Clim. Past Discuss., 2, S884–S888, 2007
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Climate of the Past Discussions

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2, S884–S888, 2007

Interactive Comment

Interactive comment on "Climate of the last glacial maximum: sensitivity studies and model-data comparison with the LOVECLIM coupled model" *by* D. M. Roche et al.

D. M. Roche et al.

Received and published: 13 February 2007

Response to general comments from anonymous reviewer 3 and to reviewer A. Paul

Comments raised both by the anonymous reviewer 3 and by Dr. A. Paul are closely related to each other, and mainly concern the oceanic circulation we simulate at the LGM. We will therefore respond to general comments from reviewer 3 and Dr. A. Paul jointly. Specific comments are treated separately.

One common concern expressed by the two reviewers is the lack of discussion of the obtained LGM circulation with the δ^{13}C data from Curry and Oppo, 2005. This is

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modified in the revised version in which we discuss the implication of the δ^{13}C to our simulated oceanic state.

As mentioned by Dr. A. Paul, δ^{13}C distribution at the LGM *may indicate the boundaries between the different water masses* and the *strong vertical gradient in the* δ^{13}C *as compiled by Curry and Oppo (2005) is indicative of an LGM water mass boundary between deep and bottom water shallower than today*. Reviewer 3 also expressed this concern, stating that *in my understanding, delta 13C data [...] suggest that the overturning cell associated with NADW formation becomes shallower at LGM than the present*. We agree that δ^{13}C data from the LGM indicates that there is a (strong) boundary between an upper and a lower water mass between 2 and 3 kilometers. However, which water mass is the upper one and which is the lower one is subject to discussion. Especially as *passive tracers with uncertain end-member values (such as* δ^{13}C *) provide limited information about circulation boundaries, as pointed out most recently by Rutberg and Peacock (2006)*. The "classical" oceanic circulation view of the LGM indicates that the Atlantic shows the interplay between two water masses: an upper one called GNAIW (Glacial North Atlantic Intermediate Water, to differentiate it from the deeper present-day NADW) and a deeper one called GAABW (Glacial Antarctic Bottom Water) assumed to originate from the Antarctic with much lower δ^{13}C values. This latter water mass has very low δ^{13}C values as it is formed from pre-formed waters with low δ^{13}C values and they are formed mainly under sea-ice preventing considerable ventilation with the atmosphere.

How does our LGM state compare with such a sketch? We do not have two water masses in the Atlantic, but three: one Antarctic deep water mass (GAABW) and two northern water masses, a dense one formed in the Nordic seas (GNADW) and one formed south of Iceland (GNAIW). As in the "classical" case, the end-member values are unknown. It is however noteworthy that the waters formed in the Nordic seas are formed in sea-ice covered regions. If the δ^{13}C was simulated in our model, this water mass ought to have quite low δ^{13}C content. Therefore, our Atlantic ocean is indeed partitioned, as seen from the δ^{13}C (Curry and Oppo, 2005), between an upper,

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well ventilated water mass (GNAIW) and a lower less ventilated water mass. This latter is composed of a mixture of GNADW and GAABW, depending on the latitude we are looking at (mainly GAABW until 20 degrees North, more GNADW northward). Our simulated state, although with a deep north Atlantic ventilated from the northern hemisphere does not seem to contradict the δ^{13}C data, at least from a qualitative point of view.
It should be noted that the overturning stream function indicates how the ocean is ventilated (in our case, indicates that the deep northern Atlantic is ventilated from the Nordic seas) but is not directly linked to the δ^{13}C distribution (this latter being a passive tracer, see comment by A. Paul). Therefore, the fact that deep waters formed in the northern hemisphere are reaching the bottom of the Atlantic ocean is not contradictory with data evidences, provided that the lower part of these waters are formed in a way to provide low δ^{13}C content. As discussed already in the paper, *the 231Pa/230Th evidence may indeed argue for a meridional overturning of NADW stronger than today in the upper 3km of the Atlantic Ocean, but weaker than today below* (A. Paul).
We therefore believe for all these reasons (which are more detailed in a new version of the manuscript that the LGM circulation we obtain in LGM ocean is not contradictory with data evidences. However, we agree with both reviewer 3 and A. Paul that stating – as we did in the previous version of the manuscript – that the circulation obtained is "close to what the oceanic circulation was like during the LGM" is an overstatement (corrected in the revised version of the manuscript).

Another common concern of the two reviewers is the link between the sensitivity experiments and the rest of the paper. Both reviewers are asking for a comparison between the states obtained in the sensitivity experiments and the paleodata, to evaluate what state better fit the data. However, it should be bear in mind that the sensitivity experiments do not represent valid LGM states, in a physical sense. Indeed, we are modifying some of the parameters well out of the range of plausible physical values (e.g. 50% reduction/increase of the wind drag on sea-ice). Therefore, even if one of the states could provide a LGM closer to the data, it would not be a "LGM" in the strict sense and therefore could be use only as an indication of the processes at work. Even so, it is worthwhile to compare to the data, and we added a paragraph in this sense to the revised version of the paper. The goal we pursued was to try to find out a state with a different balance between the Atlantic water masses, closer to the "classical" LGM. The result is that the model doesn't present any state coherent with such picture close by in the parameter space.

Specific Response to anonymous reviewer 3

1-/ *In sensitivity experiments on THC, the obtained results indicate that none of simulations could enable a drastic change in circulation. Does this reinforce the authors' claim that the circulation with standard parameters is consistent with paleo data? Or,is this an intrinsic feature of your model?* It is clearly an intrinsic feature of the model. The fact that the model doesn't present another different state close by in the parameter space does not specifically reinforce the modeled LGM state.

2-/ *I think the results of sensitivity simulations on THC is given descriptively and scientific interpretation and discussion are not made enough. In addition, as I already mentioned, these simulations seem independent from the previous part (comparison with paleo data) of the manuscript, which should be improved for clarifying the objective of the sensitivity simulations.* To improve the link between the two parts, we have added a paragraph that briefly discuss the results of the sensitivity experiments with regards tot he proxy data.

3-/ *Especially, I suggest the authors pick up the state with decreased THC from fresh-water experiment (Fig.9) and compare this with paleo data.* The aim of our study is to simulate the LGM climate with realistic boundary conditions and to evaluate it against proxy data. We have used sensitivity experiments to investigate if another equilibrium state with different circulation pattern could be found in the "tunable" parameter space. Additional freshwater fluxes (as noted in response to A. Paul) cannot be used as "tunable" parameters in a coupled model without modifying substantially the model itself. Therefore, if a state with decrease overturning due to freshwater fluxes should be compared to data, it should be compared to an Heinrich event period, not to the LGM.

4-/ Specific comments where modified according to the suggestions made.

Interactive comment on Clim. Past Discuss., 2, 1105, 2006.

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