

Interactive comment on “N₂ fixation in eddies of the eastern tropical South Pacific Ocean” by C. R. Löscher et al.

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We thank referee 1 for this thorough review of our manuscript. The comments and thoughts provided by Referee 1 were particularly helpful to improve this manuscript. Questions and comments were addressed as described in the following; modifications are highlighted in yellow in the main text: Referee Comment (RC) 1: Why is carbon fixation higher at the deeper depths and associated with N₂ fixation? Authors concluded that N₂ fixation co-occurred with N loss process. So how was carbon fixation sustained (during the incubations) without reactive nitrogen? In addition, Fig. 3 suggests that C fixation was very high in the center of eddy B at above 100m depth, but there was no reactive nitrogen at that depth either. So what sustained C fixation? My guess is that all these higher carbon fixation rates are sustained by reactive nitrogen from N₂

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fixation. If the authors have ammonium (released from the fixed nitrogen) data then my hypothesis can be (dis)proved.

Author comment (AC) 1: The fact that C fixation is very high at deeper depths may relate to so-called ‘dark carbon fixation’ as previously shown to be important in this region (Schunck et al., 2013), the Cariaco basin (Taylor et al., 2001) and lake environments with enhanced N-loss and N₂ fixation activity (Camacho et al., 2001). If I should speculate, I would also suggest that N₂ fixation greatly drives C fixation, where it is high. While nitrate and nitrite data are present, ammonia data are unfortunately not available from those samples therefore one part of the reactive N pool is missing. It is thus not entirely possible to show what drives C fixation and a real prove (or disprove) of this hypothesis cannot be given at that time but should be subject of follow-up studies.

RC 2: Was there sufficient light to sustain carbon fixation at around 300 m depth (Fig. 3).

AC 2: In order to answer this question, we analyzed the available fluorescence data (Krahmann, 2014). From this data, light should be unavailable at 300 m depth (# 1639, eddy A: fluorescence < 0.04 factory calibrated units or approx. $\mu\text{g L}^{-1}$ at 300 m, compared to 2,59 $\mu\text{g L}^{-1}$ in the upper Chl maximum at 40 m). A distribution of chlorophyll A is also given in Stramma et al. (2013, Fig. 4), which shows disappearance of Chl a between 80 and 100 m. Therefore, C fixation may rather be ascribed to dark C- fixers as previously described to significantly contribute to primary production in OMZ waters (see above). Although not much information about the character of dark C-fixers or their importance in the environment is presently available, this topic itself is highly interesting and it is tempting to address it by a separate study.

Minor comments: RC 3: Page 18948, Line 2: “Nitrogen.....ocean (Codispoti, 1989)” is slightly incorrect statement. It is reactive nitrogen (NH₄, NO₃) that limits primary production, as ocean has plenty of N in the form of dissolved gas. “is limiting” should be replaced as “limits”

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AC3: We agree and modified the term to 'Reactive nitrogen... that limits primary production'.

RC 4: Page 18948, Line 25-29: "In addition.....reported for this region (Chaigneau et al., 2009)." is confusing. Does the last part of the paragraph mean that the no of eddies are increasing, or no. of reported eddies are increasing?

AC 4: Chaigneau et al. (2009) compared different upwelling systems (Peru-Chile, California, Canary, Benguela) based on a 15 year record of satellite altimetry data. Among those systems, eddy frequency (eddies/week) was the second highest in the upwelling off Peru. In order to clarify, we rephrased the sentences:

In addition to its remarkable biological activities, the physically dynamic character of the ETSP in the upwelling system off Peru favors mesoscale activities (Chelton et al., 2011). Compared to other upwelling regions (e.g. off California, Benguela), enhanced frequency of eddies has been reported for this region (Chaigneau et al., 2009).

RC 5: Page 18950, Line 11-13: How was the age of eddies estimated?

AC 5: The age has been estimated by Stramma et al. 2013 based on satellite monitoring of sea level height anomalies. This information, as well as the reference, was added:

The age of the eddy was determined by Stramma et al. (2013) bases on satellite monitoring of sea level height anomaly data.

RC 6: Page 18951, Line 2: Why only autotrophic? Why cannot positive P* stimulate heterotrophic N2 fixation?

AC 6: This is actually true- why shouldn't it stimulate N2 fixation in general? Therefore, 'autotrophic' has been removed.

RC 7: Page 18951, Line 8: Replace "N2/Ar-1" by "N2/Ar"

AC 7: Changed as suggested.

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RC 8: Page 18951, Line 13: But anammox can occur at $[O_2] > 10 \mu M$

AC 8: Indeed, e.g. Kalvelage and colleagues (2011) showed that anammox is still measureable at $O_2 > 10 \mu M$. However, anammox rates were also found to sharply drop at O_2 levels of 10-15 μM (see Fig. 3 in Kalvelage et al., 2011). O_2 was always $> 10 \mu M$ at the reference station. Further, we argue, that anammox is not significant at this offshore station because biogenic N_2 did not significantly accumulate there, i.e., there was no N_2 excess (or biogenic N_2) peak corresponding to the O_2 minimum (Figure S1 in Bourbonnais et al., 2015).

RC 9: Page 18951, Line 13: M90 does not have any locations in the northern hemisphere. So location 1.67°N seems to be incorrect.

AC 9: M90 had several stations on the Northern hemisphere that are not shown or discussed in that study. The cruise track, as well as all metadata, is visible from Pangaea (<https://doi.pangaea.de/10.1594/PANGAEA.830245>). Therefore, the position is correct.

RC 10: Page 18951, Line 18: Replace "N2 Ar-1" by "N2/Ar"

AC 10: Changed as suggested.

RC 11: Page 18952, Line 10-12: "For each.....of the rates". Then mention the range of measured enrichment values.

AC 11: We included the range of $15N_2$ enrichment as a range (2.4 ± 0.144 atom%, p. 18952, line 4 of the Discussion paper)

RC 12: Page 18952, Line 25: "-" should be replaced by $>$ or $\hat{=}$, whichever applicable.

AC 12: This is a vacuum filtration, therefore the '-' refers to the fact that the pressure is negative. -200 mbar is therefore correct.

RC 13: Page 18956, Line 7-10: "A coastal origin.....signals" How could the movement of eddy C be the reason for lower N loss? Explain.

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AC 13: Eddy C did not stay at the coast as eddies A and B did. Thus, it was less exposed to 'coastal' conditions compared to the other eddies, e.g. organic matter load of the water mass or trace metal availability. As strong N loss is mainly present at the coast it may be considered a coastal feature and what we measure in eddies A and B would therefore be a result of their residence time at the coast.

RC 14: Page 18957, Line 5: Previous studies that the authors have mentioned also presented quantitative rates. Then why the authors say "first quantitative rates of N₂ fixation?"

AC 14: To our knowledge, this is the first study presenting N₂ fixation measurements from that region using the method developed by Mohr et al., 2010. Other previous studies, including our own, used the bubble addition method, which has been shown to largely underestimate N₂ fixation rates. The quantification in those studies was therefore biased and not fully quantitative.

RC 15: Page 18958, Line 18: Replace "consistence" with "consistency"

AC 15: Changed as suggested.

RC 16: Page 18959, Line 24-27: "As previous.eddy C.". How? Then N₂ fixation should have also occurred at the surface in the eddies A and B.

AC 16: This is true and this is also in accordance with our observations. We therefore replaced eddy C by 'the eddies).

RC 17: Page 18966: Caption of Table 1. Replace "biogeochemical properties" by "biogeochemical parameters"

AC 17: Changed as suggested.

RC 18: Page 18967: Caption of Fig. 1. Acronym SSHA does not go together with Aviso sea level anomaly

AC 18: This is true; SSHA refers to sea surface height anomaly, derived from the Aviso

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satellite. We modified the caption to 'Aviso satellite-derived altimeter sea surface height anomaly data (SSHA)'.
RC 19: Page 18968: Caption of Fig. 2. Delete "Hydrographic.....16.45'S."

AC 19: Deleted.

RC 20: Page 18969: Enlarge the legend and axes title of Fig. 3

AC 20: We enlarged the legend and axes titles.

RC 21: Page 18971: Caption of Fig. 5: Does eddy A stand for eddy A1 or A2?

AC 21: This refers to eddy A1, we added this information to the caption.

RC 22: Page 18972: Caption of Fig. 6: "Strongest negative correlations are present between N₂ fixation and O₂ and N₂ fixation and O₂." should be replaced by "Strongest negative correlations are present between N₂ fixation and O₂"

AC 22: Actually, a negative correlation with O₂ and with temperature was present; therefore, the second 'O₂' was replaced by 'temperature'.

References:

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