

## ***Interactive comment on “Multi-time scale data assimilation for atmosphere–ocean state estimates” by N. Steiger and G. Hakim***

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We would like to thank James Annan for a very helpful review and accompanying important references.

The major issue brought up by James is that of overlap between the prior and the true states. As discussed on page 3740 lines 23–25, the prior is randomly sampled (with replacement) from the entire length of the simulations while the reconstruction is over the first 500 years of each simulation, and the prior is of size 500 (though not noted in the text explicitly, we used the same prior for every Monte Carlo iteration). This means that while there is certainly overlap between the two, any given year’s prior would not be guaranteed to have the corresponding true year; for the CCSM4 run there would be

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about a 48% chance while for the GFDL run there would be about a 63% chance of including the true year value in any given year's prior. And unlike, say an analog search method, this approach isn't obviously going to home in on the true state, which would only be there about half the time anyway. We agree that having overlap is not ideal, but the challenge here is that (1) we wanted to be able to have a reconstruction long enough to reliably estimate skill at long time scales, (2) have priors representative of all the low-frequency components of the coupled-model systems, and (3) ensure that we didn't have complete overlap between the prior and the true state, while working within the constraints of the available simulations; these two pre-industrial control simulations (800 years in length for GFDL-CM3 and 1051 years in length for CCSM4) were two of the longest we could find on the CMIP5 archive. Ideally we'd use two multi-millennial CMIP5-class coupled control simulations but we are unaware of any such simulations from independent models that are publicly available. Within the text itself, we can certainly include an additional caveat about these reconstruction choices and the reasons we chose them, along the lines of what is discussed above.

We agree that state space augmentation and our approach here have some important similarities (which we can cite and discuss in the paper, such as the ability to update time-averaged information), however we do not think that the algorithm discussed in the paper is in fact formally equivalent to augmenting the ensemble members with their respective N-year averages. Here because we have observations at multiple time scales, they can affect the states at all time scales instead of just having short time scale observation information inform longer time-averages if we were just augmenting the state with time averages. Also because this is a paleo and off-line-focused algorithm, we also include issues like the assigning of priors to specific years and ensuring temporal coherency among the priors. We also agree that the specific application to atmosphere-ocean paleoclimate reconstructions appears to be unique.

As to issues of forcings, we agree that looking at how the reconstruction method handles specific forcings would be interesting to explore. However the simulations we used

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were control simulations and had static forcings, so in the present paper we would be unable to assess how well the method handles forced events such as volcanic eruptions. We note that in other research involving real-proxy reconstructions, we find clear, coherent, volcanic signatures in reconstructed fields, even if the priors have no information on volcanic eruptions.

We also agree that having uncertainty information in the reconstructions would enhance the results and interpretation, and it would not be a problem to include that information in the figures.

We included only climate variable indices for simplicity because we feel that the primary purpose of this paper is to explain and illustrate this paleoclimate reconstruction algorithm and how it performs across time scales. This is most straightforwardly shown for indices, (e.g., spatial power spectra are more challenging to illustrate meaningfully). We also wanted to be cautious in applying the results of this pseudoproxy study to actual AMOC reconstructions or in making broader claims about the AMOC, because ocean circulation tends to be less well-represented in GCMs than atmospheric circulation. We feel that our results are suggestive of the possibility of reconstructing the AMOC, but a more extensive study with real proxy data would likely be needed to adequately explore the issue.

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