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Climate of the Past Discussions

Interactive comment on "A multi-proxy analysis of late Quaternary Indian monsoon dynamics for the Maldives, Inner Sea" *by* Dorothea Bunzel et al.

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Response to Referee#1,

We acknowledge the substantial comments by the reviewer, and especially for bringing up the suggestion of including a more profound statistical evaluation of our data series, the usage of alternative element ratios as dust indicators, and the suggestion for comparison of stable carbon isotope records from various intermediate water sites. Specifically, we have generated Blackman-Tukey power spectra for the most relevant proxy records supporting our paleoenvironmental interpretation. The comments helped to improve our manuscript considerably. Below we respond to all comments raised by the reviewer. With kind regards, Dorothea Bunzel

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Discussion paper

1) I don't find the title of the current manuscript really suitable. The title suggest that the Maldives record is mainly driven by "Indian monsoon dynamics" whereas the authors conclude that the record provide a close linkage between the Indian monsoon oscillation, intermediate water circulation, productivity and sea-level changes on orbital time-scale. Therefore, a title such as "A multi-proxy analysis of late Quaternary equatorial Indian ocean for the Maldives, Inner Sea" could be less confusing.

Response: Thank you for suggesting a more suitable title. We will adjust the title accordingly, e.g. "A multi-proxy analysis of late Quaternary ocean and climate variability for the Maldives, Inner Sea"

2) Lines 57 to 59. There is much more references of Arabian Sea works at the orbital and suborbital time scales (Clemens et al., 1996; Altabet et al., 2002; Clemens and Prell, 2003; Pichevin et al., 2007; Boning and Bard, 2009; Ziegler et al., 2010; Caley et al., 2011; Caley et al., 2013, Deplazes et al., 2013 are some examples).

Response: We agree and will include the mentioned references in the revised version.

3) Lines 179-180: "Local reservoir corrections were not applied". The authors should explain why they do not applied a correction. In general a correction of 400 years is applied in the tropics.

Response: We did not correct our radiocarbon ages for local reservoir effects, because the closest available numbers of marine reservoir age corrections are from the Arabian Sea, Northern Indian Ocean and Bay of Bengal, between 821 and 864 km distance from our study site. These reservoir age correction values vary between 301 to 544 years (Dutta et al., 2001; Southon et al., 2002). Due to the contrasting values and in order to minimize potential errors we decided to apply the global marine reservoir correction of 400 yrs. We will change the text accordingly (lines 178-179): "The AMS 14C ages were corrected for the global reservoir age of 400 years and converted to calendar years using the radiocarbon calibration program CALIB (version 7.0.4; Stuiver and Reimer, 1993)."

4) Lines 202-209: Oxygen concentration should be shown on figure 3 and not only on Figure 8.

Response: We will include the $\Delta\delta$13CCm-Ga data, which were used for the bottom-water oxygen reconstruction, in Figure 3.

5) Lines 217-221: The data of core M74/4-1143 are not shown on figure 4 making the comparison with core SO-236-052-4 impossible.

Response: We will include the sortable silt data of core M74/4-1143 in Figure 4a.

6) Lines 228-233 and 258-259; Are the Fe/Ca and Si/Ca good proxies for Aeolian dust? The results could be compared to dust data from site ODP722 (Clemens et al., 1996). This is important to discuss the provenance of the dust and the interpretation of the Fe/Ca and Si/Ca that stays speculative in the discussion (lines 258-268). Also, previous study in the Arabian Sea used rather the changes in the Ti/Al ratio of the sediments as indicator for grain size and thus wind speed, since Titanium is concentrated in heavy minerals in the coarser size fraction (Reichart et al., 1997; Ziegler et al., 2010 CP).

Response: We consider the more commonly used proxies for terrigenous sediment delivery/aeolian dust fluxes and we will modify our manuscript as follows: We will replace the Fe/Ca record by the Ti/Al and Fe/Al records as proxies for aeolian dust supply and enhanced aridity of the hinterland/source area (e.g. Zhang et al., 1993; Lourens et al., 2001; Itambi et al., 2009) in order to account for a potential influence of changes in carbonate production and preservation on the Fe/Ca ratio (Wehausen and Brumsack, 2000). We have included the Fe/Al record because the aeolian Fe flux to the ocean likely has a direct impact on the seasonal surface ocean productivity (e.g. Martin et al., 1991; Boyd et al., 2000; Gao et al., 2001; Jickells et al., 2005), which also influences the deep-sea benthic ecosystems through seasonal phytodetritus pulses. Both Ti/Al and Fe/Al records show a similar glacial-interglacial pattern with relatively higher values during cold stages corroborating the foraminiferal results of enhanced surface ocean fertilisation of the Maldives Inner Sea during glacial periods. We also show and discuss the Si/Ca ratio in addition, because we argue that the increase in agglutinated benthic foraminifera is a reflection of the availability of terrestrial particles, since most of these agglutinated species preferentially use siliciclastic grains for building up their test walls (e.g., Murray, 2006). We will refer to the lithogenic flux record of site ODP722 (Clemens et al., 1996) since it supports our observation of generally enhanced glacial dust fluxes. However, we refrain from plotting the data because of its comparatively low temporal resolution for the targeted time interval.

7) Line 278: "Fe/Ca record lacks significant variability on the precession band". Statistical analyses are necessary (spectral analyses) to confirm this point.

Response: For a proper statistical analysis we have now performed a Blackman-Tukey spectral analyses for TOC, oxygen concentration, Fe/Al and Ti/Al ratios in comparison to the Δ-insolation at 30°N. The reconstructed oxygen record of core SO-236-052 reveals strong power in the precession band (23 ka period). Significant but considerably weaker variability in the precession band is also detected in the TOC and Ti/Al records. The Fe/Al record lacks substantial precessional variability but is rather dominated by long-term glacial-interglacial changes. All of the above-mentioned results will be displayed and discussed in the revised manuscript.

8) Lines 336-337: "While the benthic foraminiferal fauna preliminary show changes on glacial-interglacial time scale, the TOC content and Ba/Ca ratio are characterized by additional variability in the precessional band." Again, statistical analyses are necessary (spectral analyses) to confirm this point.

Response: See response to referee comment #7.

9) Lines 342-347: "Elevated TOC and Ba/Ca ratios at site SO-236-052 during phases of reduced northern hemisphere summer insolation suggest a direct influence of the Indian winter monsoon on productivity and related organic matter fluxes of the Maldives Inner Sea during the past 200 ka, which is consistent with the present-day situation (de Vos et al. 2014). The close link between the winter monsoon intensity and surface

water productivity in the study area is confirmed by the difference between the δ13C values of the epipelagic G. ruber (Gr) and the epibenthic C. mabahethi (Cm) (Figs. 3, 8)." Again, statistical analyses are necessary with a phase analyse. Also, what could be the role of the IEW and ENSO mentioned in the introduction part?

Response: With exception of the oxygen record, the TOC, Ti/Al, Fe/Al records reveal a comparatively weak coherence in the precession band (see also answer to referee comment #7). This result is likely related to the strong dominance of the 100 ka periodicity (as for example reflected in the dust supply) and superposition of shorter-wave variability. Hence, we did not include results from cross-spectral analyses. We have acknowledged the documented influence of IEW and ENSO variability on equatorial Indian surface ocean environments in the introduction chapter. On the other hand, the close relation of the present-day productivity in the Maldives Inner Sea surface waters (as reflected in seasonal satellite chlorophyll images) to the northern hemisphere winter season clearly demonstrates a relation to the NE monsoon. Specifically, our proxy records suggest enhanced dust fluxes and enhanced productivity during glacial boundary conditions underlining a general affiliation of Maldives paleoenvironments to the NE monsoon and high-latitude climate changes (dust availability, sea-level changes). To admit, we cannot exclude a potential additional influence of changes in IEW and ENSO but a proper statistical evaluation of phase relationships in the precessional band is unfortunately inhibited by the relatively weak precessional component and coherence in our proxy records of surface water productivity (such as TOC content, Br XRF counts). In the revised discussion chapter, we will address this issue in order to better acknowledge the possibility of IEW influence as observed in other studies.

10) Lines 372-376: "Long-term trends of similar magnitude have been recorded from sites bathed by the Antarctic Intermediate Water mass (AAIW) in the southwestern Pacific Ocean (Pahnke and Zahn, 2005; Elmore et al., 2015; Ronge et al., 2015). The general resemblance of the various epibenthic δ13C records suggests a significant role of AAIW in ventilation of bathyal environments of the Maldives Inner Sea, which

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Discussion paper

is consistent with the modern oceanographic situation (You, 1998)." It would be good to add the data of the previous work mentioned on the Figure of the manuscript for a direct comparison.

Response: Thanks for raising this important point. For the revised version of our manuscript we will create an additional figure comparing our epibenthic stable carbon isotope record with published records of Pahnke and Zahn (2005), Elmore et al. (2015) and Ronge et al. (2015). The general resemblance of the δ13C trends from different regions confirms the super-regional AAIW influence.

11) Lines 385-386: "The reconstructed O2 record reveals precessional changes between oxic and low oxic conditions during northern hemisphere insolation maxima and minima, respectively". Statistical analyses are necessary (spectral analyses) to confirm this point.

Response: Spectral analysis of the oxygen record reveals significant variability in the precession band (see also answer to referee comment #7).

12) Lines 406-412: "Agulhas leakage". I do not understand this paragraph and the link with the Agulhas leakage. If the authors want to demonstrate a link between their record and the Indian monsoon they can compare directly with published monsoon records. Also, the forcing of the Agulhas leakage at terminations is driven by the subtropical front migration and is not directly link to the Indian monsoon (Peeters et al., 2004). For the IEW impact, a statistical analyze with the phase relationship (spectral analyses) will help the interpretation of the record.

Response: We admit, that the discussion related to the Agulhas leakage is not essential for the main conclusions of our paper. In order to avoid confusion, we will delete this paragraph. For the potential IEW impact see our response to referee comment #9.

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