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Climate of the Past Discussions

Interactive comment on "Migrating subtropical front and Agulhas Return Current affect the southwestern Indian Ocean during the late Quaternary" *by* D. K. Naik et al.

D. K. Naik et al.

dineshkumarnaikdu@gmail.com

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Authors' Response to Referee's Comments:

Referee's Comment: The authors currently argue for a small effect of dissolution based on G. bulloides shells weight. This is a good approach but there is different reason why shell weight may not well represent dissolution [initial shell weight controlled by various parameters, optimal growth rate (de Villiers, 2004), or seawater carbonate ion (Barker and Elderfield, 2002)] and this need to be seriously assessed in the manuscript. Authors' Response: We agree with the reviewer and have discussed the possible dissolution and its effect on faunal assemblage as well as elemental ratio, in details in

the revised manuscript. The modified text is mentioned in a subsequent response to another similar comment below.

Referee's Comment: The other main critics is that some interpretations are either too far reached or even non-supported by the data. An example of this is lines 21 (p5534)-4(p5535) but I will try to list them in the detailed comments. Authors' Response: Both of these sentences and others, suggested by the reviewer have either been removed or modified.

Referee's Comment: Finally, since 2006 Neogloboquadrina pachyderma Dextral was renamed N. incompta (Darling et al., 2006) and the name must be changed in the entire manuscript. Authors' Response: The name has been changed throughout the manuscript, as suggested by the reviewer.

Referee's Comment: Line 4 p 5522: replace 'has' by 'have' Authors' Response: Replaced, as suggested by the reviewer.

Referee's Comment: Line 9 p 5522: Ca is not a metallic element, the notation trace metal ratio is not strictly speaking correct and I would recommend using trace element ratio. Trace metal/Ca ratio is sometime used. Authors' Response: Modified as suggested by the reviewer.

Referee's Comment: Line 6 p 5523: replace 'early' by 'earlier'. Authors' Response: Replaced, as suggested by the reviewer.

Referee's Comment: Line 19 p 5524: The link between high productivity and upwelling is not only true for the Indian ocean. Authors' Response: The sentence has been modified

Referee's Comment: Paragraph 2 the study area: this paragraph is not well organized and therefore a bit confusing. A description of the currents from Nord to South (following the flow) for example would be easier. The details on the northern part of the region (ITF, Bay of Bengal, SEC) are not necessary here. Authors' Response: The details of

the northern part of the region have been removed and the rest of the description has been modified to make it simple. The revised text is given below.

The study area lies in the southwestern part of the Indian Ocean, with the westward flowing SEC as it northern boundary. The Madagascar bifurcates the westward flowing SEC into the Mozambique Channel and the East Madagascar Current (EMC). The African subcontinent deflects the SEC, pole-ward. The pole-ward deflected SEC, the Mozambique Channel and the East Madagascar Current (EMC) join together and flow further south as the Agulhas Current (Schott et al., 2009). The Agulhas Current frequently sheds rings as a result of retroflection (Schouten et al., 2000). These rings carry warm and salty Indian Ocean water into the South Atlantic (de Ruijter et al., 1999). The Agulhas Current transports $\sim$70 Sv of water, with contributions of 18 Sv and 20 Sv from the Mozambique Channel and the East Madagascar Current, respectively (Donohue and Toole, 2003). A substantial part of the AC retroflects and flows as ARC which joins the eastward-flowing Antarctic Circumpolar Current (ACC) and then completes the loop by flowing equator-ward as the West Australian Current (Read and Pollard, 1993; de Ruijter et al, 2005). The core was collected from the ARR and falls in the path of ARC in the southwestern Indian Ocean which is characterized by a subtropical anticyclonic gyre (Stramma and Lutjeharms 1997). The region around the core is marked by year-round strong upwelling due to interaction between EMC, Madagascar Ridge and local wind (Tomczak and Godfrey, 1994; Quartly et al., 2006; Poulton et al., 2009) as well as the factors associated with the Antarctic Circumpolar productivity belt (Ito et al., 2005). The southwestern Indian Ocean receives surface waters from the subtropical gyre and subtropical current, which originate from the South Indian Ocean Current that flows north of the Circumpolar Current (Tomczak and Godfrey, 2003). Tritium data show that the Indonesian Throughflow contributes the large part of the Indian Ocean surface water north of 40°S and down to the thermocline (Fine, 1985). The Subtropical Front (STF) located at $\sim$40°S in the central South Indian Ocean separates the warmer and saltier water of the subtropics from the cold, fresh, nutrient-rich subantarctic water (Stramma, 1992). The annual average sea surface temperature (SST) near

the core location is 16.5°C while the salinity (SSS) is 35.3. The minimum (14.2°C) and maximum (18.9°C) SST at the core location is reported during austral winter and summer seasons, respectively. The SST during other two seasons, i.e. spring (17.6°C) and fall (16.2°C), differs by $\sim$1.5°C (Locarnini et al., 2010). As compared to SST, small change (0.4 su) is observed in the surface seawater salinity, with the maximum SSS (35.4) reported during austral summer (Antonov et al., 2010).

Referee's Comment: Lines 9-14 p 5526: Use only one decimal. Where do these number come from? World Ocean Atlas? If so, then add references. Authors' Response: Modified as suggested by the reviewer. The references have also been added. Please see the modified text above.

Referee's Comment: Lines 16-18 p 5526 suggestion for modification: "The top 1.2m section of a gravity core (SK 200/17, hereafter referred to as SWIOC) collected from 39.03_S latitude and 44.97 E longitude, at a water depth of 4022m was sampled every 1 cm." Authors' Response: Modified as suggested by the reviewer.

Referee's Comment: Line 26 p 5526: replace 'dried sample was' by 'dried samples were' Authors' Response: Modified as suggested by the reviewer.

Referee's Comment: Line 3 p 5527: replace 'The plus 63 _m fraction was then transferred in to small beakers for drying. The dried > 63 _m fraction was weighed and stored in plastic vials. The dried > 63 _m fraction was dry sieved using a 150 _m sieve. The > 150 _m fraction was used for picking planktic foraminifera' by 'The fraction larger than 63 _m was then transferred in to small beakers for drying, then weighed and stored in plastic vials. The samples were dry sieved using a 150 _m sieve and used for picking planktic foraminifera' Authors' Response: Modified as suggested by the reviewer.

Referee's Comment: Line 7 p 5527: what is 'coning and quartering? Splitting? Authors' Response: Yes, the phrase has been modified.

Referee's Comment: Line 6 p 5528:Mashiotta gives 1.1_C as error on this calibration, where does the 0.8 _C come from? Authors' Response: The error cited here is the error associated with Eq. 5 of Mashiotta et al., 1999, which includes both the culture as well as core-top samples and was used to convert Mg/Ca into temperature in this study.

Referee's Comment: Line 13 p 5528 add 'of' between d18O and G. bulloides. Authors' Response: Added.

Referee's Comment: Line 20-21 p 5528: The writing is not very elegant, please rephrase. Authors' Response: The line has been rephrased, as suggested by the reviewer.

Referee's Comment: Pages 5529 and 5530: This long description of the figure is very boring to read. Please synthesize, extract the main information and make a lot shorter. Authors' Response: The results section has been shortened to include only the major changes, which has been discussed later.

Referee's Comment: Lines 3-23 p 5531: I found this whole paragraph very confusing and hard to understand. Neither the Be and Hutson nor the Fraile references show the numbers cited here. Dissolution should be discussed here as it is likely to produce the difference in preservation between the 2 species. See Berger 1970 for the difference resistance to dissolution between the 2 species. Authors' Response: The numbers cited here are from the contour interval limits mentioned in the cited references. We agree with the reviewer that the role of dissolution should be discussed in detail. Accordingly, we have added the following paragraph.

"The dissolution of foraminiferal tests can also cause difference in species abundance between sediments and plankton tows/sediment traps. As the susceptibility of foraminiferal species to dissolution is different, the dissolution is also likely to produce the difference in preservation between G. bulloides and N. incompta. Berger (1975) placed G. bulloides amongst one of the most dissolution susceptible species,

suggesting preferential dissolution of G. bulloides as compared to N. incompta. The modern carbonate saturation horizon in all three sectors of the Southern Ocean lies at $\sim$3400 m water depth (Howard and Prell, 1994). Increased carbonate dissolution during glacial periods is also reported from the Indian sector of the southern Ocean. The cores recovered from the Cape Basin reveal that the carbonate saturation horizon during MIS 2 and 4 was $\sim$600 m shallower than present (Howard and Prell, 1994). The shallower carbonate dissolution horizon during MIS2 and 4, may cause increased dissolution during these intervals. Both the planktic foraminiferal number as well as the fraction >63 μm during MIS 4, are however higher than that during MIS5 and same as that during MIS3 as well as MIS1, suggesting otherwise. An abrupt decrease in both the planktic foraminiferal number as well as the fraction >63 μm is obvious during MIS2/1 transition which clearly suggests poor preservation. The abrupt drop in G. bulloides relative abundance during early MIS2, is however synchronous with the peak in planktic foraminiferal number as well as the fraction >63 μm. The subsequent peak in G. bulloides relative abundance also interestingly coincides with poor carbonate preservation as inferred from decreasing planktic foraminiferal number as well as the fraction >63 μm. The anti-correlation between G. bulloides relative abundance and planktic foraminiferal number as well as the fraction >63 μm, suggests that carbonate preservation might not have significantly altered the planktic foraminiferal relative abundance at this location. As the core site already lies below carbonate saturation horizon, any subsequent shallowing of carbonate saturation horizon during glacial period may not produce a large change in differential preservation of planktic foraminiferal species. The possible differential diagenetic alteration of planktic foraminiferal assemblages, during glacial-interglacial period cannot, however be completely ruled out."

Referee's Comment: Line 28 p 5531: 0.1‰ is within the error and therefore not significant. Authors' Response: The line has been removed.

Referee's Comment: Lines 1-3 p 5533: The effect of dissolution should be carefully examined and the effect on foraminifera abundances and geochemistry critically as-

sessed. Authors' Response: We agree with the referee and thus have modified the text to include the following at appropriate places.

Based on multinet and core top samples, Friedrich et al (2012) however concluded that dissolution does not affect Mg/Ca of G. bulloides. Mekik et al (2007) also suggested that G. bulloides Mg/Ca is mainly controlled by calcification temperature and is not susceptible to carbonate dissolution. Brown and Elderfield (1996) also suggested that the effect of dissolution on Mg/Ca is species specific depending on test wall structure and further that it may not always alter the original Mg/Ca ratio. Contrary to these findings, Regenberg et al (2006) reported a marked decrease in Mg/Ca ratio below the carbonate saturation horizon in several planktic foraminifera.

The non-correspondence between shell weight and Mg/Ca, however is not a robust indicator of well preserved Mg/Ca signal. The shell weight may not well represent dissolution as the initial shell weight is controlled by various parameters, including optimal growth rate (de Villiers, 2004), and seawater carbonate ion concentration (Barker and Elderfield, 2002). A better approach should be like the one followed by Rosenthal and Lohman (2002), wherein they assessed the effect of dissolution on Mg/Ca of Globigerinoides ruber and G. sacculifer by introducing a correction factor based on the shell weight. The development of such a correction factor for G. bulloidesÂň, however is beyond the scope of this work.

Referee's Comment: Line 7 p 5533: The high abundance in G. bulloides – and therefore high productivity is observed AT THE END of the cold period. This shortcut of high productivity during old period is found throughout the manuscript and should be corrected. The description of the curves and interpretations must be precise. Authors' Response: The text has been modified to include other parameters which support high productivity.

Referee's Comment: Lines 19 p 5533 to line 4 p 5534: This paragraph is a repetition of lines 10-29 p 5524, shorten one of the two paragraph to avoid repetition. Authors'

Response: The text has been deleted to avoid repetition.

Referee's Comment: Lines 4 p 5534: change "A difference in relative abundance of N. pachyderma Dextral and G. bulloides is" for "The lag between N. incompta and G. bulloides peak in abundance is" Authors' Response: Replaced as suggested by the reviewer.

Referee's Comment: Lines 7 to 9 p 5534 : This is a very far reached statement, it needs to be justified or deleted. Authors' Response: The sentence has been deleted.

Referee's Comment: Lines 12-15 p 5534: Typical shortcut of this paper, The observation describe here is correct for MIS 4 but a lot less for MIS 2. Authors' Response: We have modified the sentence to address referee's concern and added the synchronous increase in fraction >63 μm as a supporting evidence for high productivity.

Referee's Comment: 16-17 p 5534: The peak in abundance at the picnocline is observed for vertical profile but not necessarily in absolute abundance. This cannot be simply used as it is currently presented. The explanation of the seasonality effect presented a few lines after is much more plausible. Authors' Response: We do not argue that the peak abundance at pycnocline has anything to do with its absolute abundance. Rather, we've listed the factors which affect NI abundance and how the pycnocline is related to thermocline and high productivity, based on previous studies documenting modern distribution of NI. We further apply this information to infer possible water column structure during the glacial periods by using changes in NI and GB abundance.

Referee's Comment: Line 22 p 5534 to line 8 p 5535 appear largely unsupported. The authors should carefully examine their signals, in MIS 3 incompta abundance stays high but the Mg/Ca in G. bulloides decrease. A lot of processes (thermocline, dust, ice-rafted debris) are cited without clear logic. The authors should definitively look into the seasonality of the 2 species. Authors' Response: Thanks a lot for the suggestion. Yes, we have mentioned that a possible strong seasonality might be responsible for the synchronous increase of both GB and NI. The section discussing possible role of dust

and ice-drafted debris has been removed, as suggested by the reviewer.

Referee's Comment: Lines 10-12 p 5536: show a temperature scale on figure 4. Authors' Response: The figure 4 has been modified in view of comment by Referee 2.

Referee's Comment: Lines 17-18 p 5536: Seasonality may also explain the difference between radiolarian and foram-based temperature. Authors' Response: A sentence suggesting the same has been added.

Referee's Comment: Line 24 p 5536: cite for example Duplessy et al., 1991. Authors' Response: The reference has been added.

Referee's Comment: Line 24 p 5537 to line 9 p 5538: a figure comparing the data with the results of Martinez-Mendez is necessary to evaluate this paragraph. Authors' Response: As suggested by the referee, a figure has been added comparing the data with the results of Martinez-Mendez and the text has also been modified.

Referee's Comment: Line 18-19 p 5538: 'poor preservation of the test', Yes! This should be discussed and foraminifera abundance and fraction >63um can be used. Authors' Response: Please see the response to a previous comment.

Referee's Comment: Figure 1: The location of core SK200/17 is marked by the RED square, right? Authors' Response: The sentence has been revised.

Interactive comment on Clim. Past Discuss., 9, 5521, 2013.