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Climate of the Past Discussions

Interactive comment on "Greenland temperature and precipitation over the last 20,000 years using data assimilation" *by* Jessica A. Badgeley et al.

Anonymous Referee #1

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General comments

The authors present a new reconstruction of temperature and precipitation over Greenland covering the past 20 000 years using for the first time over such a long period a data assimilation technique successfully applied recently over the past millennia. The paper is very clear, justify nearly all the choices in a very rigorous way and provides comprehensive estimates of the uncertainties. I have thus no doubt that, in addition to the new reconstruction that can be used for instance to drive ice sheet models, this study opens new fields of application of data assimilation of multi-millennial timescales.

However, I consider that the impact of the choice of the prior is not enough discussed and this issue must be addressed before publication. If I understand well, the prior ensemble is made of 100 states obtained by averaging 50 years of model data. Those

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states are selected randomly over the full length of the simulation (line 175). This method is reasonable if the climate variations are weak, such as during the past millennia, but is it valid for very large changes as observed during the glacial interglacial periods? I may have missed something but, if I am right, a state obtained in the model in the late Holocene can be used to reconstruct the last glacial climate, which may be hard to justify. For instance, the authors argue that it is important to take into account the changes in seasonality of precipitation (e.g. line 233) but I wonder how this could be achieved by selecting model states that are coming from very different periods. I would suggest using as prior only years that are close to the period that is reconstructed so that only glacial states are used to reconstruct glacial climate for instance.

Specific comments

1. More specifically, still related to the prior, the authors explain (line 135) that 'For paleoclimate data assimilation, it is important that the climate simulation capture a range of possible climate states over the time period of interest '.They should thus first discuss the results of the Trace21ka simulation as it seems from Figure 12 that it underestimates the magnitude of the changes. More generally, the authors do not discuss at all the biases of the climate model. They correct for biases in the modern state by using anomalies compared to 1850-2000 (line 146) but this seems to be a small change compared to the signal during the whole simulation (line 366). Besides, the response to forcing is very different between different models as illustrated by the Paleoclimate Model Intercomparison Project. How this model behavior, which can also bias results for distant past, is influencing the results? Another way to phrase this point is that the model biases are not constant over time while the proposed correction assumes the stationarity of the biases.

2. Estimating the skill of the reconstruction compared to a constant prior (line 204) is a too low target for me. If the reconstruction was only showing a warming between the glacial period and the Holocene, it would already be skillful compared to this initial estimate and this does not require a very sophisticated technique. The skill of the

reconstruction should be evaluated against the transient Trace21ka simulation to see if the data assimilation brings some skill compared to the simulation not constrained by data

3. The authors explain at the end of the conclusion (line 485) that using a model that directly simulates isotopes would likely improve their results. It would be interesting to discuss that earlier because, for instance, they mention a different relationship between reconstructed precipitation and temperature at different time scales (line 352) but what is the potential role of a different relationship between temperature and d18O on this conclusion?

4. If I am right, when the technique described in section 2.3 is applied for the past millennia, records related to both the temperature and hydrology are assimilated together, as the covariance between the variables can bring interesting information and reduces the uncertainties. Here, it is claimed that having independent temperature and precipitation reconstructions is an advantage. This also means that precipitation and temperature changes could not be dynamically consistent in the proposed reconstruction? Maybe the authors do not want to rely on the covariance between those two variables as simulated by the climate model but they should explain why and, in that case, explain in a bit more detail the added value brought by the assimilation using this model results as prior.

5. Line 153, it is said that 'The offline method is appropriate when characteristic memory in the system is significantly shorter than the time step' (here 50 years). Is this valid here, for Bølling-Allerød and Younger Dryas events for instance?

6. Line 375. The reanalysis skill over the full period is clear compared to a constant climate but this would be informative to quantify it more precisely for the two selected 5000-year periods. Stating that it is lower than for the full period is not enough I think. From the figures 7 and 8, it seems that the CE is negative for nearly all the points. Stating line 377 that 'the reanalysis shows overall improvement over the prior ensemble' is

also a weak conclusion as discussed in point 2.

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