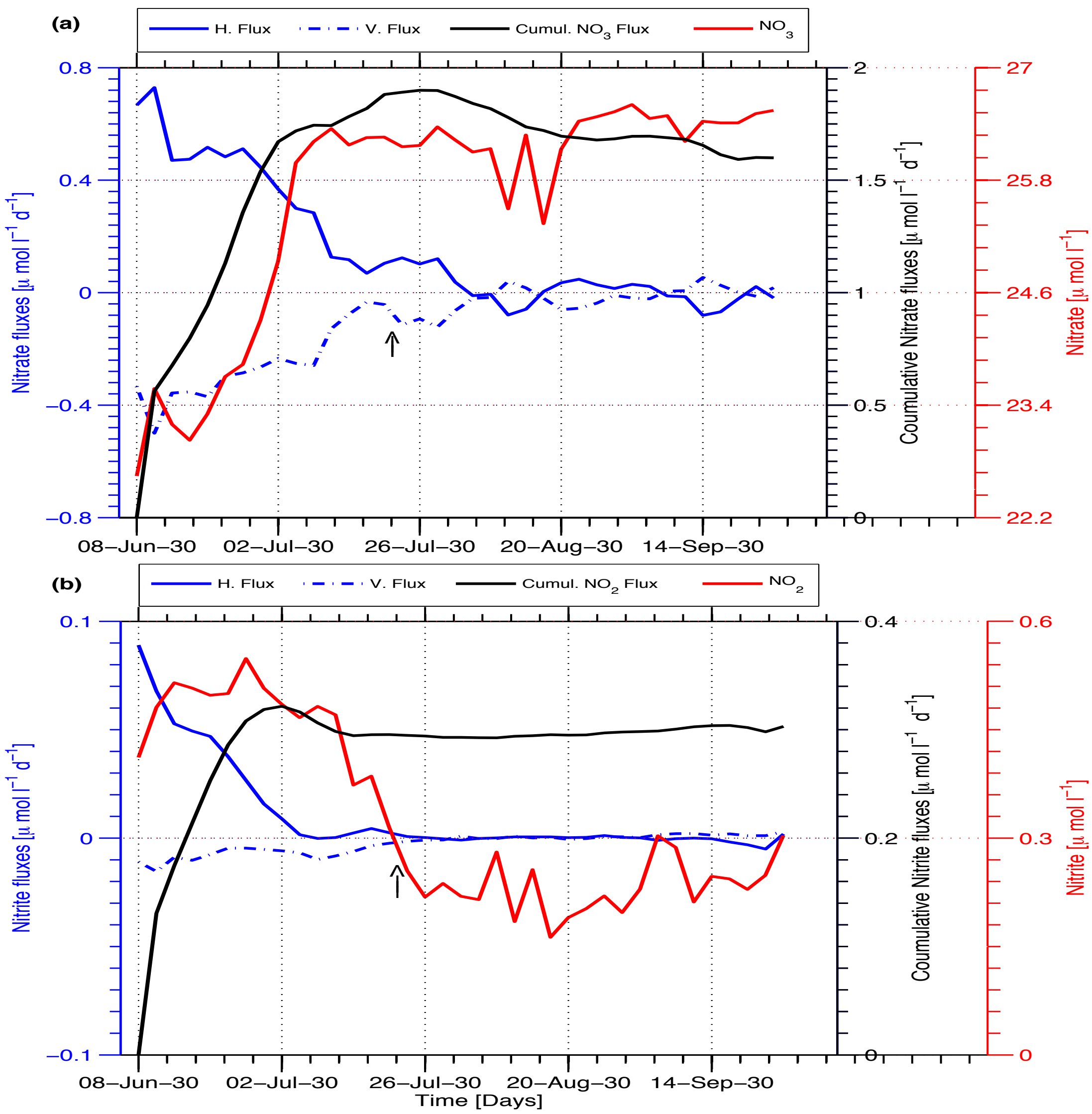

Figure 10. Nitrate (a) and nitrite (b) advective fluxes into the eddy A_{sim}. Lines indicate horizontal (solid blue, μmol $l^{-1}d^{-1}$), vertical (dashed blue, μmol $l^{-1}d^{-1}$) and cumulative (black, μmol l^{-1}) advection. Red line represents the available nitrate within the eddy [μmol l^{-1}]. Arrows indicate the time where the sections in Figure 4 were taken.

The cumulative fluxes of both nitrate and nitrite significantly increase in this period and follow the evolution of both nitrate and nitrite within the eddy. These dynamics suggest a strong exchange with the surrounding environment during this period. This is also visible in the water mass properties within the eddy structure (Fig. 11). At the surface, waters present within the eddy A_{sim} are relatively cool and fresh compared to the water masses present following the eddy formation (Fig. 11-a-b)…..

The nutrient fluxes across the edge of the eddy B_{sim} are presented in Figure 12. It shows a contribution of both horizontal and vertical transport to the nutrient variation within the eddy, during the eddy's lifetime.

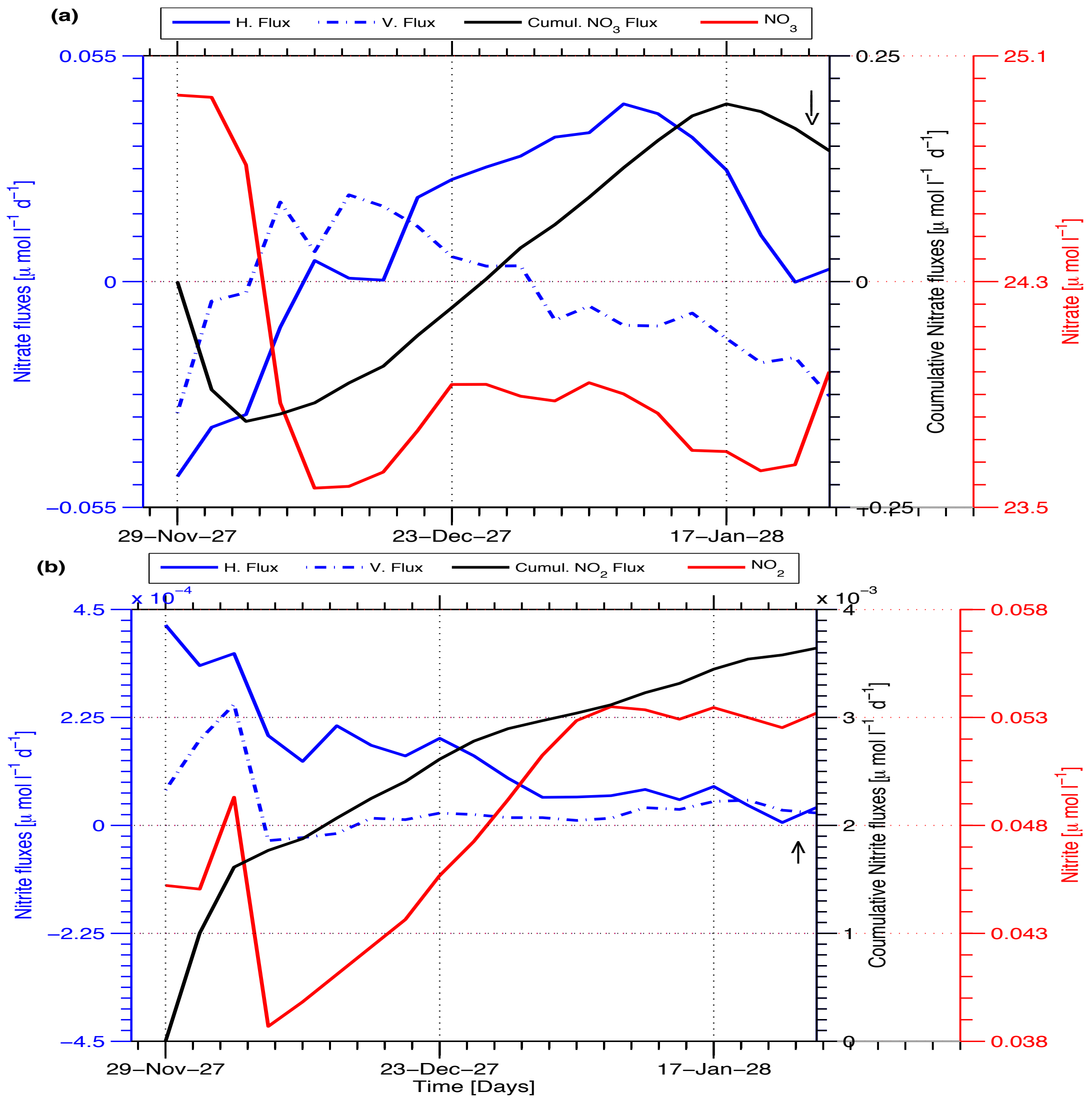

Figure 12. Nitrate (a) and nitrite (b) advective fluxes into the eddy B_{sim}. Lines indicate horizontal (solid blue, µmol $l^{-1}d^{-1}$), vertical (dashed blue, µmol $l^{-1}d^{-1}$) and cumulative (black, µmol l^{-1}) advective fluxes. Red line represents the available nitrate within the eddy [µmol l^{-1}]. Arrows indicate the time where the

sections in Figure 5 were taken.

After the eddy B_{sim} formation, the nitrate fluxes through the edge of the eddy B_{sim} is dominantly out-going, showing a loss of nitrate to the surrounding environment (Fig. 12-a). These out-going fluxes reduce the nitrate availability within the eddy. About half a month later, the nitrate concentration within the eddy increases. This increase is to a large extent due to the nitrate supply into the eddy structure from both vertical and horizontal boundaries. On the contrary, the nitrite supply into the eddy is largest and positive in the month following the eddy formation and decreases afterwards (Fig. 12-b).

Editorial comments: 1. Fig. 3: the panels should be labeled as (a), (b), and (c) instead of (a), (c), and (e). 2. Caption for Fig. 7: "B_{sim}" should be "A_{sim}" 3. Caption for Fig. 10 needs to be revised.

The panels of Fig. 3 and the caption of Fig.7 are revised accordingly in the new version of the manuscript.

References

Hutchins et al. (2002), *Phytoplankton iron limitation in the Humboldt Current and Peru Upwelling*, Limnol. Oceanography, 47, 997-1011.