**Climate
of the Past
Discussions**

Interactive comment on "Paleo Agulhas rings enter the subtropical gyre during the penultimate deglaciation" *by* P. Scussolini and E. van Sebille

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We thank the reviewer for his in-depth considerations, that denote careful consideration of the dataset we present within our work, as well as extensive familiarity with the sedimentological and micropaleontological aspects raised. We also acknowledge the kind words and motivated suggestions that are put forward for our data set. We intend to respond to the points raised, thereby expanding on the reasons that led us to suggest "ruling out concerns about excessive bioturbation" (line 2, page 2103), in the hope to reinforce our interpretation of the variability peak in the light of the very interesting objections outlined.

In regard to the first point raised, modern ocean observations, replicated by the model we used (Fig. 2 in the manuscript) led us to estimate that the number of specimens

analysed can sufficiently capture the variability of rings and other leakage features at the core site. Besides the occurrence of a ring over the core, which is likely to influence the foraminifera stock integrated by the core for more than 1 month per year, in present-day conditions, a high number of secondary events, that we interpret as "ring flanks", characterize the 20-year series. This type of disturbance has a higher frequency, and should be captured by a number of observations comprised between 18 and 30. Unfortunately we cannot access the work of Quinn et al. (2012, AGU fall meeting) mentioned by the reviewer. However, concerning how many individual foraminifera are enough, G. truncatulinoides has a low 'turnover time' – a complete renewal of the population – estimated at the central Walvis Ridge of 25 ± 7 days for the dextral form and 17 ± 5 days for the sinistral (Lončarić, 2005). This long lifespan (close to a month) and low concentration means that less variability in the data-set should be seen compared to a surface dwelling bloom species ($\sim$5-7day lifespan), and the number of individuals required to representatively reflect hydrographic conditions is therefore lower.

Regarding the second point, that size fractions determines the oxygen isotope composition, LeGrande et al. (2004, Paleoceanography), whilst depicting the isotope signal of G. truncatulinoides as very sensitive to changes in hydrographic conditions, do not present data on the size fractions we worked with, but report them from Lohmann (1995). This important work indeed shows a dependence of the δ18O to size. But size dependent oxygen isotope differences for G.truncatulinoides are not consistent between studies, for instance Elderfield et al. (2002) and Friedrich et al. (2012) present only a modest enrichment in the isotopic composition with size ($\sim$0.10-0.20 ‰ per size fraction). On the other hand Birch et al. (2013), and unpublished work (B. Metcalfe, pers. comm.) have a more striking enrichment between 'small' and 'large' size fractions ($\sim$1.50 ‰, likely a result of the local hydrography. As our data is from quite different oceanographic settings of that of LeGrande et al. (2004), we do not see the reason to hypothesize that a shift in size distribution of this species should have occurred across Termination (T) II, and how this should have eventually implied a change

in the variability, rather than a change in the average $\delta18O$

But most importantly, we intend to deal in detail with the third point of the review, i.e. the influence of sediment mixing through benthic interaction. Bioturbation is doubtlessly a problem that plagues every paleoceanographic study, even more so when the aim is to generate a record of variability across a period of shifting values, as we have set about in this project around T II, searching for the maximum in Agulhas leakage first revealed by Peeters et al. (2004). We refer to this in the manuscript, and we fully agree with the explanation that the referee has kindly provided of the phenomenon and of its bearing on our IFA. Through careful consideration of (unpresented) sedimentological details of this core we arrived at the aforementioned line regarding bioturbation (Line 2, page 2103) and therefore consider the role of the Agulhas leakage as a more relevant source of variability. We propose a number of arguments that when considered together we believe should make a convincing point in delimiting the role of bioturbation in our interpretation:

âĂć Sharpness of contact. The attached Figure 1 shows data from Scussolini and Peeters (in second review in Paleoceanography): the $\delta18O$ record of G. ruber white sensu lato (red curve) and of G. truncatulinoides sin. (blue curve, also reproduced in our manuscript). Error bars are the standard deviation of replicate samples. While for G. truncat the T II shift is more gradual, for G. ruber it occurs literally from one sample to the next, 2 cm apart. Even though the change in values is only 0.57 permil, the limited standard deviation of repeats strongly suggests the existence of an abrupt change between MIS 6 and MIS 5 values that is not compatible with strong bioturbation. Similar events in other parts of the record are: G. ruber at T I, both G. ruber and G. truncat at T IV and T V; G. truncat at T III and between MIS 7d and 7c. âĂć Differential T II timing. Bioturbation has been described as 'smearing' isotopic records (e.g., Berger and Wefer, 1996). The different timing or 'sensing' of TII for the two species is difficult to reconcile with a strong bioturbation, that should have moved specimen of both species around, in a non-differential fashion (we picked indeed the two species from the same

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fraction, whereas Bard [2001, Paleoceanography] suggests caution when dealing with very different fractions), thus smoothing both curves. âĂć 'Missing' bioturbation at other intervals. A variability peak should be observed around the shifts from MIS 5e to 5d, which in global stacks (e.g. LR04, Fig. 1 A) amounts to more than half the magnitude of that at T II. On the contrary, even taking into consideration that our age control on the end of MIS 5e is not very tight, variability is flat around minimum values from ~120 to ~105 ka, covering the period where bioturbation should have moved particles with very different signature across the sediment. âĂć Single specimen G. ruber. Unpublished G. ruber IFA on two samples from MIS 6 (168cm) and MIS 5 (136cm) (attached Fig. 2), though we have not included this in the manuscript. The clear shift in bulk $\delta18O$ of this species occurs between 154 and 156 cm, suggesting that the sample at 168 cm should, if anything, sense bioturbation more than that at 136 cm. We have on the contrary a corrected variance of 0.053 for the former and of 0.21 for the latter. Even though this evidence is only constituted of two samples, it does not resemble the strikingly regular pattern of variance of G. truncat. âĂć XRF Elemental Profiles. (Unpresented) XRF profiles for this core also point at a mild effect of mixing. Sharp variations in the abundance of, for instance, Ca and Sr are noticeable at ~175 cm, and at 140 cm for Ca, along the interval concerned in our study (attached Fig. 3). In those episodes noise is basically absent, unlike it would be expected if the core was significantly bioturbated. âĂć Core laminations. To visual inspection, even though it is not visible for the interval in question, core 64PE-174P13 appears laminated in many parts (e.g., Fig. 4), suggesting an ocean floor setting relatively undisturbed. This is to be expected given the oligotrophic character of the location (e.g., Loncaric et al., 2007), since low food supply anti-correlates with the thickness of sediment mixed layer, on a range of Atlantic cores by Trauth et al. (1997) (see also Smith and Rabouille, 2002). âĂć Variability of bulk measurements. Repeated bulk $\delta18O$ measurements of a number of shells should also reflect the variability inherent to a sample, with spread being higher at times of $\delta18O$ shift. We presented these results in Scussolini and Peeters (in review in Paleoceanography). We report in the

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attached Fig. 1 D the standard deviation of repeats, showing that while for G. truncat (blue) an increase of values at T II, as in T IV and T I, is noticeable, in agreement with what emerges from the T II IFA, we can not observe the same for surface-dwelling G. ruber (red), which we deem less susceptible to the influence of Agulhas leakage. Its variability is not higher during times of shift in δ18O, as would be expected in a core with prominent bioturbation. Average standard deviations are reported in the straight lines in the respective colors. âĂć Signature of rings. Now, considering the role of the rings in contributing an "outlier" signature to fossil forams, we question the suggestion of the reviewer that their effect in the record should be of stressing the MIS 6 to 5 shift of bulk values, and that they should skew the distribution to positive values. As we infer from the model and the observations, rings appearing at late MIS 6 should bring about forams that are lighter than the ambient ones, thus skewing the distribution to the negative side. Subsequently, according to the leakage hypothesis, during an intensified inter-ocean exchange in MIS 5, a modified background hydrography would make it difficult to distinguish, in the G. truncat signature, the light signature of rings from that of also lighter (warmer, less saline and dense) subtropical gyre waters. In other words, the contrast between Indian Ocean and Atlantic waters is diminished in interglacials. The two existing reconstructions of Agulhas leakage (Peeters et al. 2004; Martinez Mendez et al. 2010) do not allow determining with certainty the timing of the decrease its, and of course do not describe the nature of the waters withheld in the rings.

To conclude, we acknowledge the reviewer for commenting on our interpretation and raising concerns as to the bioturbation influence on the signal, because it makes clear that we have not provided sufficient argumentation in the our discussion, which therefore necessitates an additional section. In a further version of our manuscript we intend to illustrate some of the features of core 64PE-174P13 above reported, that are essential to give a clearer picture of why we deem the influence of bioturbation not critical to the interpretation that forms the core of our rationale.

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Additional references

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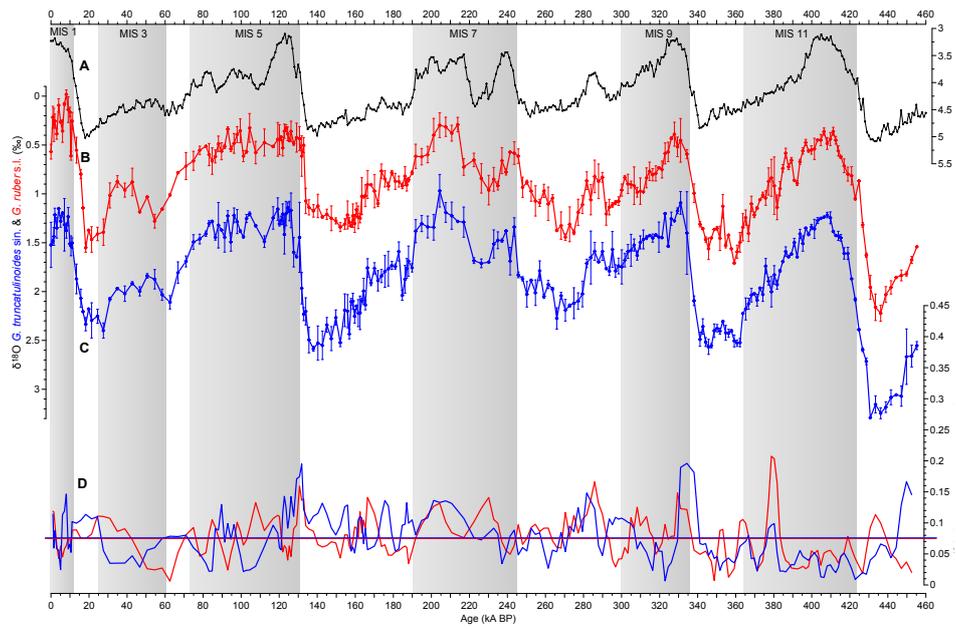
Fig. 1. Benthic LR04 stack (Lisiecki and Raymo, 2005) (δ18O); B) and C) Bulk δ18O of G. ruber sensu lato and G. truncatulinoides sin., respectively (error bars denote inter-measurement standard deviation); D)
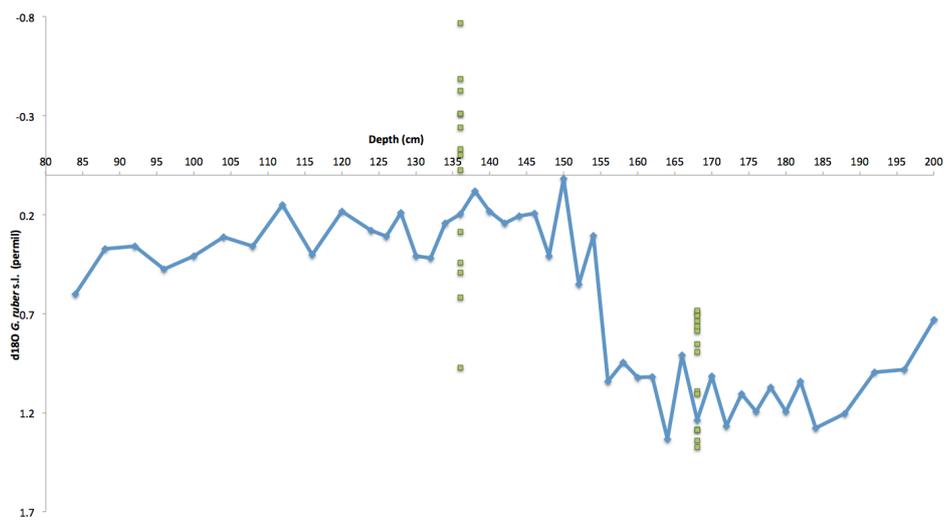
Fig. 2. Bulk δ18O of G. ruber s.l. (blue line), and relative IFA of a two samples (green squares).
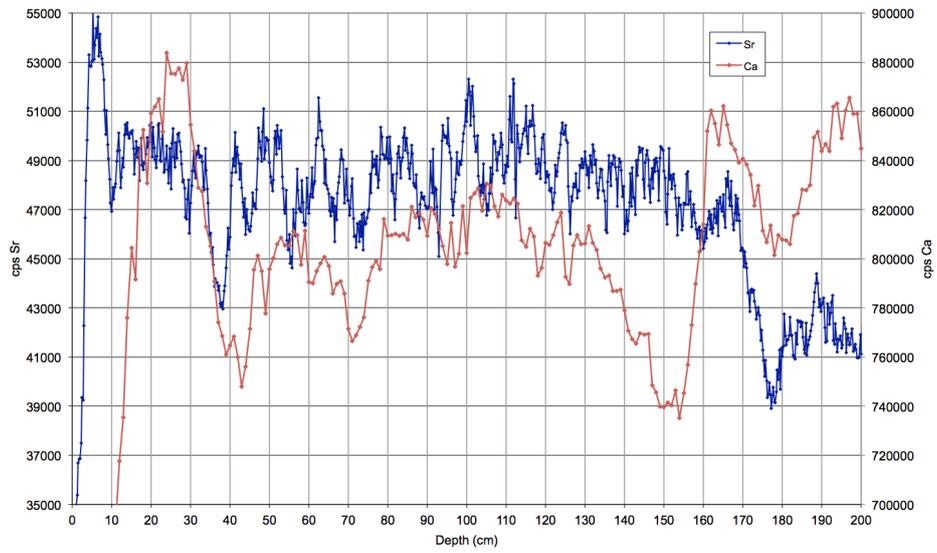
Fig. 3. XRF profiles of Ca (red) and Sr (blue).

Fig. 4. Photography of a section of core 64PE-174P13.