

Interactive comment on “Glacial-Interglacial changes and Holocene variations in Arabian Sea denitrification” by Birgit Gaye et al.

Anonymous Referee #4

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General Comments

This manuscript by Gaye et al. presents and discusses sea surface temperature (SST) reconstructions and d15N records across the entire Arabian from the Last Glacial to Late Holocene. They use the SST reconstructions to identify physical mechanisms that drive changes in water column denitrification indicated by d15N. They discuss a complex set of biogeochemical and physical processes that affect oxygen minimum zone (OMZ) dynamics and denitrification including the monsoon-driven effects on upwelling and marine production as well as ventilation by different circulation pathways.

I find this paper to be a nice, well-written discussion investigating how the dynamic monsoon system may have changed and how it affected OMZs and denitrification since the Last Glacial. Their interpretation and discussion of the sediment proxies are gener-

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ally well-reasoned and support their conclusions. However, I think there are aspects of the manuscript that can be significantly improved before publication that I have noted below.

Specific Comments

1. Introduction and 2.1 Study Area Sections: I think there should be at least a couple paragraphs in the Introduction more focused on the Arabian Sea dynamics and previous paleo d15N interpretations there. The general nitrogen cycle is sufficiently introduced, but given the strong focus of this study in the Arabian Sea and monsoon system, some of the important findings in previous literature should be mentioned here.

Most of this necessary Arabian Sea introductory information is located in the Study Area subsection of the Materials and Methods, which is awkward to me as some readers who are not interested in “Materials and Methods” may overlook this important information including acronym definitions. I recommend moving the last two paleo-related paragraphs of the Study Area subsection into the Introduction and renaming the Study Area subsection to indicate the Arabian Sea oceanographic and monsoon dynamics are introduced there so readers are better informed on that subsection.

Lines 378-395: High interstadial (IS) d15N values are often discussed, but they are not evident in any of the figures. Perhaps it's useful to show the full record (before applying the time-slice averaging) from your new cores in a Figure so these high d15N IS events can be shown. I am not sure which time period(s) and regions they occur in the Arabian Sea. Since this is an important point you make in the abstract and conclusions, I think it should be visibly supported by data rather than only referenced.

Sometimes you refer to “northern Arabian” (e.g. line 384) and sometimes more generally only “Arabian” (e.g. line 385). Since the main contribution of this paper is discussing regional differences, please always specify the region.

Lines 390-391: “The glacial Arabian Sea quickly switched to enhanced denitrification”

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Does “quickly” refer to the 16-11ka period? The eastern Arabian Sea does not follow this trend which should be noted.

Lines 411-412: “A short return to glacial conditions without denitrification across the basin occurred during the cold excursion of the Younger Dryas”

I don't see the evidence that supports this statement. The East, West, and Oman records show no significant Younger Dryas $\delta^{15}\text{N}$ decrease (Figure 6). The one point that decreases off Somali is very subtle and still higher than glacial values. The only point below 0 in the North has very high error bars. The SST reconstructions (Figure 3) also do not support a return to glacial conditions.

Lines 417-418: “Evidently, the vigorous upwelling during the Holocene climatic optimum was fed by inflow of IOCW from the south. . .”

It seems that some other external climate forcing outside of Arabian Sea monsoon dynamics must have caused this enhanced ventilation to overcome the intense upwelling and productivity that would normally cause a strong OMZ. This is an important point to make that could be expanded upon as well as some hypothesis for the mechanism(s) that could be responsible for it.

Lines 421-422: “Denitrification has continuously increased during the Holocene in almost the entire basin but focused in the northern Arabian Sea.”

This seems to be an over-generalization to me. All of the western regions (“West”, “Oman”, “Somali”) show a small decrease or no significant change from the Early to Late Holocene.

The selection of the 6 “West” cores in Figure 1b is awkward to me. I wonder if there are important differences between the southern two points near the equator, the western two points near the Red Sea, and the two points between the Somali and Oman upwelling sites since they are in different oceanographic regimes. For example, if ventilation from the Red Sea in response to sea level is a dominant forcing then maybe its

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major effect will be most evident in the two points near the Red Sea.

Another question: Where are the values from those two most southern points from the “West” in Figure 5b during 17-18kaBP?

Lines 445-460: Total organic carbon mass accumulation rates (TOC MAR)

I am not sure if the TOC MAR is a useful discussion here, especially since you have not separated it into the western, northern, and eastern regions. Since the standard deviation is so high and as you point out it is unclear whether it indicates enhanced production or preservation, I don't think it helps aid the interpretation of the sediment proxies and thus I am not sure the purpose of discussing its uncertainties.

Lines 461-473: Model results I find the discussion on the modeling results incomplete in terms of comparing it with your interpretation of the $\delta^{15}\text{N}$ and SST proxy records. The model predicts no change to export production in all regions – Isn't this incompatible with your interpretation of monsoon-driven changes to upwelling and organic matter production particularly with respect to the western and eastern basins throughout the sedimentary records (i.e. point (i) in the last sentence of the abstract)?

Does the model simulate a realistic Arabian Sea monsoon system and OMZ in the modern ocean? What causes the decelerated circulation in the model: Is it a large-scale effect relating to a slowdown of the high-latitude subduction water masses or changes to more local currents?

Discussion and Conclusions: It is not clear to me what the new findings are compared to all of the conclusions from previous literature that you reference. Does your integrative view comparing all of the Arabian Sea regions reveal new findings/mechanisms/controls on the OMZ and denitrification that has not been discussed before? They should be specifically pointed out and emphasized more throughout the Discussion section and in the Conclusions.

Minor Comments

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lines 72-73: Schmittner and Somes, 2016 reference The Schmittner-Somes team has a more recent, realistic model study on the glacial nitrogen cycle that would make a more appropriate citation here than that 2016 paper.

Somes CJ, Schmittner A, Muglia J and Oschlies A (2017) A Three-Dimensional Model of the Marine Nitrogen Cycle during the Last Glacial Maximum Constrained by Sedimentary Isotopes. *Front. Mar. Sci.* 4:108. doi: 10.3389/fmars.2017.00108

Lines 85-86: "... smooth decrease of d15N induced by the delayed increase of benthic denitrification cause by sea level rise..."

N₂ fixation would be required to decrease d15N since benthic denitrification alone would slightly increase d15N because it slightly fractionates the isotopes. I suggest rephrasing to "smooth decrease of d15N from enhanced N₂ fixation stimulated by the delayed increase..."

Lines 107-108: "dissimilatory nitrate reduction to ammonium (DNRA)"

DNRA itself is not an oceanic N sink process because ammonium is a readily bioavailable N pool so this process should not be included here.

Line 164: ", respectively" – More readable sentence if moved after "Younger Dryas"

Line 345: "interglacial" – Do you mean "interstadial"?

Line 402: "prograde" – perhaps circulate or propagate is better

Lines 441-444: You mean that there is no OMZ in the SE, right? Then I recommend rephrasing to

"Today, the OMZ is absent in the SE due to a northward undercurrent..."

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