

## ***Interactive comment on* “Can oceanic paleothermometers reconstruct the Atlantic Multidecadal Oscillation?” by D. Heslop and A. Paul**

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The following is our response to the interactive comment submitted by Anonymous Referee #2. The referee’s comments are given in *italics* and our responses are in normal text.

*Since the authors’ model does not produce AMO-like variability in control runs, is there evidence in other models for an AMO SST pattern similar to the right panel in Figure 3?*

We specifically chose to work with the UVic ESCM because it could be forced with  
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heat fluxes based on the instrumental SST record. In this way we hoped to create AMO-type behavior in the model which was as close as possible to that seen in the instrumental record and could be represented as a collection of anomalies. As can be seen from Fig 1, the spatially averaged modeled behavior is close to that of the instrumental record, but as the reviewer points out the spatial behavior shown in Fig 3 shows some differences. As the reviewer suggests, an alternative approach would have been to employ a more complex coupled atmosphere-ocean general circulation model that generates AMO-type behavior as part of its internal variability. We surveyed the literature for candidate models, and whilst a number of them produce multidecadal oscillations in the AMOC, they appear to not show a strong correspondence (in either the spatial or frequency domains) with the observed SST record. Specifically:

1) Danabasoglu (2008) observed multidecadal AMOC variability in CCSM3, but it had a period of only 21 years and the “SST and SSS anomaly patterns and magnitudes do not resemble observations”.

2) Dia et al. (2004) found large multidecadal variations in the Atlantic thermohaline circulation of the Parallel Climate Model, but with a period centered around 24 years.

3) A comparison of the AMO in the GFDL coupled atmosphere-ocean model (with flux corrections) by Delworth and Mann (2000), revealed some variability which “resembles the observed pattern”. In general they found that the positive SST anomalies in the model extended too far north and were confined to latitudes north of 20°N. In contrast their analysis of the observational record showed anomalies extending as far south as 20°S. This pattern is similar to the instrumental-model comparison shown in Figure 3 of our original manuscript.

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4) The work of Knight et al (2005) provides a comparison of the spatial pattern of the AMO in the instrumental record and that produced in a 1400 year simulation with the HadCM3 climate model. These results (based on a visual comparison) appear to show a similar pattern to those of Delworth and Mann (2000) and the UVic ESCM presented in our manuscript. The positive anomalies in the model AMO are concentrated too far north compared to the observational data and do not extend far enough to the south.

In terms of both spatial and temporal variability we would suggest that our representation of the AMO in the UVic ESCM shows a better agreement with observations than the internal variability discussed by Danabasoglu (2008) and Dia et al. (2004), and has similar limitations (geographical distribution of the SST anomalies) to the work of Delworth and Mann (2000) and Knight et al. (2005). The advantage of using our approach, however, is that by comparison to a control run we can determine anomalies due to the AMO-type forcing. This cannot be done for the models that produce multidecadal variability internally. Additional text detailing these points has now been included in the manuscript.

*...it seems the same analysis could be performed with an infinitely “looped” version observed SST. This exercise would use an SST pattern far more similar to the observed and would allow the author’s to test their results.*

The proposed analysis of the observed SST data has two drawbacks. First, the observed SST record cannot provide information concerning temperature anomalies at depth (as shown from the model results in Figure 5). Second, the observed SST at any given location in the Atlantic can contain variability from a number of sources other than the AMO. If these sources have characteristic timescales longer than  $\sim 10$  years their contributions will not be removed by the filtering. This means that performing the analysis for the observed SST data produces  $s^{max}$  for all variability with timescales

longer than a decade, rather than specifically the AMO. Because of the manner in which we performed the model calculations we can isolate anomalies that are specifically a result of the AMO-type forcing and calculate  $s^{max}$  without contamination from other modes of variability.

*Furthermore, it would be interesting to investigate the suitability of various proxies with respect to frequency. Can a proxy capture AMO-like variability if it oscillates at an 80-year period, but not capture it if AMO-like variability transitions to a shorter 30-year period? This may be an exercise for future work.*

We agree with the reviewer that this would be an interesting modeling task for the future. Possible shifts in the period of the AMO are supported by the coral based record of Saenger et al. (2009). To address the underlying question of this point we have added some additional text to the manuscript at the end of Section 3.2. We consider that if the strength of the seawater temperature variations related to AMO variability are approximately sinusoidal and their amplitude is independent of their period, their variance will be constant (since the variance of a sinusoid depends only on its amplitude). However, as the period of the AMO decreases it will be more heavily smoothed by the 10 year moving average filter. For example, a sinusoid with  $\delta t=1$  year and a period of 30 years will lose  $\sim 30\%$  of its variance once filtered with a 10 year moving average. This means that as the period of the AMO decreases, the numerator in Equation (4) will be reduced, thus  $s^{max}$  must also be reduced to maintain a  $SNR \geq 1$ . This situation is compounded for sedimentary-based proxies, which even if they can achieve a decadal resolution will only have 4 data points representing each cycle of a 30 year AMO.

*Finally, it would be of great use for paleoceanographers to generate some sort of “lookup” table or map. I envision a tool in which a paleoceanographer could provide the*

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*standard error of their proxy and the uncertainty of their age model and be informed if their record is capable of capturing multidecadal variability of a particular frequency at their site.*

We hope that Figures 4 & 5 go some way to providing “look-up” maps, but we are wary of providing more detail than the general patterns described in the manuscript. Figures 4 & 5 were constructed under an assumption of a large number of calibration samples ( $N$  in equations 1 and 2) and a minimum achievable  $S_E$ , in order to present a generalized framework which could be compared to published calibration data. Paleoclimatologists studying the AMO can use our maps as a guide but must consider the specific value of  $N$  used in their proxy calibration and fact that  $S_E$  is the minimum achievable standard error on future predictions (in fact the standard error on future predictions will become larger as measured points move away from the mean value of the calibration data set, this is given by a simple extension to Equation 2 which can be found in most introductory statistics textbooks). In the original manuscript (page 2185, line 15) we explicitly state that we are working with a best case scenario and have now added a statement that other workers must consider how well their own calibration data meet the assumptions and what to do if they do not. We feel that the overriding message of our manuscript is not to supply an “X-marks the sampling spot” map but to instead demonstrate that on the basis of their calibration statistics it appears that sediment-based proxies are currently incapable of reconstructing the AMO in a meaningful way (as discussed in the conclusions).

*Minor correction: Page 2187, change “considered” to “considering”.*

We have changed the text accordingly.

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## References used in this comment

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