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Climate of the Past Discussions

Interactive comment on "Joint inversion of proxy system models to reconstruct paleoenvironmental time series from heterogeneous data" *by* Gabriel J. Bowen et al.

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We thank the reviewer for their careful reading and overall positive evaluation of the manuscript. In our revision we propose to address the specific questions and concerns of the reviewer through improved citation and elaboration of some of the methodological details and results, as described below.

The reviewer comments are shown here following the hash sign (#).

#Parts of the methods section were difficult to assess because of missing references.

We assume that the following questions point to specific cases where additional citation

would be helpful, and address how and where this will be resolved in our responses below.

#Did the authors develop proxy system models described in equations 2 and 3 or are these described elsewhere?

These equations represent 'standard' widely-used forms used to describe the temperature sensitivity of foraminiferal calcite Mg/Ca and d18O values in the literature. In our revision we will make this clear and cite some of the literature in which these forms have been previously proposed and used. We believe this will also help address some of the reviewer's later questions about the rationale for including some of the terms in these proxy model equations (we're adopting/testing equation forms based on precedent in the community).

#Page 4 line 30: How were these uncertainties determined?

These are approximations derived from the original data sources, we will clarify this point and add citations in the revision.

#Page 5 line 27: How is paleo-seawater Mg/Ca determined?

The value given here in the text here are simply first-pass estimates used in developing the priors on the foram proxy model parameters. For the non-modern (Paleocene-Eocene) samples we use a value of 1.5 mol/mol based on prior work of Lear et al. (2015). We will clarify this and add the citation to this sentence in the revision.

#Page 4 line 30: How were bottom water temperature (BWT) uncertainties estimated?

Answered above.

#Minor comments: #As far as I understood page 5 lines 25 – 32, proxy system model parameters are estimated based on observed (and inferred) BWT, surface water Mg/Ca and Mg/Ca of foraminifera. The posterior distributions of these parameters are then used as prior distributions when past surface water Mg/Ca and BWT are reconstructed.

This is almost but not quite correct. In our framework, posterior distributions for all parameters (including the proxy model parameters and the paleoenvironmental parameters) are found together. In other words, rather than first estimating the posterior of the proxy model parameters, then applying them to estimate the posterior distributions of the paleoenvironmental (process) model parameters, we simulate both sets together. To envision one implication, imagine that the 'true' value of one of the proxy model parameters (let's say temperature sensitivity of foraminiferal Mg/Ca) was actually a bit higher than the average estimate. Given that, the most likely paleo-environmental temperature time series would be shifted relative to the 'mean' estimate, also. By solving the full system simultaneously the joint distribution of posterior parameters captures these trade-offs and can be analyzed in new ways (e.g., see some of the derived analyses later in the paper).

#The authors assume a paleo-seawater Mg/Ca of 1.5 when calibrating proxy system models. How do the authors get this value and how uncertain is it? How would including uncertainties affect parameter estimates?

As mentioned above, this value was only used in estimating the prior distribution for the Mg/Ca model parameters (and only for one species). The parameter values contained in the posterior distribution are the result of MCMC sampling of the entire model system. We have replicated the analysis using a variety of prior assumptions for the foraminiferal Mg/Ca proxy model and find little sensitivity in the posterior distributions (not shown). We will try to make this logic clearer in the revision.

#Page 4: lines 28 and 29: some BWT values for calibration are based on 18O thermometry. Please explain this method (and add references). Is 18O thermometry based on eq 3? If yes, how were surface water 18O values determined and how do these values influence surface water 18O values reconstructed in this study?

These values were only used for calibrations including data from the early Paleogene, when the globe was essentially ice-free. The BWT estimates are thus based on 'stan-

dard' assumptions for the δ18O of the ice-free ocean. The actual values used are from Lear et al. (2015), and we will add this citation to the sentence for clarity.

#Equation 2: Mg/Ca of foraminifera is modeled as a function of BWT and surface water Mg/Ca. However, credible intervals of alpha3 clearly include 0 indicative of weak (or absent) influence of surface water Mg/Ca on Mg/Ca of foraminifera, which might explain the results described page 8 line 5 (proxy data doesn't seem to inform this parameter either Fig 5c). Why is surface water Mg/Ca included in this proxy model given that it doesn't have a clear influence on Mg/Ca of foraminifera? #Equation 3: 18O of foraminifera is modeled as a function of 18O of surface water, BWT and BWTËĘ2. However, credible intervals of beta3 (parameter relating BTWËĘ2 and 18O) include 0 for Cibicioides as well as Uvigerina. Including BTWËĘ2 in the model therefore needs additional justification. As the authors note in the discussion, posterior distributions of beta3 place even more weight on values close to 0 than the prior distribution.

In both cases our approach was to adopt the model forms commonly in current use within the paleoclimate community (ref. our response to the earlier question). These forms have been adopted, usually based on empirical relationships rather than fundamental considerations, and widely used in previous studies, and we chose them for consistency and comparability with prior work. However, as noted by the reviewer, in some cases the results of our analysis suggest that one or more model parameters are not or only weakly informative. This result has been noted before in studies that have used traditional statistical approaches to calibrate model equations for these systems. The sensitivity to these parameters seems to vary among species, however, so that in most studies the full form of the equations (all terms) are considered so that the same form can be used for all species. Although we propose to continue to use the 'canonical' forms in our revision, we will better emphasize and elaborate on the result that our analyses do not support sensitivity to some of these model terms, which may 1) suggest that, for these species, a simpler proxy model is appropriate, and 2) slightly inflate uncertainty estimates when these terms are included.