Supplementary Information

The monsoon imprint during the 'atypical' MIS 13 as seen through North and Equatorial Indian Ocean records

Thibaut Caley[1]*, Bruno Malaizé[1], Franck Bassinot[2], Steven C. Clemens[3], Nicolas Caillon[2], Rossignol Linda[1], Karine Charlier[1], Helene Rebaubier[2].

Sea surface salinity (SSS) reconstructions and potential bias

In order to reconstruct past changes in seawater $\delta^{18}O$ ($\delta^{18}Osw$), we took advantage of the double influence of surface temperature and the isotopic composition of seawater ($\delta^{18}Osw$) on the planktonic foraminifera stable oxygen isotopic values (Duplessy et al., 1991). For this purpose, we used the isotopic paleotemperature equation of Shackleton and Opdyke (1973):

$$T = 16{,}9-4{,}38\ (d^{18}O_{foram(PDB)}-d^{18}Osw)\ +0{,}1\ (d^{18}O_{foram(PDB)}-d^{18}Osw)^2$$

Then, using the measured planktonic $\delta^{18}O$ values ($\delta^{18}O_{foram}$), and using the Mg/Ca-derived SST as an estimate of the isotopic temperature (T), this equation was solved in order to extract the $\delta^{18}Osw$ signal.

Method 1:

The residual $\delta^{18}Osw$ signal can be interpreted in terms of past local SSS variations and global isotopic signal. To remove $\delta^{18}O$ variations due to glacial-interglacial continental ice volume changes, we used a global, ice volume-related $\delta^{18}O$ signal extracted from the benthic LR04 stack record of Lisiecki and Raymo (2005) through an inverse approach (Bintanja et al., 2005). This approach is named method 1 in Figures S1 to S3.

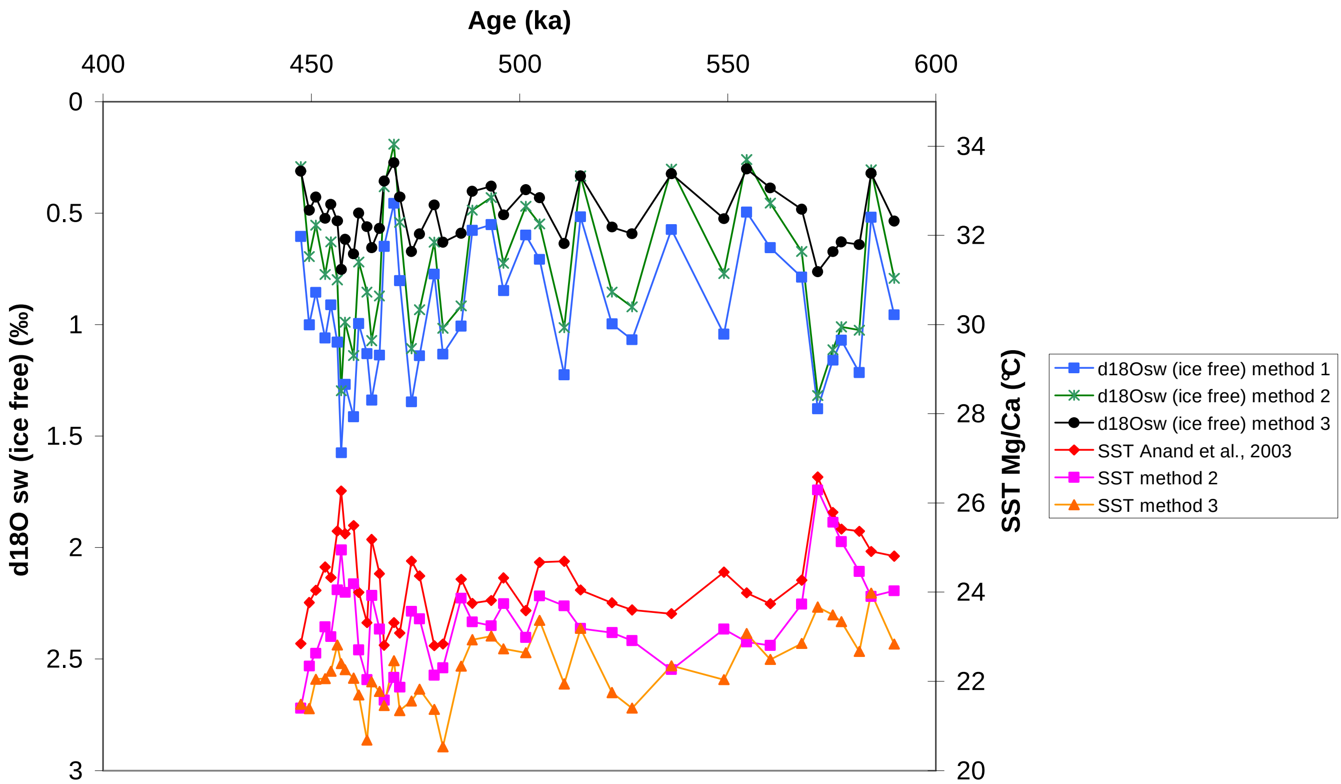

Figure S1: Comparison between three different approaches (method 1 to 3) used to obtain the δ^{18}Osw (ice free), a proxy a sea surface salinity changes at site ODP 722. Slight differences are observed for SST reconstructions. However, for δ^{18}Osw (ice free) reconstructions, the directionality and details of the record remain mostly intact.

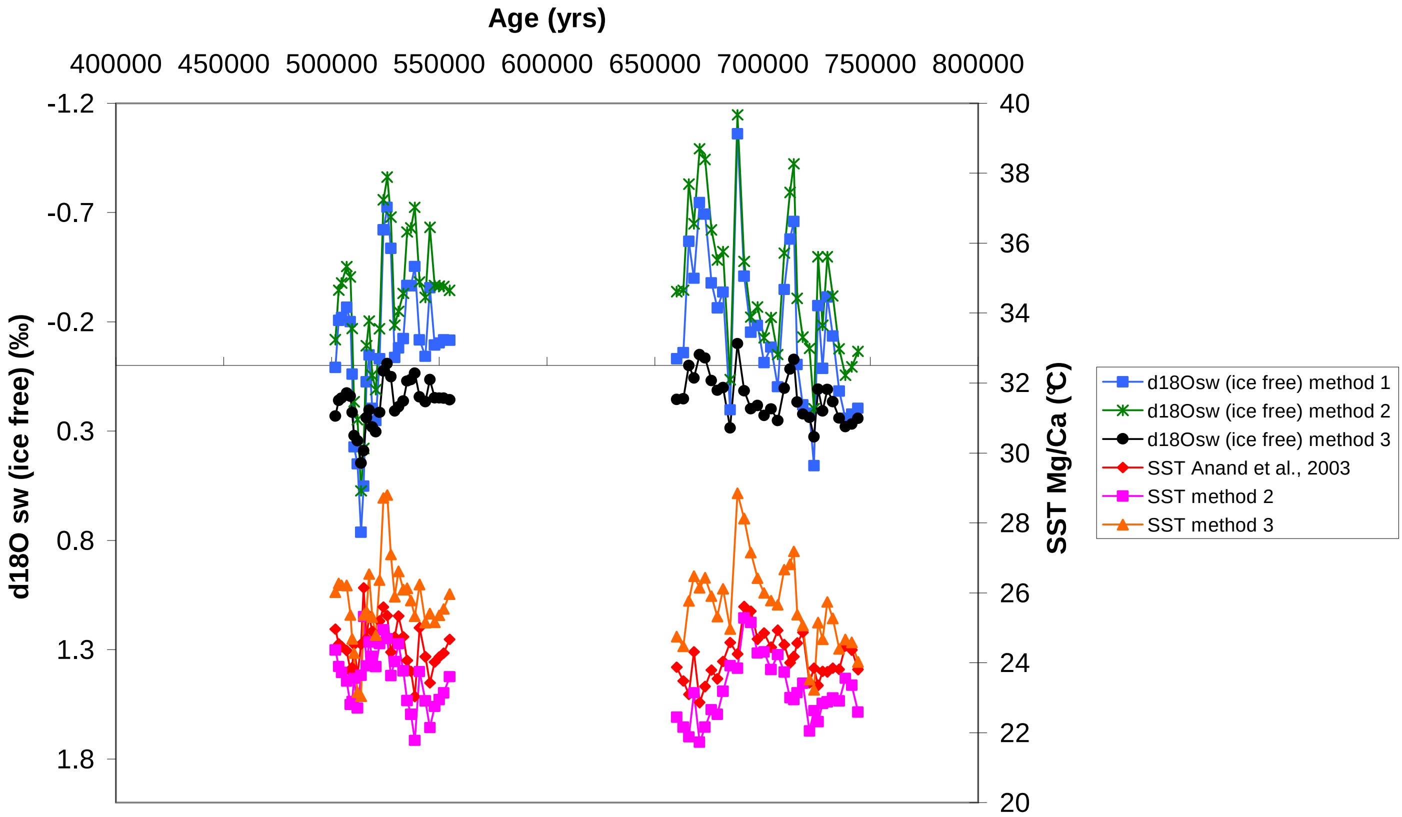

Figure S2: same as Figure S1 but for site MD90-0963.

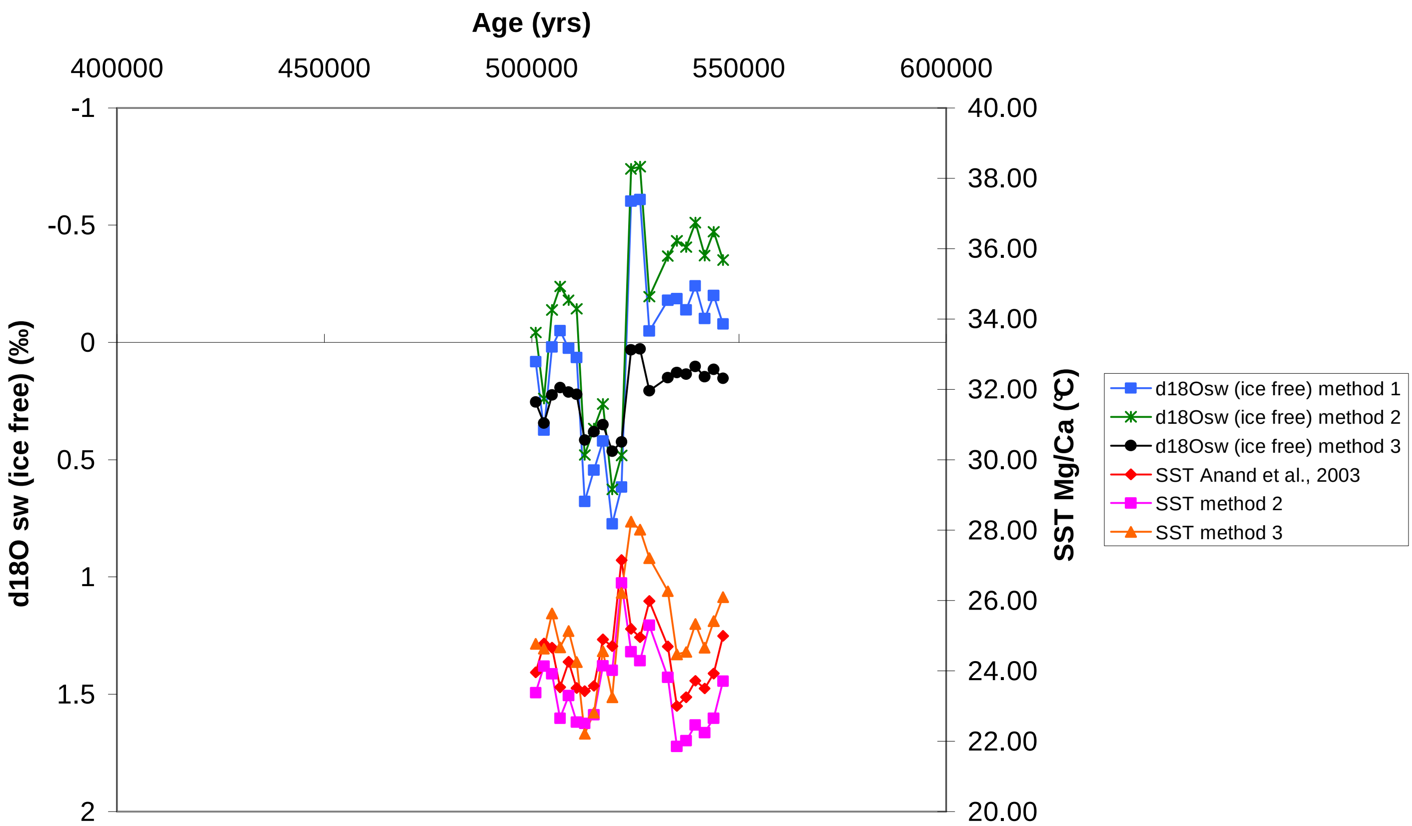

Figure S3: same as Figures S1 and S2 but for site MD90-0961.

Method 2:

A potential salinity effect on planktonic foraminifer Mg/Ca has been discussed in the literature (Nuernberg et al., 1996; Lea et al., 1999; Ferguson et al., 2008). A recent work showed that *G.ruber* Mg/Ca-derived temperatures are strongly affected by sea surface salinity variations, with a +1 psu change in salinity leading to a potential temperature bias of +1.6°C (Mathien-Blard and Bassinot, 2009).

In order to estimate the potential effect of this glacial/interglacial salinity change on the Mg/Ca-derived temperatures, we transformed estimation of sea level variations (Bintanja et al., 2005) into global salinity changes. Based on Mathien-Blard and Bassinot's results, we considered that 1 psu change in salinity would induce a 1.6°C change in $T_{Mg/Ca}$ relative to the isotopic temperature of calcification (Mathien-Blard and Bassinot, 2009). With this correction in mind, we derived salinity-corrected SST (named <u>method 2</u> in Figures S1 to S3), which were combined with foraminifer $\delta^{18}O$ to estimate a residual $\delta^{18}Osw$ signal. Thus, our correction procedure on Mg/Ca-thermometry is only partial and is based on the double assumptions that 1/ past interglacial showed roughly the same salinity as the present day, and 2/ past glacial salinity changes, relative to today, primarily reflect global ice-volume effects, with no other, local perturbation.

The residual $\delta^{18}Osw$ signal can be interpreted in terms of past local SSS variations and global isotopic signal. To remove $\delta^{18}O$ variations due to glacial-interglacial continental ice volume changes, we used a global, ice volume-related $\delta^{18}O$ signal extracted from the benthic LR04 stack record of Lisiecki and Raymo (2005) through an inverse approach (Bintanja et al., 2005). This approach is named <u>method 2</u> in Figures S1 to S3 and show a very good consistency compared with <u>method 1</u>.

Method 3:

With this method, we used the correction procedure developed by Mathien-Blard and Bassinot (2009) to derive unbiased SST and $\delta^{18}Osw$ from *G. ruber* $T_{Mg/Ca}$ and foraminifer's $\delta^{18}O$ measurements ($\delta^{18}Of$).

We used the equation (1) $\delta^{18}Osw* = \delta^{18}Of + A + 5*(B + 0.4TMg/Ca + C\delta^{18}Of + D\Delta\delta^{18}Og)$^0.5 with tropical Indian ocean parameter for site MD90-0963/0961 and Arabian Sea parameters for site ODP 722 (see Table 3 in Mathien-Blard and Bassinot (2009)). This allows to extract a term corrected for the salinity effect on $T_{Mg/Ca}$.

To obtain a calcification temperature for *G. ruber* that is corrected for the salinity bias, the adjusted $\delta^{18}Osw*$ obtained from equation (1) is reinjected in the original, thermometry equation from Shackleton and Opdyke (1973).

The correction procedure has an impact on SST reconstructions (Figures S1 to S3). However, in this study, we are interested by a potential bias on SSS reconstructions.

For $\delta^{18}Osw$ (ice free) (SSS proxy), the results indicate that while the magnitude of change is reduced using the correction procedure of Mathien-Blard and Bassinot (2009), the directionality and details of the record remain mostly intact (Figures S1 to S3). Similar results have been found in a recent work (Arbuszewski et al., 2010).

Thus, the correction procedure has no impact on our conclusion. Nonetheless, the correction procedure is based on the assumption that regional (evaporation/precipitation) and global (ice sheet) SSS-$\delta^{18}Osw$ relationships are known and invariant over the glacial/interglacial cycle. A modelisation exercice showed that this assumption is likely valid back to the Last Glaciatl Maximum in the tropical Indian Ocean (Delaygue et al., 2001). However, other authors have claimed that the regional SSS-$\delta^{18}Osw$ relationships may have changed in the past (Rohling and Bigg, 1998) and this could lead to different regional relationship during the atypical MIS 13. That is why, in this study, we present only the results for method 1 and 2 as we consider that it represents sufficient approaches, with relative simple and easily grasped assumptions. Anyway, as far as the discussion of this paper is concerned, the results are not significantly different compared to those obtain with the complete correction procedure of Mathien-Blard and Bassinot (2009).

Supplementary references

Arbuszewski, J., deMenocal, P., Kaplan, A., Farmer, E.C. 2010. On the fidelity of shell-derived $\delta^{18}O$ seawater estimates. Earth and Planetary Science Letters 300, 185-196.

Delaygue, G., Bard, E., Rollion, C. 2001. Oxygen isotope/salinity relationship in the northern Indian Ocean. J. Geophys. Res.,106, 4565–4574, doi:10.1029/1999JC000061.

Rohling, E., Bigg, G. 1998. Paleosalinity and $\delta^{18}O$: A critical assessment. J. Geophys. Res., 103(C1), 1307–1318, doi:10.1029/97JC01047.