

## ***Interactive comment on “Global and regional sea surface temperature trends during Marine Isotope Stage 11” by Y. Milker et al.***

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We thank the referees for their constructive and relevant comments, which touch several critical issues of the paper. We believe we are able to address these concerns effectively and outline below in detail how this can be done. As a result of these comments, the revised version of the paper now includes a more thorough consideration of proxy uncertainties, which resulted in two additional graphs and analyses presented in the supplementary information. We have also considered more carefully aspects of the proxy-model comparison, especially the robustness of the comparison of anomalies.

The response to the individual comments by both referees is given below, highlighting the original comments, which are followed by the response.

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“This paper compares a compilation of temperature proxy data spanning MIS-11 to modeled temperature anomalies, in order to detect the importance of orbital and greenhouse gas climate feedback processes during this interglacial. I found the paper reasonably well written, and rich in detail. However, the downside to this style of writing is that the central point of the paper is sometimes lost in the myriad of data discussion and permutations. If I could suggest one improvement, it would be for the authors to concentrate more on how their study has expanded what we know about MIS-11. For example, we know that orbital forcing had an influence on middle-Brunhes climate, and it is not clear what this study really adds to that. I agree with much of what the other reviewer has already said, but would add a few other points:”

We realize that our study is rich in detail. We fear this is inevitable considering the three novel aspects that it contains: the EOF analysis of the principle trends, the effect of age model uncertainty on these and the comparison with model results. Whilst we believe that all aspects need to be retained, we have tried to simplify the results and enhance the discussion sections to highlight what new information has been obtained by the analyses we present.

“1. Age-model: Tie-points are notoriously difficult to identify during the middle-Brunhes period due to the low amplitude orbital cycles that are expressed in oxygen-isotope records. I therefore wondered why the authors chose to use different tie points for each of their records, some of which (e.g. Figure 2) are very subjectively defined. Would a more objective approach have been to identify a more limited number of tie-points common to all records based only of the most easily identifiable features, such as the steepest part of the TV/IV de-glacial trends? I would have liked to see a table listing all age-control points for each record, and also some indication of whether individual tie-points create spurious sedimentation rate trends; these can be a good indicator of when a record has been over-tuned.”

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This is an important point, which we have indeed considered at length prior to analysis. Limiting the age model construction to a pre-defined subset of control points, optimally such that these record known climatic events, such as MIS boundaries, would have many advantages. Alas, we found that this approach requires limiting the number of control points to such that can be unambiguously identified in the record with least resolution. Following this strategy would have left us with only a handful of control points. Therefore we decided to tune each record separately using the AnalySeries software from Paillard. This software package allowed us to check the change in sedimentation rates graphically after tuning and we used this tool to avoid over-tuning, exactly in the manner as the referee hints at. The referee is right to demand information on how the individual records have been tuned. As indicated in the original version, we will make the entire compilation, including age models for each core, available via Pangaea. To facilitate a faster judgment of the age models, we have now generated age-depth plots for all records and included these in the supplementary information. Like the referee, we were much concerned about the effect of individual age control points on the results of the EOF analysis. This was the motivation to carry out the age-uncertainty analysis.

“2. SST records: Many of the SST records are attributed to mean annual temperature. However, for many of these records, especially UK’37, this attribution is empirical only, based on a good correlation to modern mean annual SST. In reality the production of these biomarkers can be heavily skewed towards a particular growth season, especially at higher latitudes. While the authors address the issue of varying SST errors in their sensitivity test for the EOF analysis, the issue of misattribution of seasonality is not addressed in the same manner. Would this alter the results?”

This is an interesting point – our data-model comparison is season-specific, but unlike the EOF analysis, it does not deal with uncertainty of misattribution of records to a given season (not to talk about the possibility that the seasonal attribution may have changed through time). In order to test what effect the seasonal attribution could have on the data-model comparison, we now carried out two simple permutation tests. In

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these tests, we took the best case of correlation between proxy and model SST (measured by the absolute value of the correlation coefficient  $r$ ) as an extreme scenario and calculated the distribution of the absolute correlation coefficient, based on random selection of all records, ignoring their seasonal attribution for each scenario. This comparison is now shown in supplementary information and also discussed in the text. We can finally state from our permutation tests, that our observed correlation cannot be significantly enhanced by disregarding the season assignment of the proxy data. It is therefore reasonable to assume, that the season assignment is correct and does not bias our results.

“3. Model-data comparison: Some big-picture points are missing from the data-model comparison sections. These include why it is necessary to use a data-model comparison to detect regional and global trends in SST evolution in response to orbital forcing? The proxy SST data, especially expressed in an EOF, should be enough to detect these variations themselves, minus the additional uncertainty introduced by comparing to a simulation with its own sources of uncertainty.”

The CCSM3 model is a state-of-the-art climate model that is widely used to predict climate changes. In particular, this model has been used for the IPCC AR4 climate projections. It is therefore of utmost importance to test the model's capability of simulating past climate variations, in particular variability within the longest and one of the warmest interglacials of the late Quaternary. We believe that this goal is well stated in the paper (e.g. Introduction) but that the abstract had to be revised to clarify this point.

“Additionally, no mention is made of why the chosen model is appropriate for this sort of study; would a different model create a totally different set of data-model comparisons, particularly given the very small range in SST values (see next point)?”

As stated above, CCSM3 is a “standard” IPCC-type model that is widely and successfully used for (paleo)climate predictions and so we do not see why the model should be inappropriate. Until now no other model with a comparable complexity has been

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used for climate predictions of the MIS11 interglacial! Obviously, our statements about the proxy-model comparison are only valid for this model. Finally, we hope to motivate other modelers to use their climate models for MIS11 and other Quaternary interglacial stages and compare their results with our study.

“Lastly, and most importantly, a central theme of this paper is to compare proxy and modeled SST data for three time slices through MIS-11, relative to a long-term baseline calculated for each dataset. What is couldn’t see is a blunt justification of why this approach (comparing anomalies rather than absolute values) is needed. Presumably it is to hide systematic differences in the two approaches and concentrate only on trends, but this needs to be stated.”

Our decision to compare only anomalies is simply guided by the expectation that absolute SST values will be highly correlated. Our comparison is global and proxies and models alike will generate cold polar waters and warm tropics. Thus, correlation in the absolute values we believe is rather unspectacular. The direction of change between the time slices, on the other hand, should be much harder to reproduce because the magnitude is low. It also, as the referee points out, alleviates the problem of systematic bias. If one proxy is systematically overestimating the target variable, it will affect a comparison of the absolute values, but not of the anomalies. We understand fully the concern of the referee and present a comparison of the actual SST values with this response letter (Fig. 1).

“Lastly, the comparison between model and proxy SST anomalies is to my mind greatly hindered by the very low variability in the proxy data across MIS-11. In Figure 7, most of the proxy SST data cluster around ‘0’ and most of the scatter could be encompassed within a 1-2oC error bar (to account for SST uncertainties and the spread of the data averaged within each time slice). So can the authors make a stronger case that the approach they take is justified for such a small range of data?”

The range of variation in the proxy data is in our opinion sufficient to reveal patterns

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beyond the uncertainty in proxy calibration. The reason is that the points in figure 7 are not individual data points but averages for each time slice. By averaging, the uncertainty on the means is reduced by up to the square root of the number of records averaged. In addition, the systematic aspect of the uncertainty (offset) should be removed by considering the anomalies. We concede that this must be seen as a close case, because the extent of the anomalies is within a range of 3°C. This by itself is good news – it would have been hard to imagine that the SST anomalies within the MIS11 interglacial would have been much higher. There is an objective way to determine whether or not the proxy-pattern for each time-slice can be considered as significantly deviation from no change. To this end, we have calculated the confidence interval for the mean proxy-based SST anomaly values as shown in figure 7 and determined the proportion of these that do not contain zero. The confidence interval is a function of both the number of records averaged and the variance among those records. The results are shown in the supplementary information and discussed in the text. They imply that in 55.6% of all cases zero is part of the confidence interval. Consequently, for these cases the direction of the anomaly cannot be estimated accurately.

Minor points:

“1. Page 836, lines 8-9: The configuration of orbital parameters between MIS-11 and the Holocene is not the same; this is why they are so difficult to align. The amplitude of variation is similar.”

We have corrected this statement according the reviewer comments.

“2. Page 836, lines 14-16: Similarly, orbital alignment is not difficult due to weak orbital forcing, but rather to a different phasing of precession and obliquity.”

We agree with the reviewer suggestion and included this fact.

“3. Page 836, line 23: Reference needed after ‘interglacial: : :’”

A reference to a record showing a longer lasting phase of higher temperatures has

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been included.

“4. Page 840, line 23: ‘what’ rather than ‘which.’”

Corrected.

“5. Page 842, line 8: I would suggest the authors employ only raw SST data; using previously constructed stacks only propagates the uncertainties from these constructions.”

In principle, the referee is right. This comment refers to one record, where we have not used the raw proxies, but a stack. In this case, the authors of the study themselves provide a guideline on how their SST data should be best used. Caley et al. (2011) write: “As each proxy has some uncertainty related to the calibration, non-temperature influences and lateral advection, the three records were averaged into a single SST stack . . . It is reasonable to assume that the uncertainties are independent between the proxy types. Therefore, the stack is a more accurate temperature reconstruction than the usual interpretation of single temperature proxy records.” We have nevertheless checked the raw proxies for this site to satisfy ourselves that the use of a stack does not generate a pattern different from that given by individual proxies. In this case, we could see that the proxies showed almost identical patterns, which were systematically offset. Therefore, there should be no significant effect on either the EOF analysis or the data-model comparison.

“6. Page 843, lines 5 and 8: ‘Principal,’ not ‘principle.’”

Corrected.

“7. Page 843, line 11: why were records interpolated to 1000 yr intervals when the average resolution of the entire dataset is triple this (\_3000 yrs)?”

The interpolation interval of 1000 years has been chosen to allow a meaningful comparison of the EOFs with global climate trends across MIS11, including potential leads and lags. Like the referee, we realized that the proportion of records interpolated is

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high and this was the motivation to carry out the age-uncertainty analysis, which assumes age uncertainty on the interpolated records in excess of the average resolution of 3 kyr.

“8. Page 851, line 15: Could the higher range of proxy SST anomalies be due to the influence of seasonality in the SST records?”

Indeed, this is another potential explanation for the higher variability in proxy-based anomalies. This is now mentioned in the discussion next to the other explanations.

“9. Page 856, line 28: although changes in plankton ecological preference are not likely to change over one glacial cycle, change in ontogeny (migration within the water-column, change in seasonal production due to food availability etc) are likely to have taken place.”

Such changes are likely to have taken place, affecting geochemical proxies. The paragraph in question refers to transfer functions, but we agree it is fair to mention the possibility of variable seasonal/vertical attribution of proxies affecting the comparison for geochemical methods.

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Interactive comment on Clim. Past Discuss., 9, 837, 2013.

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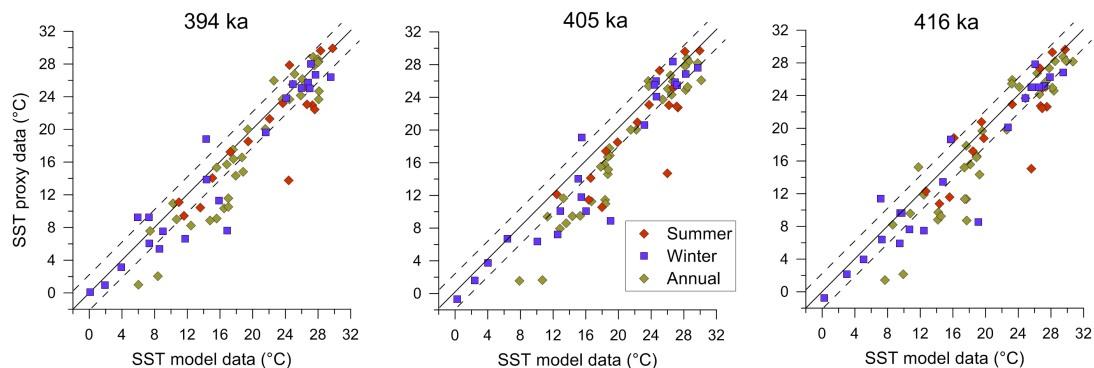
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**Fig. 1.** Comparison of absolute proxy with absolute modelled sea surface temperatures for three time slices of MIS11 (394, 405, and 416 ka). The dashed lines highlight the  $\pm 2^\circ\text{C}$  temperature uncertainties.

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