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# Reply on RC2

Michael P. Erb et al.

Author comment on "Reconstructing Holocene temperatures in time and space using paleoclimate data assimilation" by Michael P. Erb et al., EGUsphere, https://doi.org/10.5194/egusphere-2022-184-AC2, 2022

Thank you for the review. We respond to your comments below.

1. Our reconstruction differs from the one presented in Osman et al., 2021 in a variety of ways: the proxy selection, the use of PSMs, and the chosen model prior. Additionally, while we used some of the same proxy records as in Osman et al., 2021, they used additional marine records. The marine sediment records from Jess Tierney that we considered for assimilation were 103 d18O, 63 alkenone, 51 Mg/Ca, and 13 GDGT records, but they have added additional records to their database. We will look into acquiring more records for future work.

With this said, we ran two new experiments to explore the effects of land and ocean proxies on the data assimilation: one experiment only uses land proxy records and the other only uses ocean proxy records. These two experiments share some similarities, but differ in their spatial patterns especially in the early Holocene, where the ocean-only reconstruction is warmer. For the global mean, the default all-proxy experiment has a mean anomaly of 0.09°C for the 6-0.5 ka millenniums (as discussed in the paper) while the anomalies are 0.08°C and 0.04°C for land-only and ocean-only experiments, respectively. The low value of the ocean-only reconstruction suggests that some of the mid-Holocene warmth signal is coming from the land proxies, which are absent from Osman et al., 2021.

2. More Southern Hemisphere records would always be welcome, but data assimilation accounts for spatial biases to some extent. Essentially, data in unknown regions is estimated based on known data and model covariances. However, it’s likely that the reconstruction would be improved if it had more Southern Hemisphere records to rely on. The localization radius experiments in Fig. B2a-d are somewhat relevant to this question; in the default experiment, the large amount of proxies in the Northern Hemisphere may have an outsized effect on the reconstruction (after being translated through the prior’s covariance pattern), but in experiments with a localization radius, proxies cannot influence the reconstruction in distant regions. The global mean temperature reconstruction is not dramatically different between these experiments.

3. There are a few proxies in the network that do have published PSMs, notably ice cores, speleothems, and some of the tree data. However, we decided to use calibrated records for this first paper on the project, and move forward to a sensitivity test using the nonlinear/water-isotope-enabled PSMs for a second study. Furthermore, most of the

proxies we could use PSMs for depend on water isotope enabled model output. The availability of water isotope enabled output is also very limited for the Holocene (e.g., iTRACE results have only been released prior to 11 ka and iCESM covers 850-2005), but nevertheless we could use the early Holocene and last2k isotope enabled simulations to conduct sensitivity experiments. The use of such PSMs will be a focus of future work in this project.  We will add additional discussion about this to the paper.

4. The proxy records initially have a variety of temporal resolutions, from sub-annual to multi-centennial. Since we are doing the data assimilation at decadal resolution, we need to have the proxy data at a decadal resolution. As mentioned in the paper, we make the assumption that all proxy data is continuous.  To represent longer-time-averaged data in a decadal context, we use a nearest-neighbor approach.  Data is first interpolated to an annual resolution using nearest-neighbor interpolation, then binned to decadal.  This two-step process is similar to doing a decadal nearest neighbor interpolation, but is meant to better account for sub-decadal data and time intervals mid-way between data points.

If proxy data was instead assumed to represent non-continuous periods (i.e., representing shorter time means with gaps of no data in between), the variability in the reconstruction may be higher, but some of this may be non-climatic variability resulting from records alternating between having data and lacking data. To test this, we ran two new data assimilation experiments.  For simplicity, both use 200 year bins. In the first case, data was interpolated. In the second case, no interpolation was done. In both cases, the global-mean temperature reconstruction looked similar. The main difference occurred near 11 ka, where many proxy records end; in the reconstruction without interpolation, there is greater variability here, but we do not think that such variability represents a real climate signal.

5. The two models used in the prior are on different grids, so interpolation is needed to put them on the same grid.  The chosen 64 x 96 lat/lon grid is somewhat arbitrary, but is in-between the resolutions of the two models (73 x 96 for HadCM3 and 48 x 96 for TraCE).

6. There are multiple reasons why one would use a multi-scale approach and as you say, one reason would be to capture longer term ocean memory or dynamics. For our reconstruction using multiscale assimilation is particularly important because we have proxy data on very different timescales, from multi-centennial sediment records to high resolution ice core records. Given timescales that differ by orders of magnitude, we wanted to treat each proxy on its own timescale and not assume that all proxies provide meaningful information on only a single timescale. It is a straightforward exercise to show that averaging or interpolating high resolution data down to low resolution removes high frequency variability and spectral information; this is precisely what happens when we assimilate proxy data that has been bin-averaged: high-frequency information is lost in the reconstruction. Additionally, there will be differences in the covariance structures in the prior at decadal vs. multi-centennial scales.  We will revise the main text to discuss this issue more fully.

7. We will add additional explanation of how the data assimilation methodology handles seasonal proxy records.

8. As mentioned in comment 1 above, Osman includes marine records which were not included in our reconstruction. Also, because the two methods differ in their prior and use of PSMs, a straightforward comparison is not possible.  The comparison between land-only and ocean-only proxies described in comment 1 above partly addresses this topic.

9. To look into this, we did a test similar to the one on Extended Data Table 1 of Tierney et al., 2020 ("Glacial cooling and climate sensitivity revisited"). A subset of proxies was

withheld from the data assimilation, then correlation, CE, and RMSE values were calculated for un-assimilated proxies at each age. As in Tierney et al., proxy scaling factors of 1 (the default), 1/2, 1/5, 1/10, 1/20, 1/100, and 1/500 were tested. Median verification metrics were best for values of 1, 1/2, and 1/5. Since none of the other scaling factors were unequivocally better than the default, we will continue to use the default values. However, a reconstruction using a 1/5 scaling factor is still shown in Fig. B2 of the paper. As for ECR and ECPSS, we are unfamiliar with those methods. If you provide further explanation for how those methods would help, we can investigate their use.

10. Reconstructing additional climate variables will be a focus of future work. Before providing reconstructions of those variables, we would like to assimilate more proxy records. In particular, we are currently working to assimilate hydroclimate proxies.