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Discussions

# *Interactive comment on* “Modeling the impact of iron and phosphorus limitations on nitrogen fixation in the Atlantic Ocean” *by* V. J. Coles and R. R. Hood

**V. J. Coles and R. R. Hood**

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We thank Dr. Katja Fennel for her careful and thoughtful review. We have implemented most of the suggestions she made, and we added sections in the paper to clarify or note issues raised in her review. Here, we specifically respond to the comments.

General Comments:

Ţ A major concern is the neglect of denitrification in the model, and its potential influence on the basinwide N* signature. Because this is a significant concern, and a valid criticism, we will respond in some detail. There are two issues. First, is the perspective that we suggest in the paper conclusions; that we may in fact be underestimating the amount of nitrogen fixation that occurs in the Atlantic by the neglect of shelf denitrification. This assumes that shelf denitrification, and its N* signature are primarily leaving the shelf domain at depths below the maximum winter mixed layer depth, so that the negative N* signature is conserved below the euphotic zone as it is advected around the basin and thus it is a sink that we neglect in the model that would cause us to need to increase rates of nitrogen fixation. Fennel points out that the measured N* maps we provide (Figs 11,12) show a tongue of low N* water along the US east coast, and she suggests that this is evidence for shelf denitrification. In fact, this signature is entirely due to advection of low N* waters out of the Arctic. As mentioned on pp 7, P2, the representation of inflow of low Arctic N* water is critical to ensuring that the basinwide nitrogen fixation rate is not underestimated. In fact, this inflow has been noted recently as important to the Atlantic N* fields and potentially balancing 16% of the Atlantic nitrogen fixation by Yamamoto-Kawai, Carmack, and McLaughlin in their 2006 Nature brief communication (V443, p.43). Careful inspection of Figures 11,12 suggests that the low N* signal along the coast is the result of dilution of the low N* Arctic inflow with high N* Sargasso Sea water. This is corroborated by the model simulations which show very similar dilution intensity without including any sink term for shelf denitrification. (Note that the model simulations have the Gulf Stream traveling too far north along the coastline which reduces the intensity of the low N* signal between Cape Hatteras and Long Island. Note also that these density surfaces are well below the subtropical thermocline, and so do represent the conservative advection view.) Because the observational maps do not show significant reservoirs of low N* water near the broad shelves along the US east coast, we argue that the contribution of denitrification at these density surfaces to the basin wide signal is modest.

Ţ The other possibility is that the shelf denitrification provides a surface or euphotic zone source for phosphorus enriched water that might eliminate the need to preferentially remineralize phosphorus in the model to maintain the phosphorus required by nitrogen fixing organisms. Figure 1 (cannot be shown in the comment due to limitations of the submittal which requires ascii text only!) shows N* at 200m from a few WOCE sections that intersect the US east coast. While there is a slight reduction in N* from

3-2 at the closest points to the shelf, this signal is very localized to the shelf, and could not support nitrogen fixation in the oligotrophic central gyres. In contrast, the low N* signal emanating from the Arctic has a strong, broad and consistent spatial pattern which is accounted for in our model.

Ţ The claim that preferential remineralization of P (relative to N) is not supported by observations is, indeed, consistent with the results presented in the Christian et al. (1997) paper. However, preferential P remineralization is supported by several other laboratory and open-ocean studies of particle remineralization and vertical flux (e.g., Grill and Richards, 1964; Knauer et al., 1979; Karl et al. 1996), and also by observations showing shallower maxima in DIP concentrations compared to DIN and DIC (Benitez-Nelson et al., 2004). It is probably fair to say that whether or not P remineralizes faster than N as detritus particles sink through and below the euphotic zone is still a subject of debate (Benitez-Nelson et al., 2004). We therefore believe it is reasonable to invoke it as a mechanism for retaining P in surface waters to help support N2-fixation, and as a potentially important process that dictates the vertical position of the N* maximum in the water column.

Benitez-Nelson CR, O'Neill L, Kolowith LC, Pellechia P, Thunell R (2004) Phosphonates and particulate organic phosphorus cycling in an anoxic marine basin. Limnology and Oceanography 49: 1593-1604

Grill EV, Richards FA (1964) Nutrient regeneration from phytoplankton decomposing in seawater. Journal of Marine Research 22: 51-59

Karl DM, Christian JR, Dore JE, Hebel DV, Letelier RM, Tupas LM, Winn CD (1996) Seasonal and interannual variability in primary production and particle flux at Station ALOHA. Deep-Sea Res. (2 Top. Stud. Oceanogr.) 43: 539-568

Knauer GA, Martin JH, Bruland KW (1979) Fluxes of particulate carbon, nitrogen, and phosphorus in the upper water column of the northeast Pacific. Deep-Sea Research 26A: 97-108

Ţ We do not argue that shelf denitrification is small or is in any way a negligible rate, however we suggest that shelf denitrification may be fueled primarily by inorganic nitrogen derived from coastal runoff and that any negative N* signature resulting from it is largely confined and trapped in the coastal zone. As a result, its impact is to reduce the high nitrogen inputs from the coastal eutrophication rather than generate basin scale surface N:P anomalies.

Specific Comments:

1. Add mention of model differences to introduction: DONE

2. Broecker carbon export: The citation of Broecker's idea, that there is no net carbon export due to biological processes in a Redfield steady-state ocean, is relevant because, as we state in the introductory paragraph, nitrogen fixation can result in non-Redfield element cycling and net carbon export. This fact is one of the primary motivations for studying and modeling open ocean nitrogen fixation variability, and it is therefore an important justification and motivation for our study. It is true that in a Redfield, steady-state ocean (with no nitrogen fixation) biological carbon export has a very significant impact on CO2 flux between the ocean and the atmosphere even though there is no net carbon export over the annual cycle. But how is this relevant to our paper? We are not modeling carbon or air-sea carbon exchange.

3. Fennel phosphorus availability comment is slightly modified: DONE

4. Dust into detrital pool: EXPLAINED

5. Rivers: CLARIFIED

6. Timescale for nutrient stabilization: the timescale is clarified, however we have not added a figure because of space limitations

7. N* equation: We maintain the original Gruber and Sarmiento equation rather than the simpler DINXS, to maintain continuity with previous studies.

8. Section 3 comment - include RMS differences between model and data: We chose not to plot the difference between the fields, or the RMS error, because at this model resolution we do not expect to match spatial or vertical features observed in the data. It can be misleading to difference two patterns which are slightly offset spatially or vertically, when the basic patterns are represented.

9. NOLIM simulations: CLARIFIED

10. Najjar typo: NOT FOUND

11. How limitations are calculated: CLARIFIED

12. Difference phosphorus section: DONE

13. Discuss importance of denitrification signal: DONE

14. Difference N* maps: Here, the data are very patchy and there is significant variability evidenced by the noisy nature of the N* map. Differencing the two maps would not add to the visual distinction between the patterns.

15. Decline of N* toward the US east Coast: As discussed above, the decline in N* toward the US East coast is consistent with purely advective and diffusive mixing of low N* arctic waters with the higher N* subtropical Atlantic water, based on our knowledge of the observed circulation as well as based on the models ability to replicate this pattern without the process of shelf denitrification.

16. Use Z level maps to illustrate the problems with N* on isopycnals: The point we are making here, is that the N* patterns are a result of both passive DIN/DIP advection and sources from DON/DOP advection along isopycnal surfaces, and also the source/sink of N* from falling particles which is a function of depth rather than density. Thus, neither isopycnals nor Z level surfaces are ideal for deconvolving the two processes. We use isopycnals here for comparison with GS 97, and also because the depth component is illustrated in the vertical sections.

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17. Missing to: DONE

18. Mention depth of N* maxima in figure 13: DONE

19. Source of N* minimum: CLARIFIED

20. Remineralization length scale vs denitrification: As discussed above, we do not believe that shelf denitrification in the mid-Atlantic coastal area is sufficient to drive a basinwide phosphorus enrichment relative to nitrogen that would fuel nitrogen fixation across the Atlantic basin. The data do not show a low N:P anomaly extending from the coast into the basin interior that could fuel nitrogen fixation. Furthermore, the bulk of the nitrogen fixation occurs in the tropical regions well south of the mid-Atlantic, and there is no mechanism for transporting phosphorus enriched water to the tropical areas with timescales shorter than 20+ years.

21. Improved recent denitrification estimate: DONE

22. Figure caption: DONE

23. Bergquist typo: DONE

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