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Climate of the Past Discussions

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 referee 4 for close reading and helpful comments.

We understand that the use of an "off-line" approach to DA can seem unusual if one is mainly familiar with weather or ocean DA. In fact, data assimilation in general applies to a prior that may, or may not, come from a model simulation. The approach we use was originally proposed by Oke (2002, 2005) and Evensen (2003). The primary reasons for using off-line DA, as stated through most of page 3735, are computational and because of the very long intervals between assimilation times ($\sim$1 year) that appear to eliminate the predictive power the climate model might have going into the next assimilation period (see Annan and Hargreaves (2012) and Matsikaris et al. (2015)).

Such approaches are used in the paleoclimate community without recourse to renaming a technique that uses precisely the same update equations but has a different kind of prior (static vs dynamically derived). However, as the confusion illustrates, it would probably be helpful for us to discuss the off-line (or "stationary") nature of the approach in the abstract.

Concerning including uncertainty information, we note that for calibrated ensembles the error in the mean is the same as the uncertainty. The correlations in nearly all the 500 year reconstructions are indeed significantly different, though two of them are not, Fig. 6a (coefficient of efficiency does not have formal significance tests, though it is a very common metric used in the paleoclimate community). This issue about significance is the primary reason that we included three different skill metrics for each of our reconstructions and we argue throughout the paper that they tell a consistent story.

We don't agree that the climate models behave similarly and we specifically chose these two because of their very different AMOC characteristics, though our bold language on this point can be toned down.

Responses to minor comments:

dictionary.com "to leverage" (5) to use (a quality or advantage) to obtain a desired effect or result

By "any method" we mean methods that have specifically tried to approach the problem of multiple time scales (seasonal to annual to decadal to millennial) for climate reconstruction purposes. It's definitely true that adjoint methods can and do include multiple time scales, though we are not aware of any other DA-based approach that has looked at this particular problem in a paleoclimate context that includes very long time scales in comparison to weather DA.

We apply H(x) iteratively because of the nature of proxy data which is, in general,

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non-regular in time, whose values needn't correspond neatly to integer years, and can change temporal resolution through time (become more coarse further back in time). The approach we settled on was to simply go through each proxy at a time over it's own time series. Additionally we note that averaging implies a state-space decomposition (see the Appendix in Huntley and Hakim (2010) for details) so here we are making it an explicit part of the algorithm.

The state vector only contains surface temperature together with GMT and the AMOC index as single-dimension appended state variables (rather than deriving them from the state vector). H(x) simply uses the surface temperature values of the state vector at the proxy locations. We will include this information explicitly in Section 3.1.

We are not entirely sure what is meant by "success" of an inversion method, though we note that pseudo-proxy stand-alone studies are well established in paleoclimatology, and in this journal in particular. Certainly additional real-proxy data studies would help establish the robustness (or "success") of the method in the real world, though we think this is beyond the scope the present study.

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