# S1 Correction of δ18Ob inter-lab offset

In our Site U1308 records from 258.95–264.71 mcd we observe a significant inter-lab offset (Fig. S3, average: +0.29‰) between the δ18Ob measured alongside Δ47 and the previously published δ18Ob of De Schepper et al. (2013). In the adjacent interval from 253.95–259.01 mcd we find that the δ18Ob (corrected for species-specific offsets) measured alongside Δ47 is in good agreement with our new stable isotope data from *C. wuellerstorfi* and *C. mundulus* measured on a different instrument. Due to the good agreement between our two new sets of stable isotope data, we have adjusted the published δ18Ob-data of De Schepper et al. (2013) by 0.29‰. This adjustment also brings the published data in better agreement with the global benthic oxygen isotope stack (Lisiecki and Raymo, 2005).

# S2 Evaluation of contamination on Mg/Ca ratios of O. umbonatus

Clay, Fe-Mn oxyhydroxides or Fe-Mn carbonate coatings that are not removed during cleaning can bias reconstructed Mg/Ca temperatures (Barker et al., 2003). Typically, Al/Ca, Fe/Ca and Mn/Ca ratios above 0.1 mmol/mol are considered to indicate the presence of such contamination. In our samples, Al concentrations are near or below the detection limit of the ICP-OES, arguing against clay contamination. Fe/Ca ratios (Fig. S4 and S4) remain consistently above 0.1 mmol/mol for all Site U1308 samples (average 0.67 mmol/mol) and for a large portion of Site 849 samples (average 0.2 mmol/mol) suggesting Fe-bearing coatings might have been present on the surface of *O. umbonatus* tests. However, we find no correlation between Fe/Ca and Mg/Ca values (R2 =0.25 for Site 849, R2 =0.01 for Site U1308) showing that high Fe/Ca ratios are not associated with high Mg/Ca values. This indicates that Fe-bearing coatings have not influenced Mg/Ca towards higher (i.e., warmer) values.

Mn/Ca values are also consistently above the 0.1 mmol/mol threshold indicative of Mn-bearing coatings at both sites (Fig. S4 and S4). However, again we find no correlation between Mg/Ca and Mn/Ca (R2 =0.06 for Site 849, R2 =0.0009 for Site U1308), which would be expected if our samples were overgrown with Mn-rich coatings. Furthermore, the highest Mg/Ca ratios measured at both sites are associated with Mn/Ca values that are below the average Mn/Ca ratios for our records (1.0 mmol/mol at Site 849, 1.1 mmol/mol at Site U1308) further indicating that overgrowths did not bias the original Mg/Ca towards higher values. Additionally, SEM images do not show microcrystalline overgrowths on benthic foraminiferal test surfaces (Fig. S1 and S2).

# S3 Recalculation of published mid-Pliocene Mg/Ca records

To make previously published Mg/Ca records from Site 1208 (North Pacific, Woodard et al., 2014) and Site 607 (North Atlantic, Sosdian and Rosenthal, 2009) more comparable to our new records, we recalculated these data to adjust for changes in Mg/Casw following Lear et al. (2002) and using estimates of past Mg/Casw of Evans et al. (2016). The record of Sosdian and Rosenthal (2009) was generated on *C. wuellerstorfi* and *O. umbonatus*. From their full dataset, they calculate an interspecies Mg/Ca offset of 0.16 mmol/mol. After normalizing *O. umbonatus* to *C. wuellerstorfi*, their published temperatures were calculated by applying a regional *Cibicidoides* Mg/Ca-temperature calibration to the composite Mg/Ca record. Here, we instead normalize values to *O. umbonatus* and apply the *O. umbonatus*-specific calibration of Lear et al. (2002) — also used for our Site U1308 record — following Jakob et al. (2020). The adjusted temperature record of Sosdian and Rosenthal (2009) and Woodard et al. (2014) are presented in Fig. S6. We find that the recalculated North Atlantic record of Sosdian and Rosenthal (2009) is in very good agreement with our Site U1308 data, with both records indicating average temperatures of 7-8°C.

The adjusted North Pacific record of Woodard et al. (2014) is in better agreement with our Site 849 temperatures than the original record, but still suggests colder-than-present average temperatures. While applying a different calibration to these data could bring the absolute temperatures of this record more in line with our Site 849 data, we also note that temperatures at these two sites occasionally appear to record opposite trends (e.g. during KM5 and KM6), supporting a difference in the evolution on BWT and sourcing of deep water masses at these sites.

A picture containing indoor

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Fig. S1 Scanning Electron Microscope images of benthic foraminifera from Site 849. (a) *Uvigerina* spp. from sample 9H-1,140-142 cm (b) Inside view of *Uvigerina* spp. fragment from sample 9H-1,140-142 cm (c) *Cibicidoides* spp. from sample 8H-5,112-114 cm (d) Inside view of *Cibicidoides* spp. fragment from sample 8H-5,112-114 cm. Tests are well preserved — note the preservation of delicate pore channels and layered wall structure in close-up views (arrows).

A collage of images of a variety of objects

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Fig. S2 Scanning Electron Microscope images of benthic foraminifera from Site U1308. (a) *Uvigerina* spp. from sample 26H-4,101-103 cm (b) Inside view of *Uvigerina* spp. fragment from sample 26H-4,101-103 cm (c) *Globocassidulina* spp. from sample 25H-5,130-132 cm (d) Inside view of *Globocassidulina* spp. fragment from sample 25H-5,130-132 cm. Tests are well preserved — note the preservation of delicate pore channels in close-up views (arrows).

Chart, scatter chart

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Fig. S3 Foraminiferal δ18Ob data from North Atlantic Site U1308 alongside the global benthic oxygen isotope stack of Lisiecki and Raymo (2005). Orange line: De Schepper et al. (2013) *Cibicidoides wuellerstorfi* and *Uvigerina peregrina* data. Red line: This study (*C. wuellerstorfi* and *Cibicidoides mundulus)* and adjusted (+0.29‰) data of De Schepper et al. (2013). Red circles: This study from individual Δ47 measurements of *Uvigerina spp*. and *Cibicidoides spp*. All *C. mundulus*, *C. wuellerstorfi* and *Cibicidoides spp.* data normalized to equilibrium (+0.64‰) following Shackleton et al. (1984).

Chart, scatter chart

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Fig. S4 Cross plot between Site 849 *O.umbonatus* Mg/Ca and Mn/Ca ratios (left) and Mg/Ca and Fe/Ca ratios (right)

Chart, scatter chart

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Fig. S5 Cross plot between Site U1308 *O.umbonatus* Mg/Ca and Mn/Ca ratios (left) and Mg/Ca and Fe/Ca ratios (right)

Chart

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Fig. S6 a) Benthic foraminiferal δ18O (δ18Ob) from Site 849 (light blue, 5 pt. running mean, Jakob et al., 2021), Site 1208 (dark blue, 3 pt. running mean, Woodard et al., 2014), and Site U1308 (red, 3 pt. running mean: this study and De Schepper et al., 2013) and the global δ18Ob stack of Lisiecki and Raymo (2005) (grey). Note the good stratigraphic agreement between sites for our study interval. b) Mg/Ca-based temperature records covering the mid-Pliocene. Site U1308 (red, 3 pt. running mean, this study), Site 849 (blue, 5 pt. running mean, this study), Site 607 (light and dark orange representing original and adjusted values, respectively. 3 pt. running mean, Sosdian and Rosenthal, 2009) and Site 1208 (light and dark blue representing original and adjusted values, respectively. 3 pt. running mean, Woodard et al., 2014).

Chart, histogram

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Fig. S7 a) Benthic foraminiferal δ18O from Site 849 (purple, 5 pt. running mean, Jakob et al., 2021), Site 999 (green, de la Vega et al., 2020) and the global δ18Ob stack of Lisiecki and Raymo (2005) (grey), b) Site 849 benthic foraminiferal Mg/Ca and Δ47-based bottom water temperatures (this study) and c) reconstructed atmospheric CO2 from the δ11B-pH proxy from Site 999 (de la Vega et al., 2020). Note the good alignment of Site 849 and 999 δ18Ob showing that the lag between δ18Ob at Site 849 and CO2 is not an effect of age model offsets.

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