CP-2019-161 *Lessons from a high CO2 world: an ocean view from ~3 million years ago*

Reply to reviewer 2

We thank the reviewer for the positive and constructive comments on the manuscript. In response to the minor comments raised by reviewer 2 (which are italicised):

1) *I suggest changing "a ~100 kyr window of relatively low benthic δ18O values" to "a ~100 kyr window of relatively depleted benthic δ18O values" to avoid the possible ambiguity of what "low" means to the reader.*

   This has been corrected (line 98). We have edited to ensure that the statement is clear about which isotope is depleted:

   "...centred on a ~100 kyr window of relatively depleted benthic ^{18}O values..."

2) *P 7: "Thus, there is a broad, but complex, pattern of enhanced warming at the mid- and high-latitudes, reflecting a combination of regional influences on circulation patterns, and to some extent, proxy choice. This pattern is not explained by temporal variability nor sample density within the KM5c time interval: regardless of sample number per site, the standard deviation is <1.5oC (Figure S4). " In light of the "complex pattern" and "temporal variability", can the authors clarify what the standard deviation" refers to? I assume it's the variation at a given site within the KM5c time bin? So I suggest adding "the standard deviation at any site within the time bin is < 1.5oC"*

   The reviewer is correct in his interpretation of the standard deviation plot. We have incorporated the reviewer's suggested change to the text (lines 235-236).

3) *P. 7: "Mg/Ca-SST anomalies are generally lower than for UK 37', ". Since the authors have been pointing out differences in the interpretation of Uk'37 anomalies between using the Muller linear regression and the BAYSPLINE calibration, can they clarify whether the Mg/Ca anomalies are lower than BOTH calibrations or specifically the BAYSPLINE one or both? From context, given that 8 sites gave a negative KM5c anomaly (!!) It would seem that Mg/Ca deviates from both alkenone calibrations.*

   There is an inconsistent relationship between the alkenone SST anomalies and those from Mg/Ca. As we state, in general the Mg/Ca anomalies are lower than for UK'37, but at two sites we find Mg/Ca-SST anomalies which are greater than those of the model outputs (U1313 in the North Atlantic, Site 763 in the Indian Ocean). For both of these sites the original Mg/Ca calibration is lying closest to the Muller98 calibration output for sites in a similar latitude: but for Site 763 we note here that the 'closest' site by latitude is Site 1087 in the South Atlantic. This demonstrates the challenge we face for making direct comparisons between the proxy outputs: there are only three sites with <u>both</u> Mg/Ca and alkenone data available (which we stated in the same paragraph).

   We recognise the reviewers concern that it would be useful to state this complexity more clearly. We have edited the text accordingly (lines 250-265):

Overall, the U^{K}_{37}'-temperature anomalies lie within the range given by PlioMIP2 models (Figure 4). The Mg/Ca estimates are mainly from the low latitudes, and high-latitude (>60ºN/S) Mg/Ca SST data are not available to calculate meridional gradients using foraminifera data alone (Figure 4). Mg/Ca-SST anomalies are generally lower than for U^{K}_{37}', and a cooler KM5c than pre-industrial is consistently (but not always) recorded in the low-latitudes by Mg/Ca regardless of calibration choice (Figure 4). As a result, combining U^{K}_{37}' and Mg/Ca data leads to a cooler global mean SST (~2.3°C) than when using U^{K}_{37}' alone (~3.2°C, Figure 3). At 8 sites, the negative KM5c SST anomalies in Mg/Ca disagree with both the U^{K}_{37}' data and the PlioMIP2 model outputs (Figure 4). The disagreement is present regardless of whether the Müller98 or BAYSPLINE calibrations are applied, but the difference is larger in the low latitudes for BAYSPLINE because this calibration generates higher SST values here (Section 2.3.1). Only three sites have both U^{K}_{37}' and Mg/Ca data (DSDP Site 609, IODP Sites U1313 and U1143) to enable direct comparison between Mg/Ca and alkenone SST data. Reconstructed SSTs for IODP Sites U1313 and U1143 are within calibration uncertainty. At Site U1313 (41°N) there is overlap between both alkenone outputs (Müller98 21.6°C, BAYSPLINE 20.9°C) and the original Mg/Ca reconstruction (22.2°C), whereas BAYMAG generates warmer SSTs (27.0°C). At Site 1143 (9°N), BAYSPLINE-SSTs are warmer (30.6°C) than from the Müller98 (28.9°C), original-Mg/Ca (27.7°C) and BAYMAG (27.1°C). In contrast, DSDP Site 609 (49°N) has colder Mg/Ca estimates (original 11.7°C, BAYMAG 12.5°C) than alkenones (Müller98 17.7°C, BAYSPLINE 17.1°C) or models (Figure 4).

4) *p. 8: "KM5c is characterised by a surface ocean which is ~2.3 C (alkenones and Mg/Ca) or ~3.2 C (alkenones-only) warmer than 240 pre-industrial, with a ~2.6 C reduction in the meridional SST gradient. " Which alkenone calibration was adopted for the "alkenones-only" estimate? What would be the difference of Muller vs BAYSPLINE?*

The alkenones-only global SST anomaly we stated was generated using only the Müller calibration. For clarity, we now indicate in the text (lines 288-289) the two values:

"...~3.2°C (alkenones-only, Müller 98) or ~3.4°C (alkenones-only, BAYSPLINE calibration)...".

The abstract has also been edited to reflect this (line 56):

"...or by ~3.2-3.4°C (alkenones only)."

5) *p. 11: I think there's something funny about the NOAA-ERSST temperatures for the region. We have unpublished alkenone SST estimates from Site 1085 for the KM5c interval that show an anomaly of ~3 degrees when using the WOAA. My sense is that the large Benguela anomalies arise entirely from using the NOAA-ERSST atlas and that they would fall in line with expected values if other atlases were used. The authors should at a minimum consult other atlases and explore the possibility of a regional SST bias in the NOAA-ERSST estimates. I think this is a much more parsimonious explanation than the oceanographic ones proposed in lines 340-352. This in fact is my major suggestion: to examine whether that data base imposes a significant bias to the results here.*

The reviewer raises a concern about the alkenone SST anomalies we show for the Benguela upwelling region, which far exceed the anomalies calculated from the models (Figure 4 in the main text, <u>and below</u>). We have compared the data anomalies generated using NOAA-ERSST or the World Ocean Atlas 2018 (Locarnini et al., 2018), and show the results. Using WOA18 reduces the two of the SST anomalies in the Benguela upwelling sites: Site 1082 (from +9.5°C to +8.0°C) and Site 1081 (from +8°C to +6.5°C). In contrast, at Site 1084 there is an increase in the SST anomaly by ~0.5°C when using WOA18. The reviewer queried whether the NOAA-ERSST database introduces a bias to the SST anomalies we generate: our comparison indicates that on the whole there are minor offsets between the two products. However, regardless of which database is used, the main Benguela upwelling sites in the Pliocene continue to show SST anomalies which far exceed the PlioMIP2 model output (see Figure below). We therefore prefer to keep our reflection on the possible oceanographic causes of this data-model offset on page 11.

The reviewer comments that he finds lower SST anomalies at Site 1085 than our main Benguela sites when using WOA18. We note here that the +3°C anomaly he states is comparable with Site 1087, where the difference in the SST anomaly between NOAA-ERSST and WOA18 is also less than 0.5°C. Both Site 1085 and Site 1087 lie in the Southern Benguela region, which is today under greater influence from the Benguela Current (and potentially the Agulhas retroflection) than the main cells to the north (Sites 1081, 1082 and 1084; Wefer et al., 1998). It has also been shown that during the mid-Pliocene, coastal upwelling in the Southern Benguela region was enhanced compared to today (e.g. Petrick et al., 2018), which may account for the similarities between Sites 1085 and 1087, and their differences to those sites located in the central and northern upwelling region.

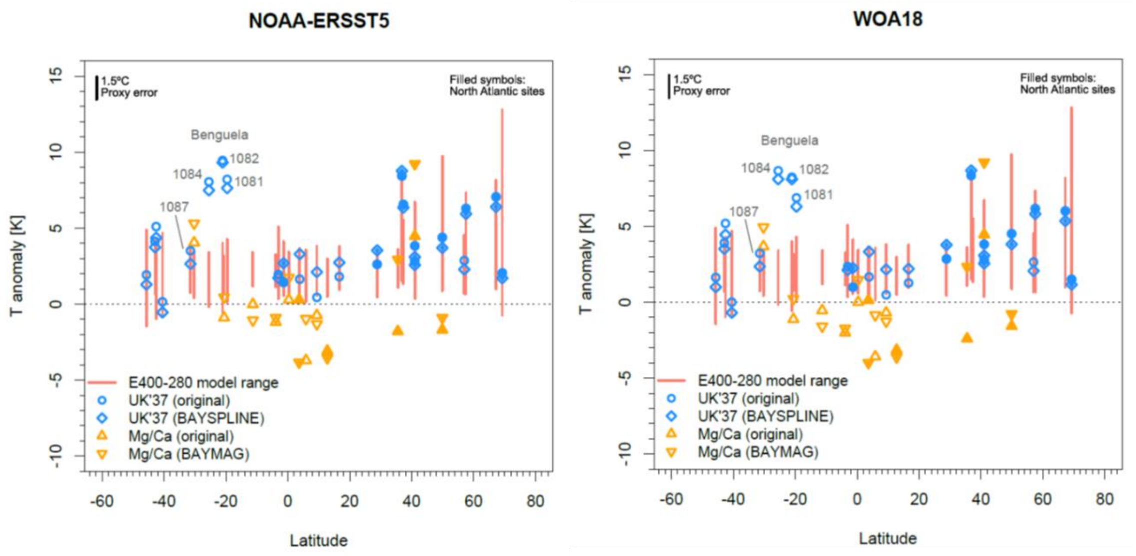

Figure 1: comparison of SST anomalies for the proxy data, using NOAA-ERSST5 (left, as undertaken in the original submission) and World Ocean Atlas 2018 (right, Locarnini et al., 2018). Sites from the Benguela upwelling region are annotated.

Literature cited:

Locarnini, R. A., A. V. Mishonov, O. K. Baranova, T. P. Boyer, M. M. Zweng, H. E. Garcia, J. R. Reagan, D. Seidov, K. Weathers, C. R. Paver, and I. Smolyar (2018) World Ocean Atlas 2018, Volume 1: Temperature. A. Mishonov Technical Ed.; NOAA Atlas NESDIS 81, 52 pp.

Petrick, B., McClymont, E. L., Littler, K., Rosell-Melé, A., Clarkson, M. O., Maslin, M., Röhl, U., Shevenell, A. E., and Pancost, R. D. (2018) Oceanographic and climatic evolution of the southeastern subtropical Atlantic over the last 3.5 Ma, Earth and Planetary Science Letters, 492, 12-21, https://doi.org/10.1016/j.epsl.2018.03.054.

Wefer, G., Berger, W.H., Richter, C., et al. (1998) Proc. ODP, Init. Repts., 175: College Station, TX (Ocean Drilling Program). doi:10.2973/odp.proc.ir.175.1998.