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Interactive comment on "Influence of mesoscale eddies on the distribution of nitrous oxide in the eastern tropical South Pacific" *by* D. L. Arévalo-Martínez et al.

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Author's response to comments by Referee #1 (Prof. Dr. Nicolas Gruber)

On behalf of the authors I would like to thank Prof. Dr. Nicolas Gruber for the comments to our manuscript. We acknowledge that some parts of the interpretation and discussion of our results can be written more concisely and that both the advantages and potential caveats of our approach need to be put in perspective in the final manuscript. Furthermore, in attention to the suggestion by Prof. Gruber, we will add a new section to the manuscript in which we provide a synthesis of the source-sinks processes for N2O under the influence of mesoscale eddies in the ETSP. On the following I will

list our replies to punctual issues raised by Prof. Gruber, indicating how they will be addressed in the revised manuscript.

Major points

Comment by Prof. Gruber:

Overinterpretation of the data: While I admire the authors for their very thorough and deep discussion of the data, sometimes I had the feeling that they went too far and started to pick up simply "noise", resulting from the fact that they investigate a rather dynamic environment. For example, some of the differences in "aging" could simply be just within eddy variations, stemming from differences in formation, transport, initial nutrient levels, etc. I suggest that the authors acknowledge this alternative interpretation more strongly and adjust their wording accordingly.

Reply by authors:

We acknowledge that due to the station density and time scales of our survey, it is difficult to assess at what extent the changes in N2O concentrations between coastal and open ocean features were due to biogeochemical cycling during their lifetime, as opposed to variability induced by their properties at the time of formation. Furthermore, analysis of our full data set showed that, for example, stations within the center of the same eddy might have different anomalies (difference between center and outside) despite of sharing the same distribution in the water column. This clearly points out to an unaccounted variability within the eddies which might be indeed reflected in these N2O concentration differences. Since with our methods we cannot directly evaluate this effect, and we are not aware other studies dealing with N2O and mesoscale eddies in the ETSP, our discussion in centered in our "best guess" of how the N2O-cycling proceeds within mesoscale eddies during their transport offshore. In the revised manuscript we will include anomaly plots in order to better depict the differences in N2O concentrations between stations in the center of the eddy and stations outside. Likewise, we will show additional stations located between the center and the edges of the sampled eddies so as to illustrate the spatial variability in N2O concentrations. We will also discuss alternative explanations for our observations given the potential limitations of our sampling methods.

Comment by Prof. Gruber:

Stronger synthetic view: The paper would greatly benefit from the authors taking a more synthetic view of their results. As it stands, the authors emphasize differences and much less the common aspects. Thus, the reader comes away with the impression that every eddy is different, preventing them from formulating more general principles. I thus strong encourage the authors to add a synthesis section where they develop a diagrammatic view of how N2O is formed, consumed and transported in such a dynamic environment such as the ETSP.

Reply by authors:

We agree with this suggestion and therefore we will include a new section in the revised manuscript. In this section we use our biogeochemical and molecular ecology data to provide a schematic view of the processes producing and depleting N2O in the water column of the ETSP, also including the impact of mesoscale eddies. This synthesis section will be complementary to the work by Kock et al. [2015] who presented a comprehensive description of the water column distribution of N2O in the ETSP. We also agree in that the manuscript could benefit from highlighting the common aspects of the N2O distribution within mesoscale eddies and for this the discussion will be modified accordingly in sections 4.1 and 4.2.

Reference: Kock, A., Arévalo-Martínez, D. L., Löscher, C. R., and Bange, H. W.: Differences between coastal and open ocean distributions of N2O in the oxygen minimum zone off Peru, Biogeosciences Discuss., 12, 10167-10193, 2015.

Comment by Prof. Gruber:

Molecular genetic methods. I applaud the authors' combination of the (bio)geochemical

measurements with those using molecular genetic methods. But in the text, the integration is not as strong as it could be, as the genetic information is used in a rather qualitative manner. In particular, one wonders whether the bacterial biomass present would suffice to produce/consume the amount of N2O needed in order to produce the environmental concentrations and gradients in N2O.

Reply by authors:

We thank Prof. Gruber for the positive evaluation of our approach. The overall problem with gene abundance data is that they give an idea of what could possibly be found in an environment under certain conditions rather than providing indication of the activity or importance of a process. Therefore, we used the molecular data only in a qualitative way to show that the potential for nitrification and denitrification (or also for anammox) is present. Our data mirror the high abundance of archaeal ammonia oxidizers as it is typically found in coastal waters of that region, and a comparably lower abundance of denitrifiers. Since amoA (as key gene for nitrification) dominates the upper part of the water column, we consider nitrification to be a quantitatively more important process here. Nevertheless, both genes (nirS, amoA) were present where the deeper maximum in N2O could be found, and therefore both processes may contribute to the N2O budget. We modified the respective part of the manuscript (p.9254, l.6ff.) in order to better integrate the molecular data. From our point of view it is however difficult to determine what part of the biomass is sufficient to shape the observed gradients, particularly because the potential for N2O production/consumption does not only depend on the overall abundance of microbes or their relative importance regarding the biomass but rather on the efficiency of the process and the environmental conditions, such as substrate availability and O2. (For example, N2-fixers are considered to account for only 2% in ocean surface metagenomes, and yet they contribute up to 80% of the new N to these waters). We are therefore critical towards a comparison with the overall biomass.

Minor comments

Comment by Prof. Gruber:

Introduction: I suppose the authors want to refer also to their Nature Geoscience paper.

Reply by authors: This reference will be included as suggested.

Comment by Prof. Gruber:

page 9215, line 22: "This result can be explained by lower water column O2 concentrations in eddy A than in eddy B (36.4 and 42.9 molm-2)" This is an example of a possible "overinterpretation" of the results. This is a rather small mean difference, which I doubt is big enough to really explain the difference.

Reply by authors: This paragraph will be reorganized for more clarity and the interpretation of this result will be presented in a way that our observational constraints are clearly stated. In particular for oxygen and nutrients we will compute integrated water column concentrations from additional stations (even though there was not N2O sampling) in order to provide a measure of the uncertainty of our estimates.

Comment by Prof. Gruber:

page 9252, line 19 "Therefore it is likely that the decaying primary production of eddy C during its transit away from the shelf led to a diminished supply of organic matter which could fuel N-loss within the OMZ's core, explaining the relatively high N2O concentrations observed in comparison to eddies A and B." This speculation is reasonable, but again, the difference is not as marked as the authors portray it to be. Hence, I would be more cautious in the interpretation of these differences.

Reply by authors: Text will be changed accordingly and it will be supported by anomaly plots which better depict the actual extent of the observed differences between the center and the edges of a given eddy as well as among mode water and cyclonic eddies.

Comment by Prof. Gruber:

page 9254, line 13ff "[..] show that denitrifiers produce increasing N2O:N2 ratios as the O2 concentrations increase..." It would be very interesting if the authors were able to be more quantitative here. Shouldn't it be possible to estimate this ratio by combining an estimate of the N-loss with the increase in N2O?

Reply by authors: Knowing that the denitrification pathway can be either a source or a sink for N2O, in section 4.3 we used a geochemical approach to estimate the amount of this gas that can be produced within the denitrifying conditions (i.e. O2 concentrations < 5 μmol L-1), as well as to estimate the amount of N-loss due to denitrification. In the revised version of the manuscript we use these two values in order to provide a computed N2O:N2 ratio and to show its sensitivity to the oxygen gradient through the water column within eddy A. Moreover, we use this ratio as a tool to evaluate the differences between profiles in the center and outside of the eddy, further supporting our previous analysis based on concentration anomalies.

Comment by Prof. Gruber:

page 9257, line 5ff "After integrating ΔN over the depth range of the OMZ, we obtained values of 8.9 and 0.02 molm-2 for eddy A during M90 and M91, respectively". I don't understand this result. A nitrogen deficit that is once created cannot be easily alleviated. One of the few options is to have N2-fixation to kick in, providing a lot of newly fixed N to compensate for the lost N2. Thus, it is puzzling to me how this change in ΔN can happen.

Reply by authors: During the second survey of the coastal eddy A (M91, December) we observed an overall reduction of N2O concentrations in its center, despite the fact that right at the boundaries of the OMZ concentrations were high. Considering the evidence of N-loss during M91, it would be reasonable to assume the N-deficit (and also the N2O consumption at the OMZ core) to be higher during that cruise. However, our computed N-deficit suggests that what we measure during M91 is most likely a remaining signal of enhanced N-loss activities during a period in which the eddy A stayed (and strengthened) on the shelf. As for other comparisons between M90 and M91within our manuscript, however, it should be considered that the station density for N2O during our study does not fully guarantee that we sampled exactly the same waters, even if the criteria for defining the center of the eddy was the same (i.e. the sea surface anomaly height data). On the other hand, recently Löscher et al. [2015] presented N2-fixation data for the same cruises, showing enhanced N2-fixation rates in the center of mode water eddies. Moreover, they also observed co-occurrence of N2-fixation and N-loss within these eddies, suggesting a spatial link between both processes in the ETSP. However, a comparison of the eddy A during M90 and M91 showed that in general N2-fixation rates tended to be lower during M91, most likely indicating a decline of biological production during "aging" of the eddy. Hence, although N2-fixation rates were lower within the mode water eddy A during M91, its occurrence, together with the fact that during M91 we most likely sampled the eddy after a period of intense N-cycling might help to explain the alleviation on the N-deficit, as pointed out by Prof. Gruber. Since we have more nutrient and oxygen than N2O data, in the revised version of the manuscript, we present a more robust calculation of the N-deficits along with property plots that illustrate the variability between the two cruises. Likewise, we will adjust the discussion paragraph accordingly and include the reference to Löscher et al. [2015] since that work was not published at the time of submission of our manuscript.

Reference: Löscher, C. R., Bourbonnais, A., Dekaezemacker, J., Charoenpong, C. N., Altabet, M. A., Bange, H. W., Czeschel, R., Hoffmann, C., and Schmitz, R. A.: N2 fixation in eddies of the eastern tropical South Pacific Ocean, Biogeosciences Discuss., 12, 18945-18972, 2015.

Kind regards,

Damian L. Arévalo-Martínez

Interactive comment on Biogeosciences Discuss., 12, 9243, 2015.