Geosci. Model Dev. Discuss., 6, C1850–C1854, 2013
www.geosci-model-dev-discuss.net/6/C1850/2013/

Geoscientific Model Development Discussions

Interactive comment on "Can sparse proxy data constrain the strength of the Atlantic meridional overturning circulation?" *by* T. Kurahashi-Nakamura et al.

Anonymous Referee #2

Received and published: 1 November 2013

The manuscript, "Can sparse proxy data constrain the strength of the Atlantic meridional overturning circulation?," by Kurahashi-Nakamura, Losch, and Paul, represents an important reality check about how well we can reconstruct the past ocean circulation given observations restricted to the sea surface and seafloor. Paleo SST observations are not reliably capable of setting overturning rates in a state-of-the-art optimization system that uses many of the same tools as the ECCO (Estimating the Climate and Circulation of the Ocean) system used in the modern day. Even in the case that the surface observations can be made more dense, the authors find that their reconstructions are not significantly improved. The authors write that additional temperature observations at depth and the addition of salinity observations would help, and although such

a statement seems incontrovertible, it is unclear which experiments actually buttress this conclusion. Additional deep temperature observations seem to be a realistic possibility in the future, but additional salinity observations will only come at great cost or as an indirect result of other observations. Thus, it is not clear that the experiments with additional salinity measurements give us much practical information, and those experiments could have been replaced by experiments that include other stable isotope measurements (that are already in hand). Of course, stable isotope measurements are typically said to not contain any rate information, but nonconservative effects due to remineralization (or the equivalent) do have some (perhaps indirect) rate information. The implication of this work is that the coherent surface-subsurface fingerprint of the AMOC (an expression of AMOC strength in SST, e.g., R. Zhang, GRL, 2008), does not exist, is not powerful enough to constrain the AMOC in the face of other ongoing processes, or is not captured in an ocean-only model. The past ocean circulation is likely to be as complex as the modern circulation, and thus the MIT GCM and its adjoint are well suited for application to the Last Glacial Maximum problem. The downside of this sophisticated state estimation technique is that the results do not seem to conform to any straightforward pattern and the complexity of the technique resists simple interpretation. Unless some of the surprising results can be explained more completely, there is the remaining possibility that the inability to reconstruct the AMOC is not due to the sparsity and uncertainty of the observations, but rather to difficulties in implementing the method.

Point-by-point analysis ——————

P4420, L3: No paragraph break appears necessary.

P4420, L5-14: This paragraph sounds like it will recap all previous LGM state estimates, but it does not.

P4423, L3, and throughout: The maximum AMOC streamfunction should not be confused with the NADW formation rate. In Speer and Tziperman (1992), the water-mass

transformation and mass flux are treated distinctly, as they should be.

P4425, L10: The authors report that experiments with the colder ocean state (Targets 1 and 2) were "very inconsistent." At the resolution of this study, which was not explicitly stated but appears coarse, the ocean model responds fairly linearly to external forcing. In such a linear case, the Quasi-Newton search method should be quite consistent. As it is the cold states that are inconsistent, could it be that nonlinearity due to the sea-ice model is the cause of the inconsistency in finding a solution?

P4425, L24: Is it surprising that complete coverage of SST is insufficient to reconstruct the AMOC? This would be surprising if satellite-retrieved SST was found to be sufficient to monitor the AMOC for the last several decades. It is clearly not capable of such a task. Instead, satellite altimeters and field campaigns have been necessary and some uncertainty still remains.

P4426, L11: Errors in the internal parameter of viscosity could be detected if "their sources were known." What does that mean?

P4426, L14: The dependence of the final solution on the first guess is potentially a sign of nonlinearity in the model or the inability to iterate the search procedure to convergence. Were computational costs a factor in the convergence of the solution? Do all experiments fit the data equally well, as determined by a chi-squared statistical test?

Figure 1 indicates that two distinct latitudes (40N and 60N) are the potential location of the maximum of the overturning streamfunction. The possibility of the maximum streamfunction jumping between the locations is a serious nonlinearity. Sinking in the North Atlantic (either south or north of the Greenland-Iceland-Scotland Ridge) would be a better behaved target.

P4428, L20: Some elaboration is required on how deep convection sites differ from sites with a deep mixed layer. Is there some kind of temporal averaging that makes a difference? Why doesn't the modeled mixed layer extend as deeply as the deep

convection?

P4429, L1: "Providing prior knowledge ... may alleviate the problem." What kind of prior knowledge could be used for the LGM? Or is this simply a statement that holds in "assimilation world." The Conclusions begin to address this, but it's not clear what the take-away message is.

Table 1: Why are some AMOC estimates worsened by the addition of observations? Something doesn't add up here.

Figure 5: The pseudo-data appear to have significant high wavenumber variability. On the other hand, the ocean tends to have a red wavenumber spectrum. To what extent is the small scale data variability fit? Do these small scales excite numerical instabilities in the model?

A 2007 paper with a very similar title, "Can Paleoceanographic Tracers Constrain Meridional Circulation Rates?", was published in the Journal of Physical Oceanography and is not cited here. That work suggested that using conservative tracers together with knowledge of density makes a significant improvement in an idealized reconstruction. That suggestion is ignored here. Additionally, it was found that increasing the accuracy of paleo-data by one order of magnitude would be necessary to make a reliable estimate of LGM AMOC strength. What are the specific points that distinguish this 2013 paper from the one that is 6 years old?

References: Huybers, P.; Gebbie, G. & Marchal, O. Can paleoceanographic tracers constrain meridional circulation rates? Journal of Physical Oceanography, 2007.

Speer, K. & Tziperman, E. Rates of Water Mass Formation in the North Atlantic Ocean J. Phys. Oceanogr., 1992, 22, 93-104.

Zhang, R. Coherent surface-subsurface fingerprint of the Atlantic meridional overturning circulation Geophysical Research Letters, American Geophysical Union, 2008, 35, L20705.