
Interactive comment on “Spatio-temporal variations of nitrogen isotopic records in the Arabian Sea” by S.-J. Kao et al.

S.-J. Kao et al.

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Received and published: 29 September 2014

Reply to Anonymous Referee #1

1) Abstract: should be revised, and specifically talking about the modern-day first, and then the downcore record and its implications.

Reply: Modified as suggested.

“Available reports including dissolved oxygen, $\delta^{15}\text{N}$ of nitrate ($\delta^{15}\text{N}_{\text{NO}_3}$), as well as $\delta^{15}\text{N}$ of total nitrogen ($\delta^{15}\text{N}_{\text{bulk}}$) for trap material and surface/downcore sediments in the Arabian Sea (AS) were synthesized to explore its past nitrogen dynamics. According to $25 \mu\text{mol kg}^{-1}$ dissolved oxygen isopleth at 150 m deep, we classified all reported data into northern and southern groups. By using $\delta^{15}\text{N}_{\text{bulk}}$ of surface sediments, we obtained geographically distinctive bottom-depth effects for northern and southern AS. After eliminating the bias caused by bottom depth, the modern day sedimentary $\delta^{15}\text{N}_{\text{bulk}}$ values largely reflect the $\delta^{15}\text{N}_{\text{NO}_3}$ supply from the bottom of the euphotic zone. Additions to documentation, nitrogen and carbon contents versus their isotopic compositions for past 35 ka in a sediment core (SK177/11) collected from the southeastern part of the AS were measured for comparison. We found a one-step increase in $\delta^{15}\text{N}_{\text{bulk}}$ starting at the deglaciation with a corresponding decrease in $\delta^{13}\text{C}_{\text{TOC}}$ similar to reports elsewhere revealing a global coherence. By synthesizing and re-analyzing all reported down core $\delta^{15}\text{N}_{\text{bulk}}$ we derived bottom-depth correction factors at different climate stages respectively for northern and southern AS. The diffusive $\delta^{15}\text{N}_{\text{bulk}}$ values in compiled cores became confined after bias correction revealing a more consistent pattern except recent 6 ka. Such high similarity to the global temporal pattern indicates that the nitrogen cycle in the entire AS had

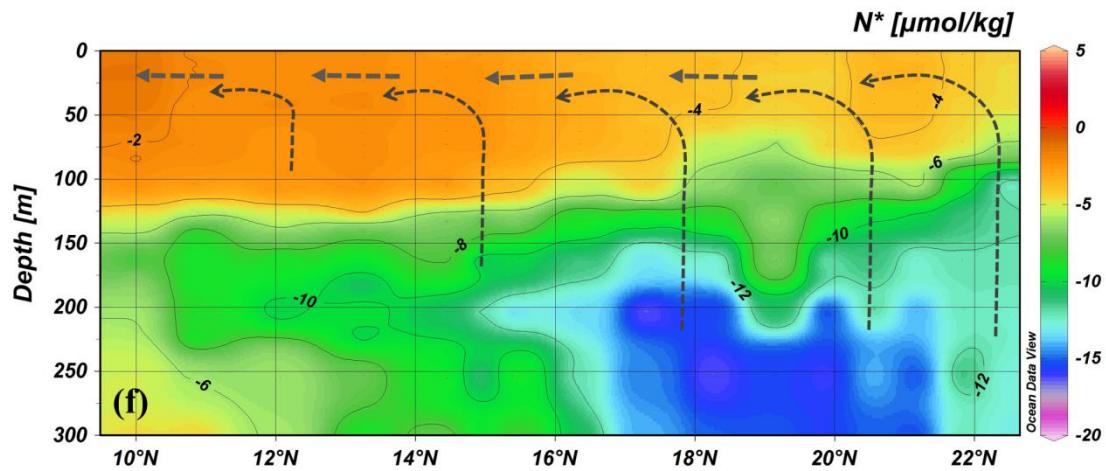
responded to open-ocean changes until 6 ka BP. Since 6 ka BP, further enhanced denitrification (i.e., increase in $\delta^{15}\text{N}_{\text{bulk}}$) in the northern AS had occurred and likely driven by monsoon; while in the southern AS we observed a synchronous reduction in $\delta^{15}\text{N}_{\text{bulk}}$ implying that nitrogen fixation was promoted correspondingly as the intensification of local denitrification at the northern AS basin.”

2) *Introduction: The second paragraph deals with how the $\delta^{15}\text{N}$ signal might be altered. It is an important paragraph, though, I would put it at the beginning of the "results" paragraph, somewhere in paragraph 4.2 or 5.1, where it is useful to understand how the $\delta^{15}\text{N}$ signal might be altered. In the introduction it just alters the flow of the manuscript.*

Reply: Thanks for this suggestion. We agree with the reviewer. This part had been moved to the second graph in Section 5.1.

3) *Study area: A rapid sketch explaining how intermediate-depth water mass ventilate the AS would be useful to figure out how the OMZ erodes from below, especially since the core depth might be sensitive to that as well (see e.g. the Picchevin paper). For example, it is unclear what is meant by in the last sentence of the paragraph. Arrows on the transects, and their expansion, should help envision what you write.*

Reply: We added a new N* transect specifically for the upper 300 m (Fig. 1f), in which arrows were added to reveal the flow direction and the reference line of N* of -4 mentioned in text can be seen clearly.



4) *Material and methods: Second sentence: why pushing this? It is a useless sentence that alters the flow of the text - and it's probably wrong (check core MD77-191 in Bassinot et al., 2012, Climate of the Past).*

Reply: The sentence is only correct in terms of documenting $\delta^{15}\text{N}$. The sentence is now “Although the Core MD77-191 locates further south in the AS (Bassinot et al., 2012), SK-177/11 is so far the most southeastern core with $\delta^{15}\text{N}$ record to refer.” This sentence is kept to emphasize we add one more core at the southern boundary (i.e., more open-ocean type) into the dataset.

5) *Results: In paragraph 4.2, you can't say the $\delta^{15}\text{N}$ excursion at 13 ka occurs in the Younger Dryas chronozone given the uncertainties associated with your age model.*

Reply: Reviewer is right under considering the age uncertainties. The sentence is now: “The $\delta^{15}\text{N}$ values increased rapidly since ~19 ka BP, with a peak at ~15 ka BP and then started to decrease gradually toward modern day except the low $\delta^{15}\text{N}$ excursion at around 14 ka BP.”

6) Also, in the C and N increase seen in the first meter of sediments, could it be the signature of syn-sedimentary degradation of organic matter?

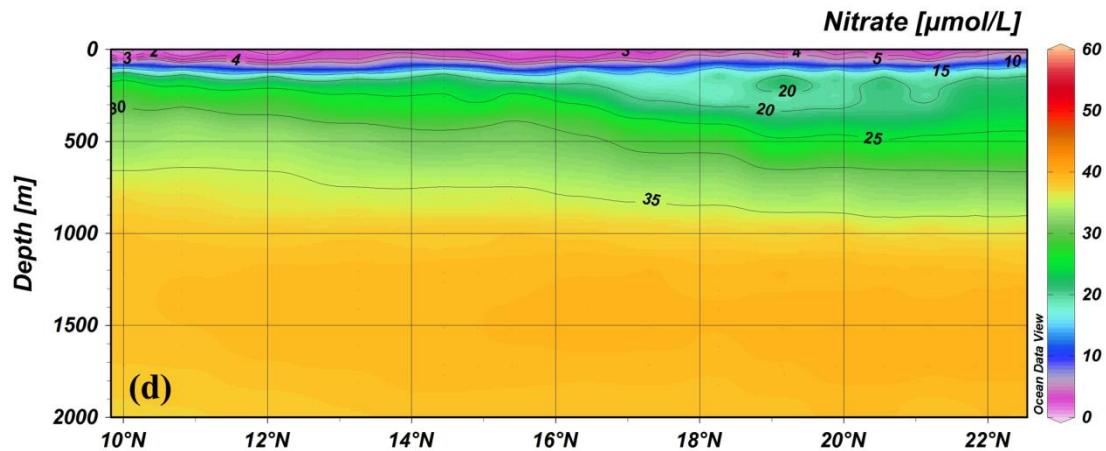
Reply: We added more descriptions to the changing patterns of TOC and TN in the first meter. We also add the temporal variation of C/N into Figure 3 for discussion. In this version, syn-sedimentary degradation was addressed; however, increased sedimentation rate in Holocene should create higher preservation efficiency. Since $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ did not show concomitant variations with C/N in first meter, we believe the influence of organic degradation on isotope signal was insignificant, thus, no influence on our original story. According to this comment, we added more illustrations for the patterns in first meter in Results.

7) Discussion: Paragraph 5.1: please clarify the sentence "This implies that the degree of addition processes, most likely the N_2 -fixation, varied in concert with the intensity of denitrification underneath." by mentioning the key results inferred in Deutsch et al. (2007) cited just after. It would prepare the reader to get the mechanism presented in paragraph 5.4.

Reply: Thanks for this comment. We elaborated more about the spatial coupling between N_2 -fixation and denitrification following the mentioned sentence.

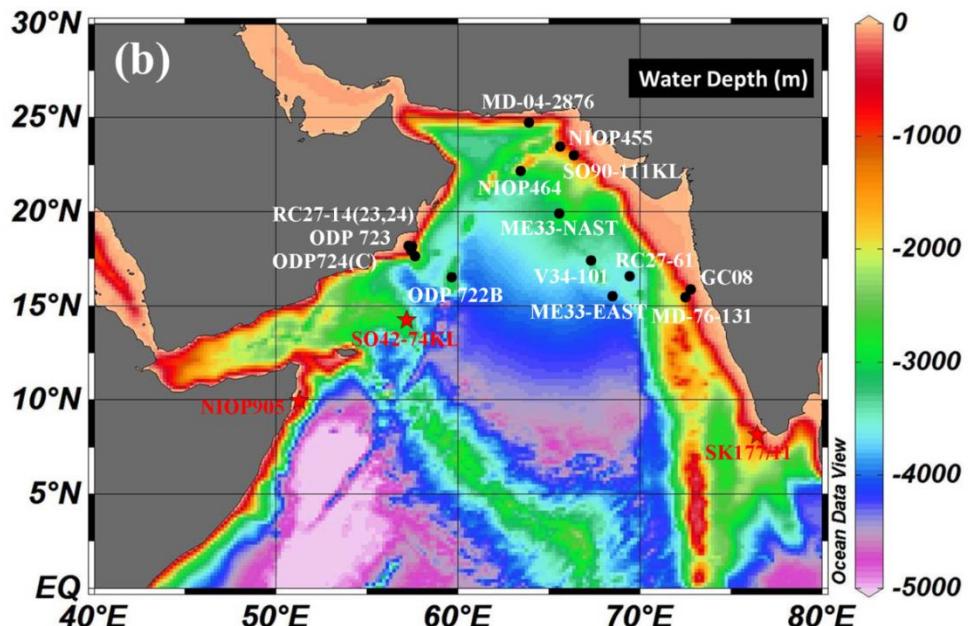
8) Figure 1: why not expanding the panels b and c to the latitude where the core was collected?

Reply: We wish to have the data also, unfortunately, no available hydrography data extending to 8 degree. Nevertheless, we added nitrate transect (Fig. 1d) for background introduction.



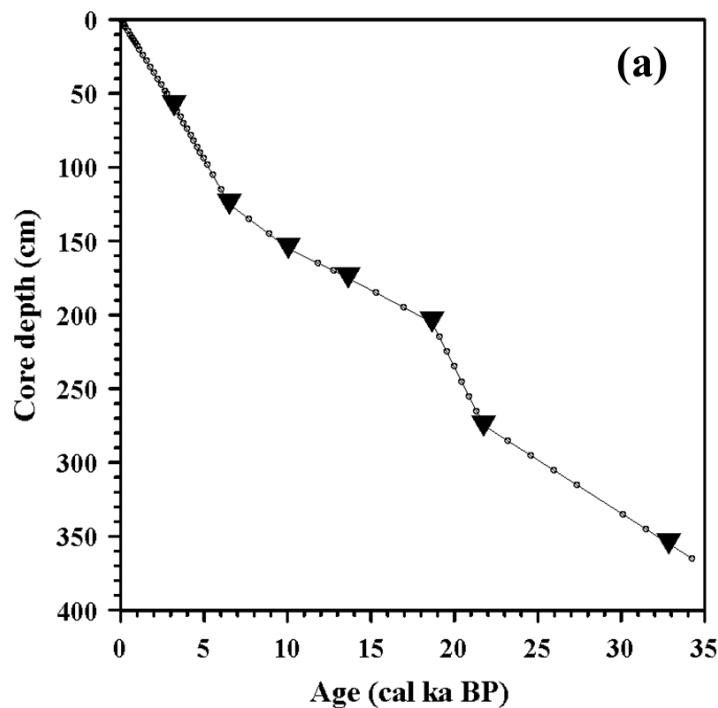
9) You should try also to plot at depth the cores you deal with later, with appropriate markers and colors, so that an easy comparison will help the reader checking where the downcode records come from. It's really uneasy to figure out where the cores mentioned are given the figure caption.

Reply: We added a bathymetric map superimposed by core locations as Fig. 1b.



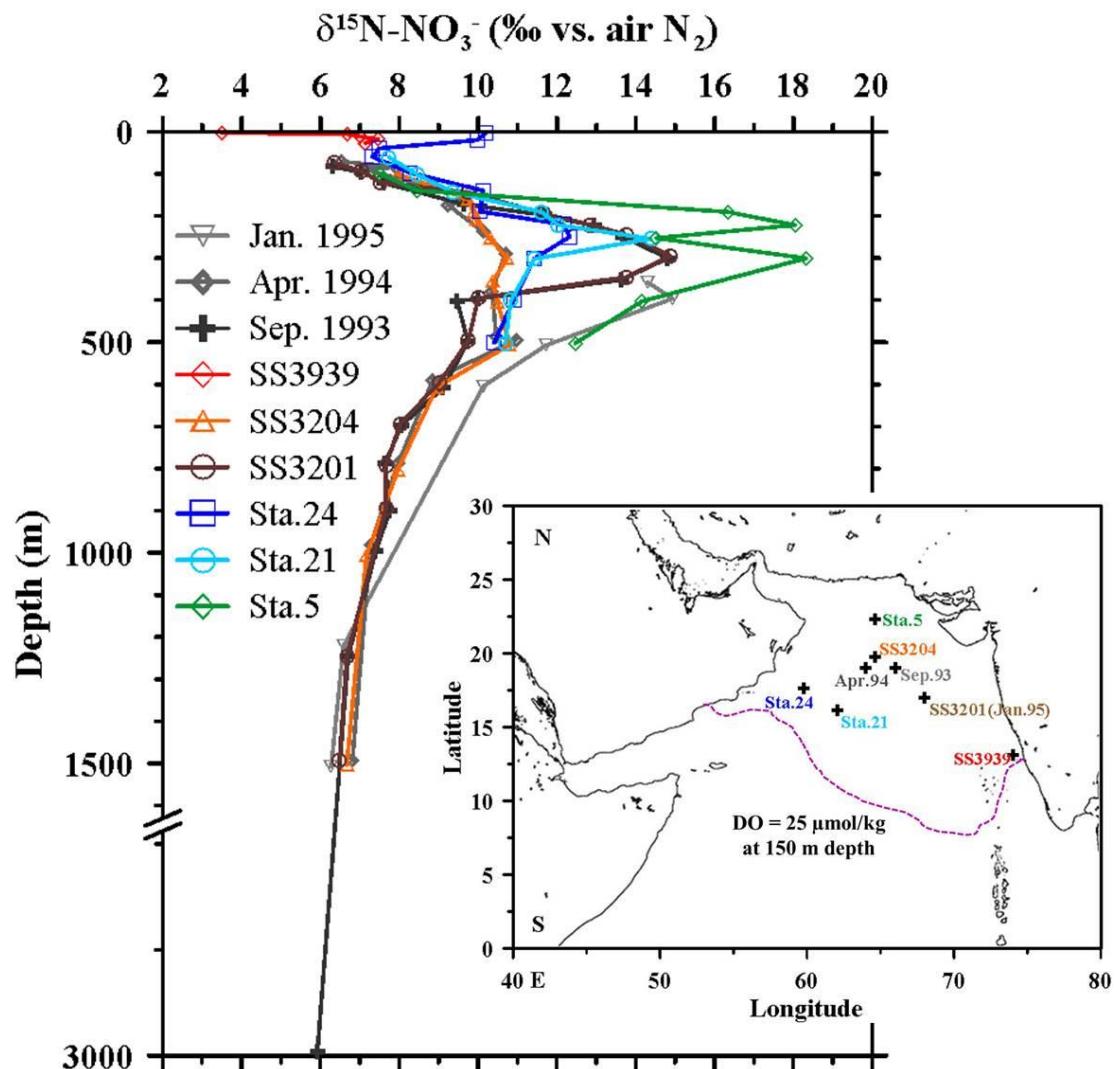
10) Figure 2: one radiocarbon date seems to be missing on panel A. Please provide the calibration equation used.

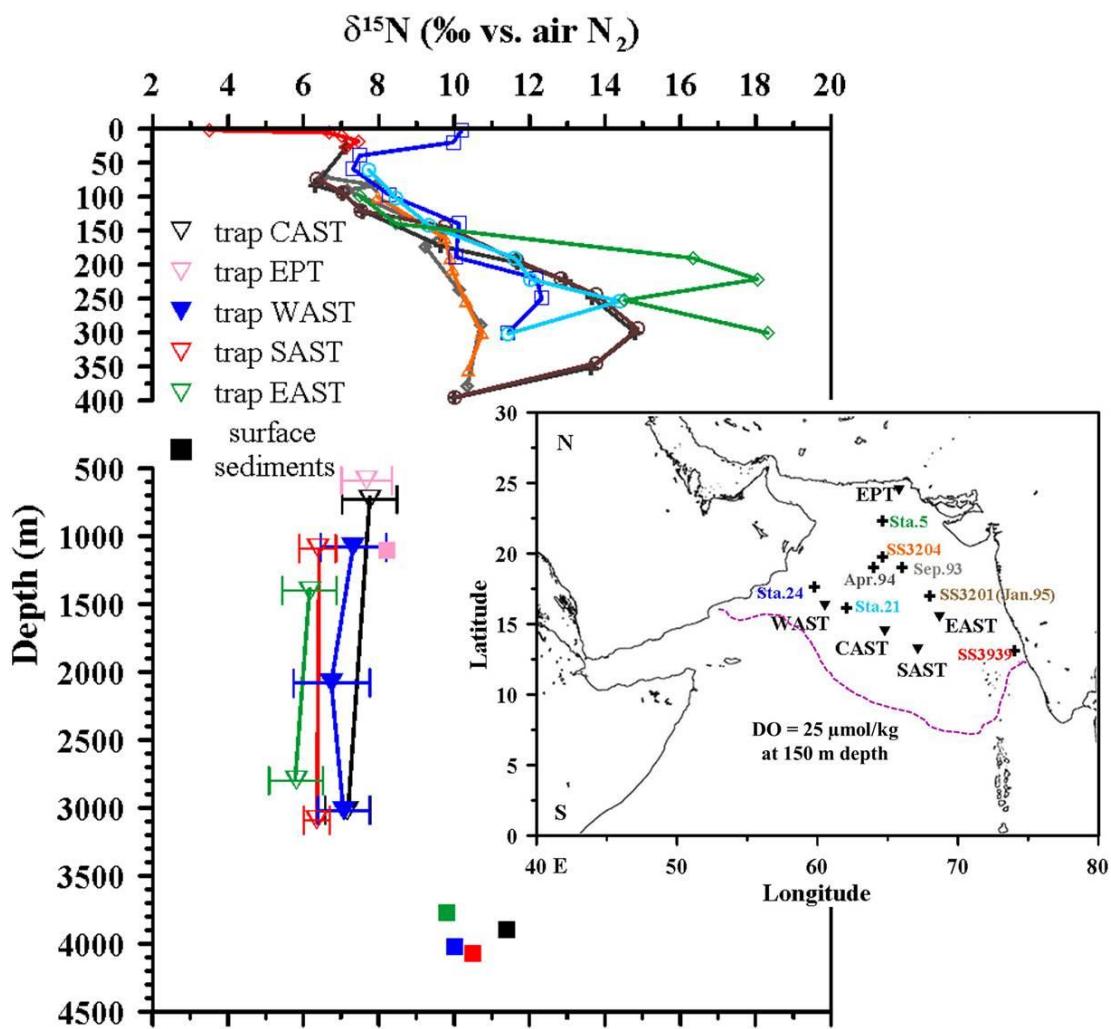
Reply: The missing radiocarbon date has been added into Fig.2a. The information about calibration can be referred to Table 1.



11) Figure 5: please enlarge the map and use colors on the map

Reply: Done. The new plots are shown below.





12) Other details:

-choose between ODZ and OMZ (OMZ is more used)

Reply: We choose ODZ.

-in general, there are many English mistakes. A native English speaker should get a read over the manuscript.

Reply: We have our manuscript corrected by a native speaker.

Reply to Anonymous Referee #2

1) Even the stratigraphy of core SK177/11 is well constrained by 7 AMS ^{14}C , the $\delta^{15}N$ record is very different from the two other records from the southern part of the Arabian Sea (Fig. 8a; cores NIOP 905 and SO42-74KL). Is this difference only the result of an age offset due to different methods of chronology or does it reflect a peculiar dynamics off SW India?

Reply: The foraminifera are absent in our core, thus, we have our dates by organic carbon. This may introduce age uncertainties. Due to insufficiently high time resolution, we cannot prove whether the differences during transition period were caused by peculiar dynamics off SW India. Since the geographic and glacial-interglacial differences in bottom-depth effect is one of the key points of this paper, thus, we focus on the comparison between Holocene and glacial period when water depth and climate condition were relatively stable.

2) You cannot say that the $\delta^{15}N$ low at 13 ka occurs during the YD event which is younger (Fig. 3 and text page 8720, lines 15). Anyway, this low should be in phase with those centered during the YD of cores NIOP 905 and SO42-74KL (Fig. 8a). Please clarify.

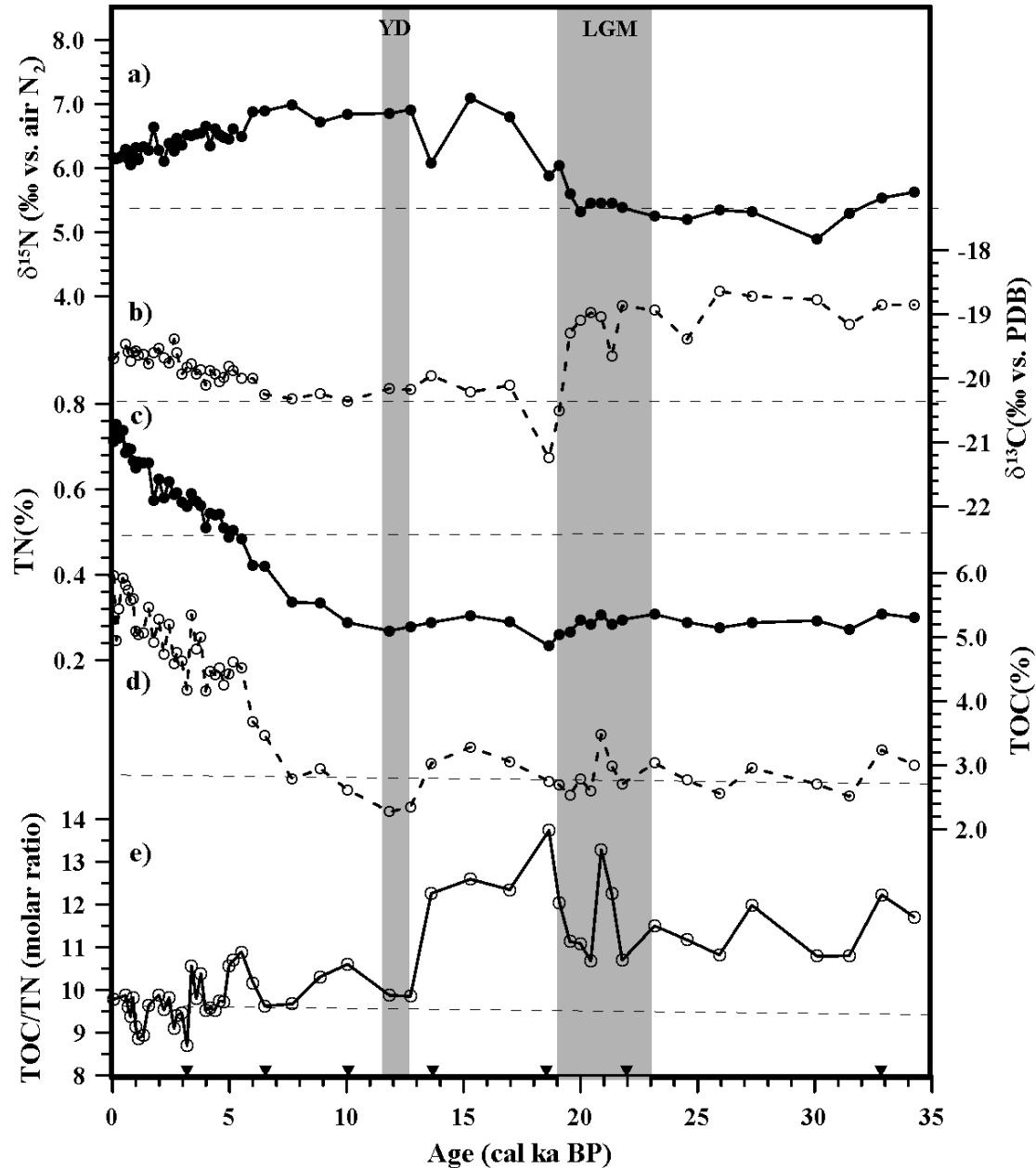
Reply: We do not mention YD in this version. And of course, this is the main reason we exclude the transition period in our comparison.

3) More details concerning especially the oceanography and climatology (nutrients, production, water masses, and currents) of this region would be then helpful to better constrain the dynamics of the region. For instance, are the $\delta^{15}N$ variations just a matter of denitrification versus nitrogen fixation? Maps showing nitrate dynamics off SW India (concentration, utilization) would be helpful.

Reply: We added nitrate and shallow water N* transects as Fig. 1f.

4) C/N ratio and $\delta^{13}\text{C}_{\text{org}}$ (Fig 3 and 4) are clear indications that organic matter is pristine autochthonous (planktonic) material irrespectively of the climatic period. However, I would suggest the authors to plot the C/N profiles in Fig. 3.

Reply: We added the temporal variation of C/N into Figure 3. We also elaborate more about the temporal variation and the scatter plot (Fig. 4) according to the comment by Reviewer #1.



5) Moreover, the authors noticed that “An abrupt decrease in $\delta^{13}\text{C}$ was observed in concert with the dramatic increase in $\delta^{15}\text{N}_{\text{bulk}}$ at the start of deglaciation”, and that “A sharp decrease of $\delta^{13}\text{C}_{\text{TOC}}$ in SK177/11 at the start of deglaciation (Fig. 3b) may indicate a rapid change of physical circulation had occurred in characteristics of the intermediate water flowing into the AS”. They should also notice that the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}_{\text{org}}$ profiles mirror each other. It might be important and interesting to discuss these observations in more details.

Reply: This suggestion is well taken. We rewrote this paragraph and added more illustrations to associated paragraphs. The latter one is now “In fact, the AAIW cannot penetrate over 5°N and further north in present day and even during the late Holocene (You, 1998; Pichevin et al., 2007). Since the $\delta^{13}\text{C}$ of autochthonous particulate organic carbon is negatively correlated to $[\text{CO}_2(\text{aq})]$ in euphotic zone (Rau et al., 1991), the sharp decrease of $\delta^{13}\text{C}_{\text{TOC}}$ in SK177/11 at the start of deglaciation (Fig. 3b) may indicate the timing of a rapid accumulation of dissolved inorganic carbon driven by the shrinking of oxygenated intermediate water (Pichevin et al., 2007) or enhanced monsoon-driven upwelling (Ganeshram et al., 2000); both facilitate the promotion of denitrification. Nevertheless, the mirror image between $\delta^{15}\text{N}$ and $\delta^{13}\text{C}_{\text{TOC}}$ profiles revealed their intimate relation, of which the variability was attributable to the change of physical processes “

6) What do the authors mean by a rapid change of physical circulation in characteristics of the intermediate water flowing into the AS?

Reply: See reply above. This sentence is not clear and had been expanded to a paragraph.

7) In the core of the ms, the way the authors made to remove the bias due to water depth is not clear. Please improve.

Reply: We added an equation to make this clearer. Correction factor = (bottom depth-100)*slope.

8) My last comment concerns the choice of the authors to reject in their compilation the record of Pichevin et al. (GBC, 2007) from the NE Arabian Sea (Kao et al., page 8725, lines 14-15), arguing that it might be influenced by terrigenous input. This assumption contradicts the interpretations of Pichevin et al (2007). The authors should integrate the record of Pichevin in their comparison.

Reply: Thanks for reviewer's correction. We have considered the MD-04-2876 in this study for comparison. We revised the table 2 as well accordingly. Since Pichevin's core was taken from shallower water depth, we suspected inorganic nitrogen (clay-fixed) might have influence to deviate their $\delta^{15}\text{N}$ values from that of other cores in northern basin. In this version, we put this core into estimation and follow their explanation for the relatively low values.

9) Minor comments : Refs : Mollenhauer et al. instead of Mullenhauer et al.

Reply: Corrected.

10) Fig. 8a: I would suggest the authors to separate in two different graphs the 3 cores from the southern part of the Arabian Sea from the northern cores (including Pichevin's core). The figure would be then more readable.

Reply: We used a lighter color for cores from the northern AS. Pichevin's core is also included in this version.

