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Climate of the Past Discussions

Interactive comment on "A dynamical reconstruction of the Last Glacial Maximum ocean state constrained by global oxygen isotope data" *by* Charlotte Breitkreuz et al.

Anonymous Referee #1

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This paper is an interesting and potentially significant one. Many of the comments that follow are directed at amplification, explanation, and better definitions. In a field such as paleo-modelling, one is dealing with a very diverse audience and it becomes even more important than normal to make sure that readers will not be misled or misunderstand.

Many papers modelling the LGM and other periods have taken pains to demonstrate that their model does at least a reasonable job of describing the modern system. Readers would benefit from knowing e.g., what the current set up does with the modern AMOC and other features such as the heat transport, depth of mixed-layer, etc. (credibility of the results are at stake). There is a brief reference to an earlier paper directed

at oxygen distributions, but one should not have to hunt that down in order to have a sense of what the model capability is or isn't.

The AMOC is the center-piece of the paper, but it is never even defined here! Perusal of the modern literature shows a variety of definitions, involving depths of integration (different density surfaces, physical depths, depth of maxima defined somehow, latitudes, etc.). Values differ by an order of magnitude by latitude and sometimes even depth and integration intervals and show little or no covariance with latitude, a result going back at least to Bingham et al. GRL 2007 and several subsequent studies using data.

The Gulf Stream is the dominant component of the AMOC (see especially some of the recent ECCO discussions of AMOC and/or the RAPID array data). What is the strength of the western boundary currents? No paleo-scientist, unfamiliar with the modern literature, would appreciate how time and space variable the modern AMOC is, however it is defined. The authors do use 45N latitude, but with no discussion of how that cuts across the Gulf Stream system in the modern ocean, rendering it particularly spatially and temporally noisy. They say "southward transport"–but to what depth, over what zonal integral? Modern average results show a complex of both northward and southward flows, changing with depth with boundary currents on both coasts.

No modeler would ever try to construct the modern circulation without a considerable knowledge of the wind system. Winds are barely even mentioned beyond the statement that they are taken from a model, and in passing, as part of the control vector. Given the dominance of wind forcing, particularly its curl, in the modern circulation, the reader needs some discussion of sensitivity to it and/or the reliability of the field that was used/emerged.

"Kalman smoother" is not standard terminology and tends to suggest the authors are not fully aware of the optimization literature. There is a Kalman filter (a predictor) and there are lots of smoothers (RTS, fixed lag, fixed interval, etc.) Any optimization

textbook gives definitions. What is intended?

The discussion of SST, the isotopic tracers, and MARGO on P. 4-6 left me totally confused. Are the oxygen isotope tracers inconsistent with MARGO? In light of the misfits found later, one should know a priori. MARGO is based on proxies as well, and labelling it as SST as opposed to planktic and benthic isotopes is a strange distinction.

Table 3. If I'm interpreting this correctly (?), some of the residuals look far to large (e.g., S0, precip., et al., and some look much too small e.g., F8. Unless I'm misunderstanding (?), such results would lead to formal rejection of a solution.

Table 5. The imposition of hard maxima and minima is not a part of conventional least-squares. How were these implemented?

P. 3 A better discussion of the ECCO model adjoint is Heimbach, P., Hill, C., Giering, R., 2005. An efficient exact adjoint of the parallel MIT general circulation model, generated via automatic differentiation. Future Gener. Comput. Syst. 21 (8), 1356–1371.

P. 14, line 14. Should be 'decrease'

P. 11 and elsewhere. Given the prominence of MARGO data in previous estimates, it would be helpful to know why the MARGO cooling is not seen here? Is this a systematic misfit to MARGO data? How do the N. Atlantic results compare e.g., to Dail's?

P. 16, line 4. The objective function is a conventional quadratic misfit. How is it possible for it to become non-convex? Maybe owing to the presence of the Lagrange multipliers in it (although that is never mentioned)?

Table 2 and elsewhere. Are the underlying variables at least approximately Gaussian? That's required for the chi-square fit to be used.

The re-weighting of the control portion of the objective function in the equation on P. 7 implies a major change in the errors relative to Jdata. Does that make physical sense?

Section 2.4 seems pointless: there is no inference or conclusion.

P. 14. Worth explaining that in the modern ocean there exists a theory of AMOC sensitivity to Southern Ocean winds (Toggweiler).

P. 14, line 15. Isn't the N. Atlantic regarded as relatively salty mainly because of the Med. Water outflow?

P. 15 line 5. Is it possible there is a systematic misfit to the data in the NADW and deep ocean? Or is that ruled out?

P. 16. The meaning of the phrase "do not necessarily support" is not obvious to me. Not consistent with?

P. 17 "exacerbates" is a peculiar adjective. Maybe "exaggerates"?

P. 18. Is the flow steady at 16.1 Sv or is there time variability? And what is the heat transport of the estimate? That's an essential element of the climate state. Is a North Atlantic state without any overturning physically feasible? How is the heat budget balanced? Is it geostrophic? line 31 "Additional to the type of.." isn't English.

P. 19 The second sentence, claiming consistency with all the data appears to contradict much of what has come before. And "consistency" here, given the vagueness of the error discussion is not easy to interpret. MARGO?

It would be helpful to have a broader discussion of the most important of the consistencies or otherwise, of the previously published solutions including Kurahashi-Nakamura et al., but also Amrhein, Thornalley, Gebbie, Oppo, etc.

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