**Climate
of the Past**
Open Access

EGU

Discussions

Interactive comment on "Mediterranean Outflow Water variability during the Early Pleistocene climate transition" by Stefanie Kaboth et al.

Stefanie Kaboth et al.

S.Kaboth@uu.nl

Dear Editor,

Firstly, we would like to thank our two anonymous Referees for their careful handling of the manuscript as well as for the constructive comments and suggestions which we kindly acknowledge. The main criticism of the two referees generally concentrated on: (1) the validity of the grain-size distribution and its corresponding spectral analysis (Referee 1), (2) the applied benthic stable isotope correlation (Referee 2), and (3) the presentation of the data in Figure 4 (Referee 1 +2). In the following, we would like to give a detailed explanation concerning the comments and recommendations given by the Reviewers, as well as the intended revisions in our revised manuscript.

C1

Stefanie Kaboth, on behalf of all co-authors

Referee 1

1.) Chapter Spectral Analysis & Precession control on MOW strength during the Early Pleistocene The spectral analysis will be improved as requested by Referee 1, and the corresponding section 4.2 in the manuscript will be enhanced to properly reflect changes in the stability of the precession signal throughout our investigated intervals and its relation to insolation at 30°N. For this, we will include the insolation variability at 30°N to Figure 4A, and also add wavelets analysis for both investigated intervals which will be added to Figure 5 as Figures 5C and 5D. These adaptions are also in line with suggestions made by Referee 2 (see below) to include the findings of Becker et al. (2006, 2005) about precession related signals in the Eastern Mediterranean Sea during interval I. The methodological description of the wavelet analysis will be added to Method section 2.7 (section 2.6 in the initial manuscript).

2.) Chapter Glacial-Interglacial change We believe that the MIS102 interval is robust in its represented version and no adaptions will be necessary. Following the age constrain of MIS 102 according to Lisiecki and Raymo, (2005) the interval extends from 2.575 to 2.554 Ma. Through the initial age model based on bio- and magnetostratigraphy (see Table 1 in our initial manuscript) the age interval between 2.5 and 2.588 Ma is very well constrained. In contrast to Referee 1, we argue that the grain-size variability is a reliable representation for MOW variability during our investigated intervals despite in-part low recovery and sample resolution. As stated in the initial manuscript (see Lines 90 to 93) the grain-size proxy has been successfully used for Late Pleistocene studies (i.e. Kaboth et al. 2016). We think that the argued absolute amplitude reduction in MOW flow strength between interval I and II (see Lines 173 in the initial manuscript) is also visible in Figure 4D and does not relay solely on the calculated relative change in amplitude expressed in Line 173. We also believe that the description of the change in δ13C through North Atlantic water influence is sufficient in its current state (see Lines 168 to 177).

C2

3.) Chapter: Did Mow contribute to the Early Pleistocene climate transition? The occurrence of Neogloboquadrina atlantica (sin) is denoted in Figure 4 with black stars during mid-MIS 100, 98, 96 at Site U1389. However, as also stated by Referee2 this occurrence pattern is not clearly understandable for readers in its initial version, and Figure 4 will be modified to this respect in the revised manuscript. The reference for abundance patterns of N. atlantica in the eastern Mediterranean Sea and North Atlantic are already provided in the discussion section 4.3 (Lines 239). The south Atlantic SST record of Site ODP 1090 will be added to Figure 4A following Bell et al. (2015) (this also aligns with suggestions made by Referee 2, see below).

Figures 1.) Figure 1: A sub-figure (Figure 1B) highlighting the Mediterranean Sea circulation will be added. 2.) Figure 3: Indeed, the correlation arrow for MIS 101 in Figure 3A is graphically displaced. This will be revised. The dotted line indicating the mean sedimentation rate in Figure 3C will be removed. 3.) Figure 4: In the revised version we will unify the age notations between Figure 4 and Table 1. As stated above the insolation curve will be added to the revised Figure 4. However, the mid-point levels of sapropels throughout the investigated intervals are already clearly highlighted in Figure 4C and we do not think it necessary to add them again to Figure 4B. We will add data pointer to the grain-size record in Figure 4C to better visualize the existing gaps in the record. 4.) Figure 5: Red noise level will be added to Figure 5A and 5B.

Table 1.) In the revised version of the Table 1 we will list the full planktic foraminifera species names. The citation Raffi et al. (2006) will be properly cited in the reference list in the revised manuscript.

Referee 2

Major comments

1.) As stated under Lines 232 to 234 in our initial manuscript, the argument regarding the intensification AMOC is based on the findings by Bell et al. (2015) and not just the SST data published by Lawrence et al. (2009) and shown in our Figure 4A. Including

the SST record in Figure 4 is for orientation purposes of the reader as to the onset of the prosed "plateau" in the North Atlantic SST development. The arguments made in Bell et al. (2015) are based already on a wide spread analysis of SST records across the North Atlantic including Sites (ODP Sites 607, 1090, 1082 and 982). However, we agree that including the studies by Khélifi and Frank (2014) and Lisiecki (2014) will be beneficiary for our study as they highlight the lack of increased overturning circulation in the deep water opposed to the increased overturning postulated by Bell et al. (2015) in relation to the surface water trajectory. In our opinion this would strongly argue for the effect of MOW on the intermediate branch of overturning circulation, a scenario already highlighted in Bahr et al. (2015) for MIS 5. This argument will be newly added into the revised manuscript (under subsection 4.3) and complement the existing argument of the prevalence of MOW along intermediate water death within the North Atlantic by Loubere (1987) (see Lines 228 to 239 of our initial manuscript) which was already included in the initial manuscript.

2.) The δ18O correction between both benthic species for the Early Pleistocene is y=1.06x-0.17 (R2= 0.80). Hence, the slope of the linear relationship is $\sim$1 and the y-intercept is minor considering the analytical error of the measurements which is $\pm$0.08‰ This suggests a comparable oxygen isotope fractionation between Planulina ariminensis and Cibicidoides ungerianus. A similar behaviour has been postulated for P. ariminensis and other Cibicidoides species (e.g. Marchitto et al. 2014). For δ13C, the computed correction factor for both benthic species during the Early Pleistocene is y=0.13x+0.84 (R2=0.02). Following the suggestion of Referee 2, we have reanalysed our data for a possible climate driven bias. Firstly, the samples utilized for the analysis of the interspecies correction were not specifically chosen for their warm/cold climatic background but under the premise that both benthic species were present in sufficient numbers for stable isotope analysis. Hence, the suggested form of analysis leads to the exclusion of $\sim$ 25% (n=20) samples from the original data set corresponding to transional climate conditions. This exclusion changes the inter species correlation to y=-0.02x+0.83 (R2< 0.02). The correlation for only "warm" climatic conditions

(corresponding light δ18O values) shifts the interspecies correlation to y=0.005x+0.83 (R2<0.02; n=26). Similar, the correlation for only "cold" climatic conditions (corresponding heavy δ18O values) shifts the interspecies correlation to y=-0.04x+0.84 (R2<0.02; n=29). Hence, it becomes obvious that no climatic driven bias can be found. We argue instead that the high scatter might relate to the variability of C. ungerianus from a preferably epifaunal to a very shallow infaunal life style in correspondence to different nutrient fluxes, oxygenation state, habitat changes etc. This would cause an enhanced variability in the δ13C microhabitat-offset between both species. Such variability has been observed at recent for other Cibicidoides species (Fontanier et al., 2006). In contrast, P. ariminensis has been argued to be a reliable recorder of the δ13C signal of MOW (Zahn et al., 1987; already stated on Lines 83 to 85 in the initial manuscript) and aligns with findings of e.g., Schönfeld (2002), Rogerson et al. (2011) and García-Gallardo et al. (2017) further suggesting that P. ariminensis is a true "elevated" epifaunal living species directly recording MOW properties. Specifically, the influence of remineralisation of sedimentary carbon on benthic δ13C which may overprint the MOW signal was discussed by Rogerson et al. (2011). The authors considered the δ13C signal ambiguous for most benthic foraminifera with the exception of P. ariminensis which showed the highest (positive) correlation with MOW flow strength. We will add the above stated information to section 2.3 (section 2.2 in the initial manuscript). This will further strengthen our argument to exclude the C. ungerianus δ13C data points from the discussion and presentation in section 4.1 and Figure 4A. The reference in the caption of Figure 4 to Kaboth et al., in prep. is a typo and will be removed in the revised version of the manuscript. Only the stated inter species relations were applied in this study.

3.) We agree with the Referee 2 and will include the findings of Becker et al. (2006, 2005) on precession influence on climate variability during MIS 100 in the Mediterranean Sea into the revised manuscript under subsection 4.2.

4.) Vertical movements of the MOW plume are an important mechanism as stated by

Referee 2. However, the Late Pleistocene study of Bahr et al. (2015) has shown that Site U1389 is generally less prone to vertical movement than sites further up the shelf even under much more severe sea level variability than during the Early Pleistocene. The validity of utilizing δ18O to trace MOW prevalence in the Gulf of Cadiz has been already established in Kaboth et al. (2016). This approach argues that MOW is the dominant water mass at the site with the heaviest oxygen isotopic signal compared to ambient North Atlantic water due to its density. We will highlight this statement by revising Figure 1 of our manuscript and add the modern vertical water mass distribution along T, S and δ18Ow profiles for Site U1389 as Figure 1C. Based on this assumption the isotopic differences between the δ18O of the Mediterranean Sea (input signal) and the Gulf of Cadiz (output signal) reflects MOW variability as the ice volume contribution for the same time interval in both stable oxygen isotope records can be assume to be identical. As the isotopic gradient in δ18O are generally small throughout both intervals it seems feasible to argue that MOW prevailed throughout our studied time frame. The grain-size and δ13C gradient for both intervals give indication that the intensification of MOW occurred as outlined in subsection 4.1 of the initial manuscript.

Minor comments

1.) We will follow the suggestion by Referee 2 and change the title into: "Mediterranean Outflow variability during the Early Pleistocene"

2.) Line 51: Following the suggestions by Referee 2 we will add more details on sequence stratigraphy and paleo-water depth of the Singa/Vrica sections in a newly designed subsection 2.2 under Material & Methods. It seems more befitting to add additional information for the reader about the Singa/Vrica section separately rather than into the Introduction.

3.) Line 112-118: The high variability at Site U1389 in sedimentation rate is not unusual if compared to findings from the same site during the Late Pleistocene which shows a similar range (see Figure DR2 in Bahr et al. 2015). Generally, contourites are very

dynamic depositional systems which is reflected in the evolution of sedimentation rates though time (Hernandez-Molina et al., 2014).

4.) Line 216: Yes, the black starts in the initial version of Figure 4B indicate the occurrences of N. atlantica during cold periods in Interval I of our study. As also suggested by Referee 1 (see above) we will modify Figure 4B to improve the visual occurrence pattern of N. atlantica to the reader also in relation to interval II.

5.) Line 263: We do not make this argument based on our data but instead this is based on the findings of Bell et al. (2015) as clearly stated in Lines 232 to 234.

6.) The superscription on δ18O and δ13C will be checked in the revised manuscript.

7.) Figure 1: This figure will be improved by adding a recent vertical water mass profile at Site U1389 including T, S, and δ18Ow.

8.) Figure 2: The different climatic intervals will be highlighted, and it will be made clear to readers which figure represents stable oxygen and carbon correlations.

9.) Figure 3: Commas will be replaced by dots.

10.) Figure 4: As also suggested by Referee 1 we will improve Figure 4A by adding the South Atlantic SST record ODP 1090 to highlight the discussed intensification of AMOC (Bell et al. 2015). Furthermore, we will clarify the occurrence of N. atlantica (also see Referee 2 comments on Line 216 and Referee 1), and also visually improve the time range of the studied intervals in relation to the shown SST records.

References

Bahr, A., Kaboth, S., Jiménez-Espejo, F.J., Sierro, F.J., Voelker, A.H.L., Lourens, L., Röhl, U., Reichart, G.J., Escutia, C., Hernández-Molina, F.J., Pross, J., andFriedrich, O., 2015, Persistent monsoonal forcing of Mediterranean Outflow Water dynamics during the late Pleistocene: Geology, v. 43, p. 951–954, doi: 10.1130/G37013.1.

Becker, J., Lourens, L.J., Hilgen, F.J., van derLaan, E., Kouwenhoven, T.J., an-

dReichart, G.-J., 2005, Late Pliocene climate variability on Milankovitch to millennial time scales: A high-resolution study of MIS100 from the Mediterranean: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 228, p. 338–360, doi: 10.1016/j.palaeo.2005.06.020.

Becker, J., Lourens, L.J., andRaymo, M.E., 2006, High-frequency climate linkages between the North Atlantic and the Mediterranean during marine oxygen isotope stage 100 (MIS100): ATLANTIC MEDITERRANEAN LINKAGE: Paleoceanography, v. 21, p. PA3002, doi: 10.1029/2005PA001168.

Bell, D.B., Jung, S.J.A., andKroon, D., 2015, The Plio-Pleistocene development of Atlantic deep-water circulation and its influence on climate trends: Quaternary Science Reviews, v. 123, p. 265–282, doi: 10.1016/j.quascirev.2015.06.026.

Fontanier, C., Mackensen, A., Jorissen, F.J., Anschutz, P., Licari, L., andGriveaud, C., 2006, Stable oxygen and carbon isotopes of live benthic foraminifera from the Bay of Biscay: Microhabitat impact and seasonal variability: Marine Micropaleontology, v. 58, p. 159–183, doi: 10.1016/j.marmicro.2005.09.004.

García-Gallardo, Á., Grunert, P., Van derSchee, M., Sierro, F.J., Jiménez-Espejo, F.J., Alvarez Zarikian, C.A., andPiller, W.E., 2017, Benthic foraminifera-based reconstruction of the first Mediterranean-Atlantic exchange in the early Pliocene Gulf of Cadiz: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 472, p. 93–107, doi: 10.1016/j.palaeo.2017.02.009.

Hernandez-Molina, F.J., Stow, D.A.V., Alvarez-Zarikian, C.A., Acton, G., Bahr, A., Balestra, B., Ducassou, E., Flood, R., Flores, J.-A., Furota, S., Grunert, P., Hodell, D., Jimenez-Espejo, F., Kim, J.K., et al., 2014, Onset of Mediterranean outflow into the North Atlantic: Science, v. 344, p. 1244–1250, doi: 10.1126/science.1251306.

Kaboth, S., Lourens, L., andDepartement Aardwetenschappen (Utrecht), 2016, Deciphering the paleoceanographic and paleoclimatic evolution of the Gulf of Cádiz during

the past 2.6 million years. Khélifi, N., andFrank, M., 2014, A major change in North Atlantic deep water circulation 1.6 million years ago: Climate of the Past, v. 10, p. 1441–1451, doi: 10.5194/cp-10-1441-2014.

Lawrence, K.T., Herbert, T.D., Brown, C.M., Raymo, M.E., andHaywood, A.M., 2009, High-amplitude variations in North Atlantic sea surface temperature during the early Pliocene warm period: VARIABLE PLIOCENE NORTH ATLANTIC SSTS: Paleoceanography, v. 24, p. n/a-n/a, doi: 10.1029/2008PA001669. Lisiecki, L.E., 2014, Atlantic overturning responses to obliquity and precession over the last 3 Myr: Paleoceanography, v. 29, p. 71–86, doi: 10.1002/2013PA002505.

Lisiecki, L.E., andRaymo, M.E., 2005, A Pliocene-Pleistocene stack of 57 globally distributed benthic d18O records: Paleoceanography, v. 20, p. 1–17, doi: 10.1029/2004PA001071.

Loubere, P., 1987, Changes in mid-depth North Atlantic and Mediterranean circulation during the Late Pliocene âĂŤ Isotopic and sedimentological evidence: Marine Geology, v. 77, p. 15–38, doi: 10.1016/0025-3227(87)90081-8.

Marchitto, T.M., Curry, W.B., Lynch-Stieglitz, J., Bryan, S.P., Cobb, K.M., andLund, D.C., 2014, Improved oxygen isotope temperature calibrations for cosmopolitan benthic foraminifera: Geochimica et Cosmochimica Acta, v. 130, p. 1–11, doi: 10.1016/j.gca.2013.12.034.

Raffi, I., Backman, J., Fornaciari, E., Pälike, H., Rio, D., Lourens, L., andHilgen, F., 2006, A review of calcareous nannofossil astrobiochronology encompassing the past 25 million yearsâŸĘ: Quaternary Science Reviews, v. 25, p. 3113–3137, doi: 10.1016/j.quascirev.2006.07.007.

Rogerson, M., Schönfeld, J., andLeng, M.J., 2011, Qualitative and quantitative approaches in palaeohydrography: A case study from core-top parameters in the Gulf of Cadiz: Marine Geology, v. 280, p. 150–167, doi: 10.1016/j.margeo.2010.12.008.

Schönfeld, J., 2002, A new benthic foraminiferal proxy for near-bottom current velocities in the Gulf of Cadiz, northeastern Atlantic Ocean: Deep-Sea Research Part I: Oceanographic Research Papers, v. 49, p. 1853–1875, doi: 10.1016/S0967-0637(02)00088-2.

Zahn, R., Sarnthein, M., andErlenkeuser, H., 1987, Benthic isotope evidence for changes of the Mediterranean outflow during the Late Quaternary: Paleoceanography, v. 2, p. 543–559, doi: 10.1029/PA002i006p00543.