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Antarctic control on tropical western Indian Ocean sea surface temperature and productivity during the late Pleistocene

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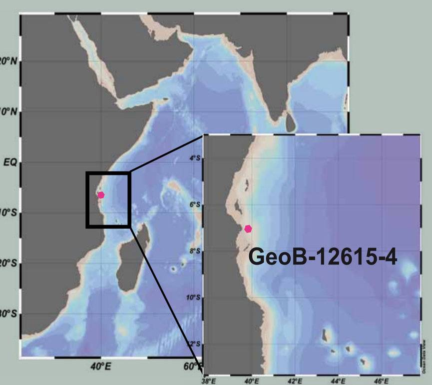
INTRODUCTION

Sea Surface Temperatures in the Indian Ocean have been proposed to play an important role in affecting climatic processes, such as the monsoon system.

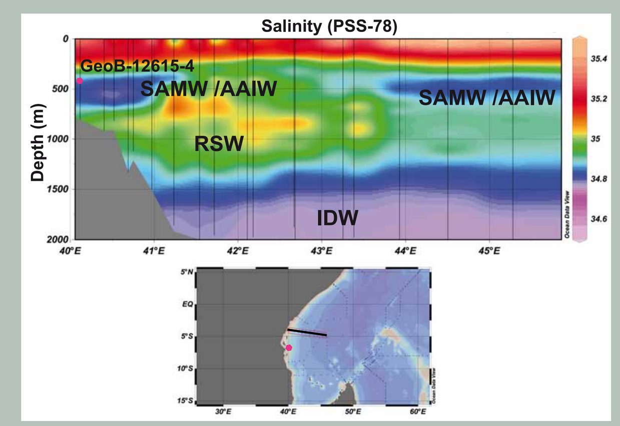
We reconstructed Sea Surface Temperatures, benthic foraminiferal assemblages, geochemical sediment properties as well as seawater $\delta^{18}O$ and $\delta^{13}C$ of the western Indian Ocean for the last 40 kyrs to identify what in turn controlled Sea Surface Temperature variability.

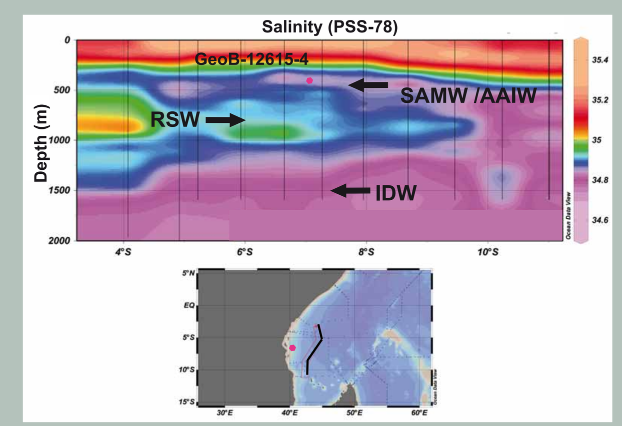
This study is part of the MARUM research area "Ocean and Climate, OC2: Glacial to Holocene history of the tropical rainbelt".

OVERVIEW



The sediment core GeoB12615-4 was retrieved during Meteor cruise M75 in 2008 at 07°08.30'S 39°50.45'W (446 m) in the SW Somali Basin off the Tanzanian coast. It is located close to the Rufiji River delta.





The core is located in the area of influence of a **low-salinity layer** identified as a mixture of Subantarctic Mode Water (SAMW), subtropical sourced Indian Central Water (ICW) and Antarctic Intermediate Water (AAIW). Via equatorial upwelling in the central Indian Ocean SAMW reaches subsurface water masses and is transferred to the core location by the South Equatorial Current (SEC) (Schott, 2001). In addition, we suggest a westward flow of AAIW north of Madagascar through the Amirante Passage (Mc Cave, 2005), following the direction of the East African Counter Current (EACC) and gliding over deeper located Red Sea Water (You, 1998), though the northward extension of AAIW in the Western Indian Ocean is rather controversial.

METHODS

SST reconstructions are based on Mg/Ca measurements on the planktic foraminifer *Globigerinoides ruber white, s.s.*, 250-300 µm and have been measured at the Faculty of Geosciences, University of Bremen, Germany.

Stable Isotope data were analized on the planktic foraminifer species *G. ruber white, s.s.*, (250-300 µm) as well as on the benthic species *Planulina ariminensis* (350-1000 µm) in the Stable Isotope Laboratory at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany.

Geochemical analyses (Total $CaCO_3$) were carried out at Alfred Wegener Institute as well.

The **age model** is based on 16 radiocarbon dates, with ΔR=140yrs (Southon, 2002), measured on samples containing up to three shallow dwelling planktic foraminifera species at the Leibniz Laboratory for Radiometric Dating and Isotope Research in Kiel, Germany.

Benthic foraminiferal assemblages were composed by determining and counting all benthic foraminifera species per sample (or aliquot).

Statistical methods (Q-mode Principal Component Analysis) were then applied to the dataset to reduce the large number of different species and compose few benthic assemblages. The factor loadings reflect the effect of ecological and physical parameters, associated to dominant species, on the total fauna / benthic fauna.

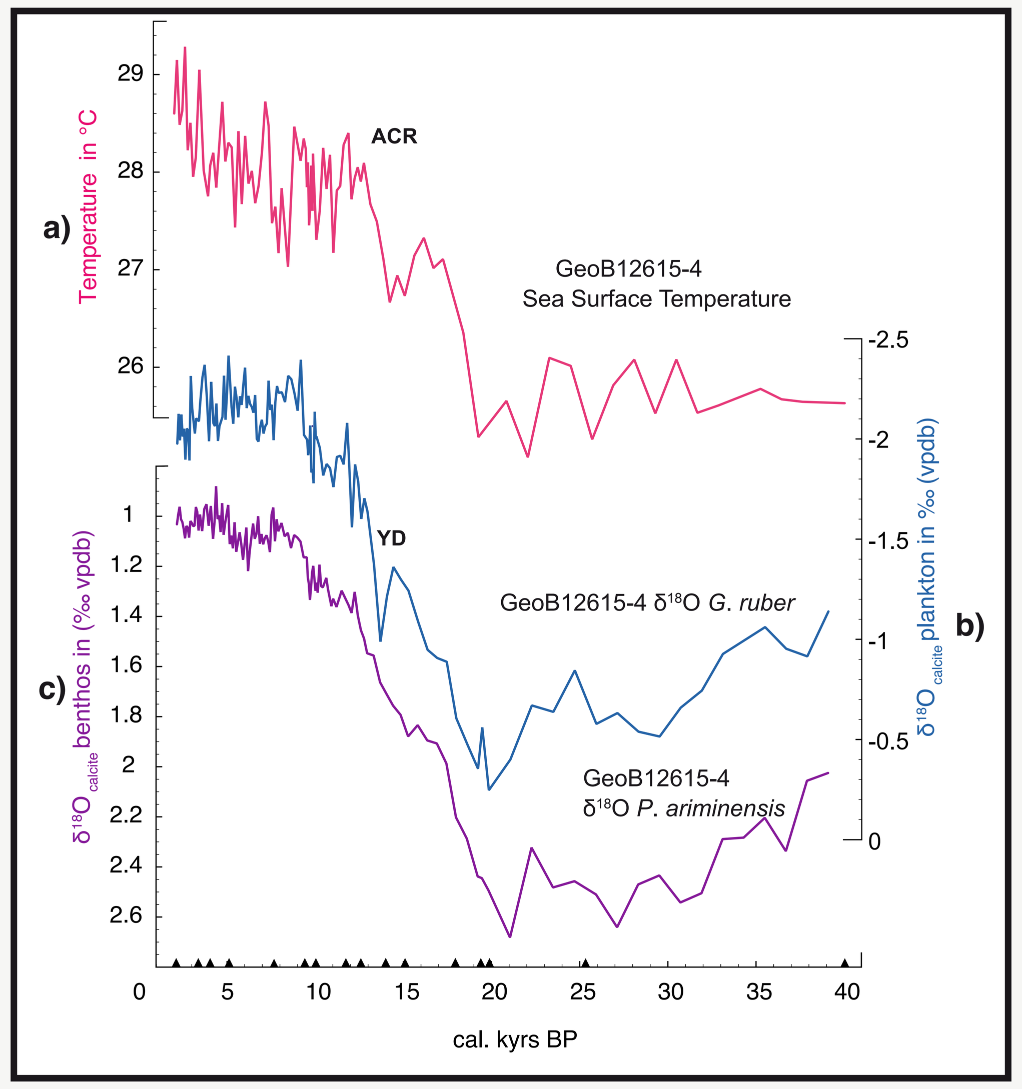


Figure 1): Sea Surface Temperature reconstruction and oxygen isotope records: **a)** reconstructed Sea Surface Temperature **GeoB12615-4**, based on Mg/Ca ratios, measured on *G. ruber white, s.s.* (red). **b)** $\delta^{18}O$ record **GeoB12615-4,** measured on planktic foraminifer *Globigerinoides ruber white, s.s.* (blue). **c)** $\delta^{18}O$ record **GeoB12615-4,** measured on benthic foraminifer *Planulina ariminensis* (purple). Grey bar indicates time window of Antarctic Cold Reversal (ACR). Black triangles indicate age control.

The presented Sea Surface Temperature record shows an early onset of the deglaciation after the LGM at ~ 20 kyrs BP and a temperature setback at ~15.4 kyrs BP, which clearly correlates with Antarctic climate records. The $\delta^{18}O$ record, reflecting the surface water properties, indicates an increase in seawater salinity at 13.0 kyrs BP, simultaneously with the Northern Hemisphere Younger Dryas. We suggest a sudden shift or weakening of the monsoon system to cause this tropical Younger Dryas, resulting in less freshwater influx from the African Continent.

But what causes the SST variability ??

Literature:
Schott, McCreary (2001), The monsoon circulation of the Indian Ocean. Progress in Oceanography, 51/1.
McCave (2005), Deep flow in the Madagascar-Mascarene Basin over the last 150000 years. Phil. Trans. R. Soc. A . 363, 81–99
Southon, (2002), Marine reservoir corrections for the Indian Ocean and Southeast Asia. Radiocarbon, 44(1)
You (1998), Intermediate water circulation and ventilation of the Indian Ocean derived from water-mass contributions. Journal of Marine Research, 56, 1029–1067
Kiefer (2006), Antarctic control on tropical Indian Ocean sea surface temperature and hydrography. Geophysical Research Letters, 33(L24612)
Naidu (2010), New evidence on the sequence of deglacial warming in the tropical Indian Ocean, Journal of Quaternary Science, 25(7)

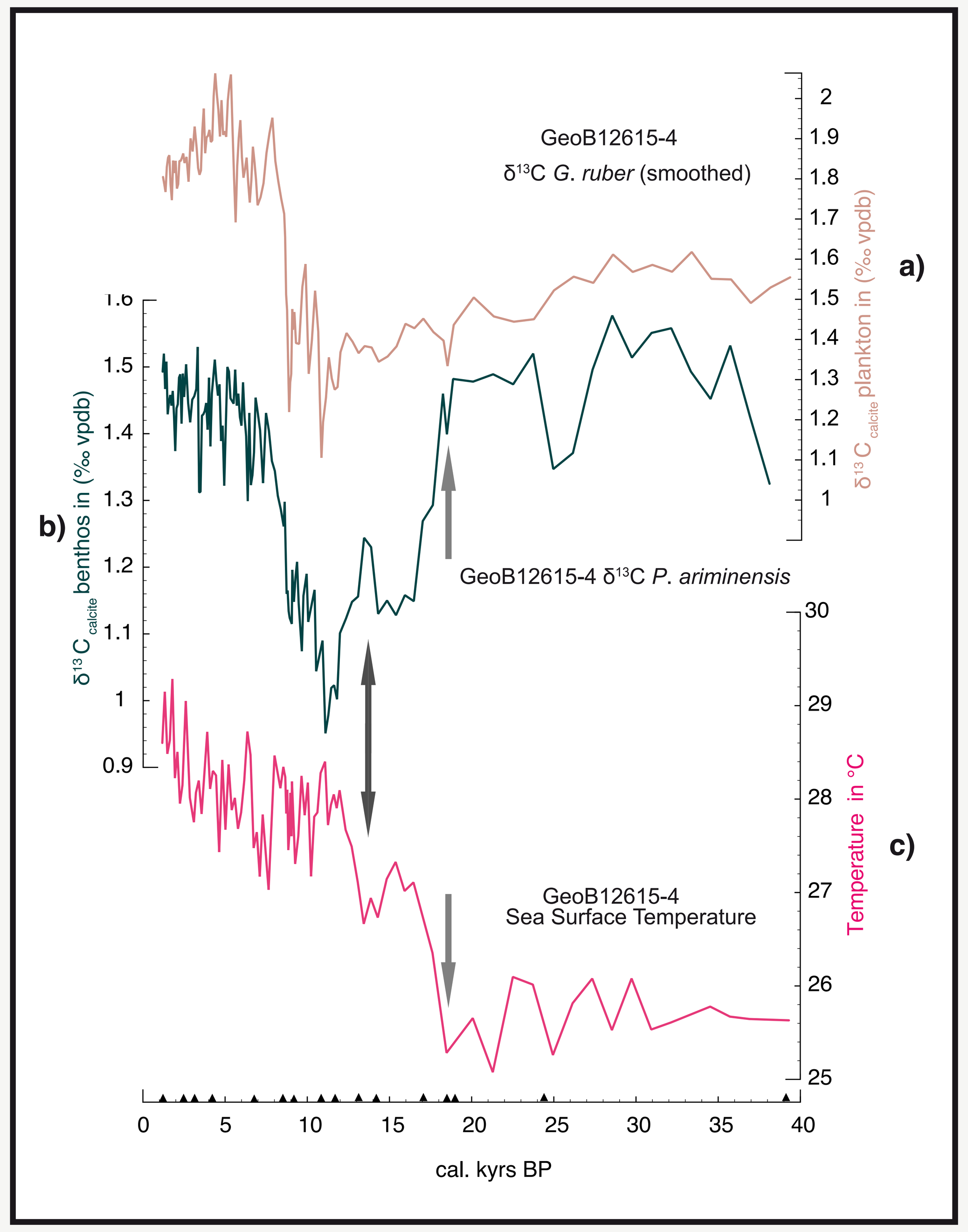


Figure 2): Carbon isotope record and Sea Surface Temperature reconstruction: **a)** $\delta^{13}C$ record **GeoB12615-4,** measured on planktic foraminifer *Globigerinoides ruber white, s.s.*, moving average-smoothed (brown). **b)** $\delta^{13}C$ record **GeoB12615-4,** measured on benthic foraminifer *Planulina ariminensis* (green). **c)** reconstructed Sea Surface Temperature **GeoB-12615-4**, based on Mg/Ca ratios, measured on *G. ruber white, s.s.* (red). Grey bar indicates time window of Antarctic Cold Reversal (ACR). Black triangles indicate age control.

The comparison of the carbon isotopic records and SST show an explicit correlation of $\delta^{13}C_{benthic}$-values and SST of GeoB12615-4 (Fig. 2). Two recent studies suggest that the SST in the Western Indian Ocean was controlled by the influence of Subantarctic Mode Water (SAMW) and thereby modulated by Antarctic temperature (Kiefer et al, 2006, Naidu, 2010). The cooler the source area of SAMW (just as the Indian Ocean SST), the higher the carbon isotope composition of SAMW (and hence the Indian Ocean surface water). Our data corroborate this opinion.

The $\delta^{13}C_{planktic}$ record does not show a distinct Antarctic signal, which might be due to other processes that affect the carbon isotopy of the surface water.

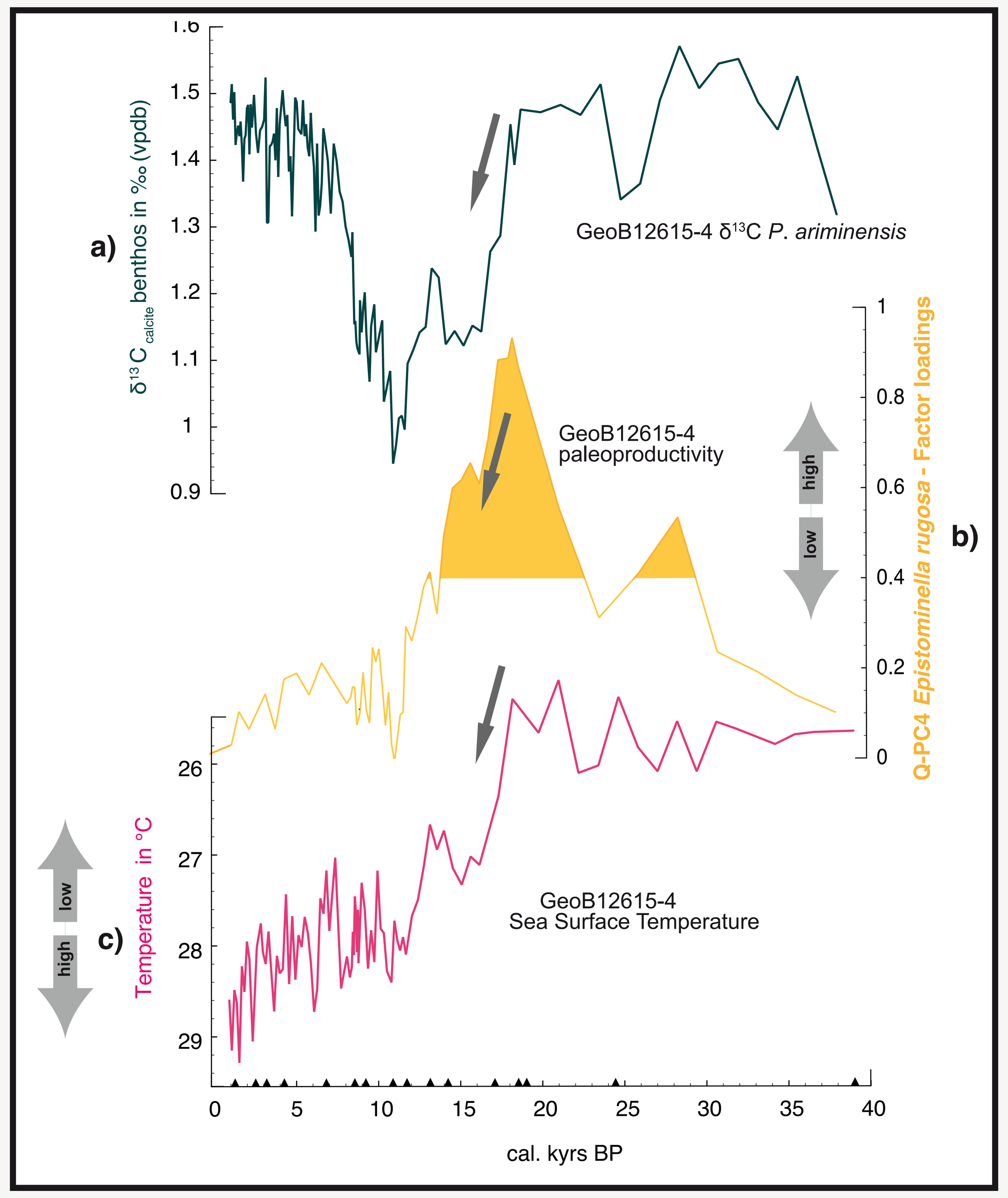


Figure 3): Comparison of carbon isotope record, benthic foraminiferal assemblage faunal principal component analysis and Sea Surface Temperature record: **a)** $\delta^{13}C$ record **GeoB12615-4,** measured on benthic foraminifer *Planulina ariminensis* (green). **b)** principle component (PC) loading PC4 record ("High Productivity"-fauna, *Epistominella rugosa*). Level of significance is given at >0.4. (yellow). **c)** reconstructed Sea Surface Temperature **GeoB12615-4**, based on planktic Mg/Ca ratios (red). **Note that y-axis is inversed**. Black triangles indicate age control.

Productivity can influence the $\delta^{13}C$ signal as well. The comparison of bottom water carbon isotopy, the benthic assemblage paleoproductivity index and the SST record show a simultaneous change at the early onset of the deglaciation (arrows), but the ACR is not recorded by the paleoproductivity index.

This suggest the $\delta^{13}C_{benthic}$ record in large part reflects water mass variability, especially during Termination I, which supports our interpretation of a water mass induced surface cooling during the ACR.

The mismatch of the $\delta^{13}C_{planktic}$ record and our paleoproductivity reconstruction contradicts a strong atmospheric control on paleoproductivity, we therefore assume a causal link between Antarctic water mass influence and paleoproductivity in the Western Indian Ocean.

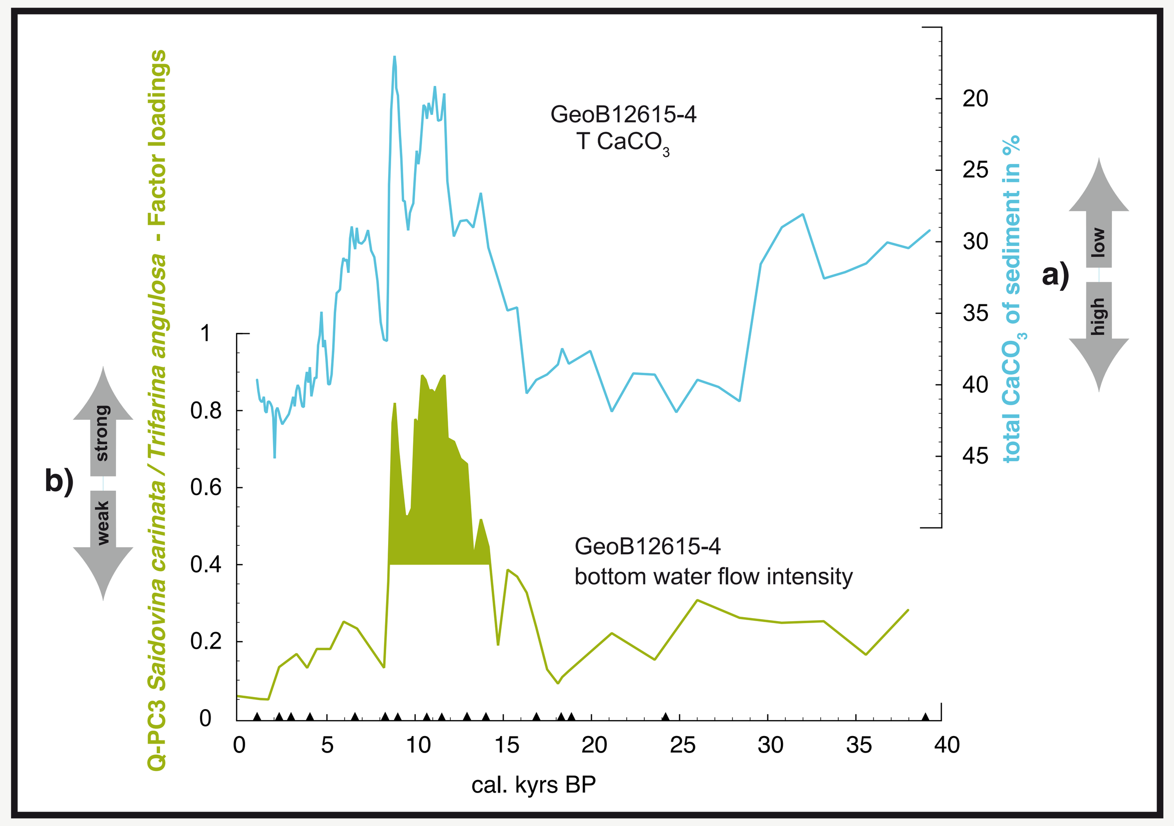


Figure 4): Comparison of sediment composition and benthic foraminiferal assemblage faunal principal component analysis: **a)** total carbonate content of sediment of GeoB12615-4 in % (blue). **Note that y-axis is inversed. b)** principle component (PC) loading PC3 record ("bottom water flow intensity"-fauna, *Saidovina carinata / Trifarina angulosa*). Level of significance is given at >0.4. (green).

The variability of the carbonate content of the sediment can be explained by comparison to a „bottom water flow intensity" index, which is derived by using Principal Component Analysis of the benthic foraminiferal fauna. Bottom water flow is strongest between 15–9 kyrs BP, correlating to the lowest carbonate content in the sediment. Preliminary, we interpret the gradual increase in bottom water velocity as a result of water mass reorganization, whereas the sudden slow-down is likely induced by the increasing sea level.

CONCLUSIONS

1) Past Sea Surface Temperature in the Western Indian Ocean have been modulated by Antarctic temperature via Southern Hemisphere sourced intermediate water masses, presumably SAMW and AAIW.

2) Changes in paleoproductivity during the last 40 kyrs can be likely linked to Antarctic controlled water mass variability, rather than to changes of the East African monsoon system.