A first look at past sea surface temperatures in the equatorial Indian Ocean from Mg/Ca in foraminifera

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[1] Sea surface temperature (SST) for the central equatorial Indian Ocean, has been reconstructed over the last ~137 kyr, from Mg/Ca of the planktonic foraminiferal species *Globigerinoides ruber*. According to our record the equatorial Indian Ocean SST was ~2.1°C colder during the last glacial maximum as compared to present times. The data further shows that the surface equatorial Indian Ocean was comparatively warmer during isotopic stage 5e than at present (~29.9 vs ~28.5°C). Comparison of the equatorial Indian Ocean SST with the Antarctic δD and Greenland δ^{18}O records, shows that the major high-latitude cooling/warming events are also present in the equatorial Indian Ocean SST variation record. Similarity between the equatorial Indian Ocean SST and the equatorial Pacific SST suggests the possibility of a common mechanism controlling the SSTs in both the equatorial Indian Ocean and the Pacific Ocean. **Citation:** Saraswat, R., R. Nigam, S. Weldeab, A. Mackensen, and P. D. Naidu (2005), A first look at past sea surface temperatures in the equatorial Indian Ocean from Mg/Ca in foraminifera, *Geophys. Res. Lett.*, *32*, L24605, doi:10.1029/2005GL024093.

1. Introduction

[2] In view of the findings suggesting independent ocean-atmosphere forcing of the Indian Ocean [*Nicholls*, 1995] supported by recent discovery of the Indian Ocean Dipole [*Webster et al.*, 1999; *Saji et al.*, 1999], it has become imperative to understand climatic variability in the Indian Ocean. Reconstructing climatic parameters on longer time-scales and exploring the phase relationship of the climatic variations in the equatorial Indian Ocean with climatic variations from other parts of world will help in understanding the role of the Indian Ocean in global climatic variations. Estimates of the glacial/interglacial changes in SST in the tropics and equatorial oceans based on a variety of proxies provide values that oscillate between 1°C and 4°C [*Gagan et al.*, 2004; *Montaggioni*, 2005]. So far, SSTs from the tropical and equatorial Indian Ocean have been reconstructed using faunal transfer functions [*CLIMAP Project Members*, 1976, 1981; *Prell and Hutson*, 1979], alkenone unsaturation ratios [*Rostek et al.*, 1993, 1997; *Sonzogni et al.*, 1998] and artificial neural network (ANN) analyses of planktonic foraminifera [*Naidu and Malmgren*, 2005]. Mg/Ca ratios of foraminifera is another rather well established proxy for SST [*Nürnberg et al.*, 1996; *Elderfield and Ganssen*, 2000]. However, this technique has not yet been applied in the northern Indian Ocean. Here we report the first millennial scale SST record from the equatorial Indian Ocean over the last ~137 kyr, based on Mg/Ca analysis of planktonic foraminiferal species *Globigerinoides ruber* (white).

2. Samples and Methods

[3] In order to reconstruct past sea surface temperatures from the equatorial Indian Ocean, Mg/Ca analysis was performed on the top 270 cm of core (SK 157/4), collected from the eastern flank of the Comorin ridge (02°40′N, 78°00′E, water depth 3500 m). Mg/Ca analyses were performed, using Perkin Elmer Optima 3300 R ICP-OES, on the surface dwelling planktonic foraminiferal species *G. ruber* (white), a species that has been demonstrated to reliably record the SST [*Dekens et al.*, 2002]. We followed a slightly modified version of the method of *Barker et al.* [2003] that included the reductive step performed by *Martin and Lea* [2002]. In order to monitor the effectiveness of our cleaning protocol, Ba, Mn and Fe were also measured simultaneously. The Mn/Ca values ranged up to 0.4 mmol/mol while the Fe/Ca values were measured to a maximum of 0.16 mmol/mol. We found Mn/Ca ratios slightly increasing towards the older samples (especially, below last glacial maximum). However, we did not find correlation between Mg/Ca and Mn/Ca, suggesting that the slight increase of Mn/Ca had no effect on the Mg/Ca ratios. Unfortunately, since there are still no published Mg/Ca core-top calibrations for the Indian Ocean, potential effects of dissolution on glacial-interglacial SSTs are difficult to assess. However, the insignificant difference between the core top SST estimated from foraminiferal Mg/Ca ratio and modern SST in the study area, the location of the core well above (~900 m) the carbonate lysocline, (presently placed at 4400 m, by *Banakar et al.* [1998], in a study based on surface sediment samples collected along a north-south transect across the equator in the central Indian basin, very near to the location of the core used in the present study) and the high carbonate content throughout the studied interval (V. Ramaswamy, personal communication, 2004), suggests unimportant bias in glacial-interglacial SSTs as a result of dissolution. The possibility of glacial-interglacial bias in Mg/Ca based SST, due to dissolution, is further reduced as negligible differences have been noticed in $CaCO_3$ dissolution between the interglacial and glacial periods in the central equatorial Indian Ocean [*Ku and Oba*, 1978]. The chronology for the upper part of the core

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Table 1. AMS (Marked With Asterisk) and Conventional Radiocarbon Ages for the Core SK 157/4

Depth, cm	^{14}C Age, yr BP	Calendar Calibrated Age, yr BP
00	3840 ± 210	3317–3895
*22	9361 ± 52	9838–10159
*32	12770 ± 60	13886–14205
38	17050 ± 340	19293–19975

is based on monospecific (*Globorotalia menardii*) accelerator mass spectroscopy (AMS) and conventional radiocarbon dates (Table 1). Radiocarbon ages are calibrated to calendar years before present (1950) using calibration program (Calib Rev 5.0.2) of *Stuiver and Reimer* [1993]. The chronology was extended down to ~137 kyr by tuning the $\delta^{18}O$ ratio of *G. ruber*, measured at Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, to the low latitude isotopic stack of *Martinson et al.* [1987] and *Bassinot et al.* [1994] (Figure 1). The Mg/Ca ratio was converted to SST using the depth corrected *G. ruber* Mg/Ca-SST calibration of *Dekens et al.* [2002] (Mg/Ca = 0.38 exp 0.09 [SST − 0.61 (core depth km)]).

3. Results

[4] The core top SST reconstructed from Mg/Ca analysis (28.1°C) matches precisely with the modern SST (28.5°C) [*Levitus and Boyer*, 1994] at the core location. Analytical reproducibility of our SSTs based on triplicate analyses of the core samples is of ~0.1°C. However, the long-term accuracy of standard is ±0.05–0.07 mmol/mol Mg/Ca, and the standard error of the calibration is of ~1.2°C [*Dekens et al.*, 2002]. The down core variation of Mg/Ca SST, shows that the equatorial Indian Ocean was ~2.1°C cooler during the Last Glacial Maximum (LGM) as compared to present (Figure 2). Over the last ~122 kyr, the period after the penultimate glacial-interglacial transition, temperature has been as low as that during LGM at least during three more occasions, ca. ~31 kyr, ~43 kyr and ~65 kyr. The maximum SST in the equatorial Indian Ocean during the penultimate interglacial period (stage 5e) was higher (~29.9°C) than present interglacial period (maximum ~28.8°C). Even though the temperature contrast over the last two glacial-interglacial transitions was comparable (~2.2°C and ~2.6°C), the equatorial Indian Ocean was comparatively warmer during the penultimate glacial-interglacial transition than during the last glacial-interglacial transition. SSTs were considerably lower throughout the isotopic stage 4 and the beginning of stage 5. The last glacial-interglacial transition followed a two-step warming insert a pattern not represented in the penultimate glacial-interglacial transition. The signatures of the Younger Dryas cooling (~0.4°C) are present but could not be resolved further due to the limitation of sample resolution.

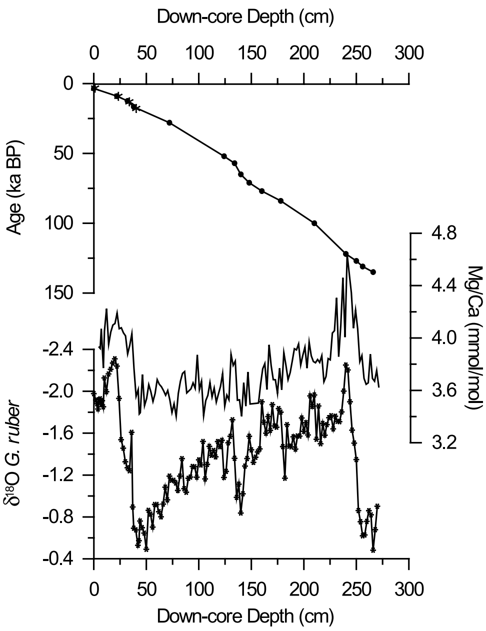

Figure 1. Chronology for the core based on Accelerator Mass Spectrometer and conventional radiocarbon ages along with comparison of $\delta^{18}O$ *G. ruber* with low latitude global isostack of *Martinson et al.* [1987] and *Bassinot et al.* [1994]. The points on the age vs core-depth curve are the tie-points used to develop chronology. The tie points with asterisks are the reservoir corrected radiocarbon dates. The Mg/Ca values (mmol/mol) are also given in order to assess the relative timings of $\delta^{18}O$ and Mg/Ca variation.

4. Discussion

[5] Solar insolation and large-scale upwelling in the western Indian Ocean induced by strong seasonally reversing currents mainly regulates SSTs in the equatorial Indian Ocean. SST gradients in the equatorial Indian Ocean are reversed relative to those of other world oceans, with temperatures increasing from west to east [*Webster et al.*, 1999]. Thus, understanding past temperature variation from the equatorial Indian Ocean is important to understand past upwelling and associated monsoon variations. The foraminiferal Mg/Ca based glacial-interglacial SST difference estimate from the equatorial Indian Ocean, though slightly higher than the CLIMAP estimates of tropical glacial-interglacial SST difference [*CLIMAP Project Members*, 1976, 1981], agree with the alkenone unsaturation ratio

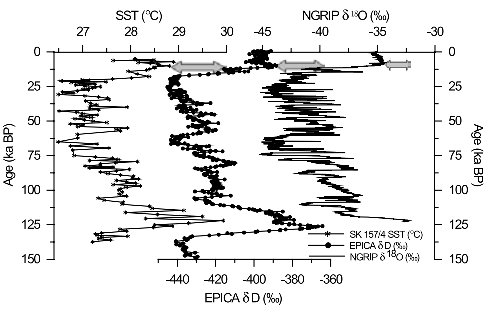

Figure 2. Comparison of SST variation in equatorial Indian Ocean reconstructed from the Mg/Ca analysis of surface dwelling planktonic foraminifer *G. ruber*, with δD variation over Antarctic [*EPICA Community Members*, 2004] and $\delta^{18}O$ variation over Greenland [*North Greenland Ice Core Project Members*, 2004]. The gray arrows indicate the contrast between isotopic stage 5e and present interglacial temperature.

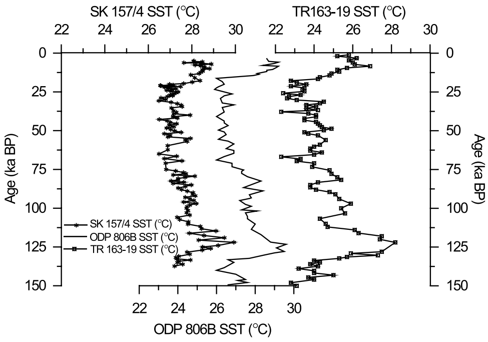

Figure 3. Down-core variation of SST from equatorial Indian Ocean reconstructed from the Mg/Ca analysis of surface dwelling planktonic foraminifer *G. ruber*, and SST variations over the eastern and western Pacific Ocean [*Lea et al.*, 2000].

based SST estimates [*Rostek et al.*, 1993, 1997; *Sonzogni et al.*, 1998] as well as the SST estimated through ANN based on quantitative analyses of planktonic foraminifera [*Naidu and Malmgren*, 2005]. The decreased SST during glacial periods would have resulted in decreased land-ocean temperature contrast, one of the main driving factors for southwest monsoon [*Clemens et al.*, 1991]. Thus, during glacial periods the southwest monsoon would have been weaker. Various workers have reported weaker southwest monsoon during glacial times [*Clemens et al.*, 1991; *Naidu and Malmgren*, 2005].

[6] The comparison of the equatorial Indian Ocean SST variation over the last ~137 kyr with the temperature estimates from the Antarctic ice core δD variation and $\delta^{18}O$ variation over Greenland (Figure 2) [*Petit et al.*, 1999; *EPICA Community Members*, 2004; *North Greenland Ice Core Project Members*, 2004] shows that similar, comparatively high temperature during isotopic stage 5e are also reported in the Vostok, EPICA Dome C and Greenland ice cores, as well as alkenone unsaturation based paleotemperature estimates from the equatorial Indian Ocean region [*Bard et al.*, 1997]. The comparison further shows that the major high-latitude cooling/warming events are also present in the equatorial Indian Ocean SST variation record. The signatures of ~115 kyr warming, reported from the NGRIP ice core [*North Greenland Ice Core Project Members*, 2004] are also evident in SST variation from the equatorial Indian Ocean (Figure 2). However our Mg/Ca based SST difference during the penultimate glacial-interglacial transition (~2.6°C) differs significantly from the alkenone based SST contrast for the same period (~1.0°C), as estimated in a nearby core MD 900963 [*Rostek et al.*, 1993]. Also, the alkenone-SST record shows an unusual glacial/interglacial variation encompassing almost constant values from 150 to 60 kyr BP, whereas our Mg/Ca-SST record shows a more typical glacial/interglacial SST changes during the same period. The possible resuspension and bottom transport of alkenones due to bottom currents [*Kolla et al.*, 1976] might have influenced alkenone SSTs.

[7] A comparison of SST variation over the last ~135 kyr from the equatorial Indian Ocean with the SST variations over the similar period from the eastern and western Pacific [*Lea et al.*, 2000] shows that the amplitude of LGM cooling in the equatorial Indian Ocean (~2.2°C) was slightly less than that in both the eastern and western Pacific (2.6 ± 0.8°C and 2.8 ± 0.7°C, respectively, Figure 3). The comparison further shows that the equatorial Indian Ocean was warmer than the western Pacific throughout the isotopic stages 2, 3 and 4. The SSTs in the equatorial Indian and western Pacific Ocean were comparable during the later part of the isotopic stage 5, except for the slightly higher equatorial Indian Ocean SST during the stage 5e. Interestingly, the SST contrast between stage 5e and present interglacial in the equatorial Indian Ocean is similar to that of the eastern Pacific despite the proximity of the core location with the western Pacific Ocean [*Lea et al.*, 2000] (Figure 3). Since the amplitude as well as pattern of SST variation over the last ~137 kyr from equatorial Indian Ocean closely matches the SST variation over the same period from the western Pacific, it appears that the equatorial Indian Ocean mimics the climatic variation in the western Pacific. There appears to be a common mechanism regulating the SST variation in both equatorial Indian Ocean and equatorial Pacific Ocean. Further detailed study is in progress and results will be published elsewhere.

5. Conclusion

[8] Based on this first record of *G. ruber* (white) Mg/Ca-SST from the central equatorial Indian Ocean, we conclude that the cooling in this location during the LGM is comparable with cooling estimates based on other proxies. Though, the SST contrast over the last two glacial-interglacial transitions was comparable, the equatorial Indian Ocean was comparatively warmer during the penultimate interglacial period. Equatorial Indian Ocean SST variation over the last ~137 kyr period contain all the major cooling/warming events as reported from high-latitude climatic variations over the same period. Comparison of the equatorial Indian Ocean SST variation with that of the Pacific Ocean shows stark similarity between SST variation in the equatorial Indian Ocean and the western Pacific Ocean, thus suggesting the possibility of a common mechanism regulating the Indian Ocean and Pacific Ocean SST over larger time scales.

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