

Interactive comment on “Glacial climate sensitivity to different states of the Atlantic Meridional Overturning Circulation: results from the IPSL model” by M. Kageyama et al.

Anonymous Referee #3

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GENERAL COMMENTS

The study by Kageyama et al. describes the response of the IPSL climate model to freshwater perturbations imposed on a glacial background state. The response of the Atlantic Meridional Overturning Circulation (AMOC) appears to be very sensitive to small differences in the applied freshwater forcing, and the spatial and temporal characteristics of the response of the model are described in great detail.

It is crucial to understand the sensitivity of the climate and how it might be different depending on the initial background state of the system. Such a study should also help elucidate the mechanisms responsible for past abrupt climate changes such as

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the Dansgaard-Oeschger events of the last glacial cycle.

One major weakness of the manuscript is its excessive length and lack of focus. In particular, the main scientific contribution of the work should be stated clearly in the text and repeated in the abstract. At the same time the significance of the new findings should be emphasized. Although the introduction includes an extensive literature review, the summary section does not discuss the relevance of the new findings in the context of existing proxy data and previous model studies, nor their impact on future work in the field.

It could be in the interest of the authors to focus their results in more than one manuscript. In this case it would be better to focus on one of the main topics presented in the paper such as (this is not an exhaustive list):

- 1) the response of the ITCZ and monsoon system to AMOC changes;
- 2) relevance of changes in ITCZ and transport of moisture across latin America;
- 3) transient nature of AMOC response;
- 4) possible link between AMOC changes and signature of H-events as seen in proxies.

If the authors chose to continue with the present format it would be best to skip experiment LGMb as well as several of the figures (e.g. 9,10, 11, 12, 14).

SPECIFIC COMMENTS

A few suggestion for improvements are as follows:

- 1) Abstract needs to clearly summarize the main findings and their significance.
- 2) It is stated that the observed rapid millennial scale climate changes observed during the glacial period are a response to changes in the AMOC. This is not clear from the proxy data and is rather a hypothesis to be tested and should be clearly stated as such.
- 3) Introduction is nearly 8 pages long and should be shortened substantially. Part of

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the discussion of changes observed in the proxy records should be moved to the end of the manuscript and discussed in the context of the model results.

4) In the introduction it is stated that one has tried to tie observed changes in the ocean to the abrupt changes in temperature on Greenland (D-O events) and that marine proxies suggest that the most stadials show little evidence for ocean circulation changes. At this point it should be made clear to the reader if the simulated AMOC changes are used as an example in the context of H-events (and not D-O events). In addition, a discussion of the difference between these events is required as most of the records described in the introduction have been related to D-O cycles and not to H-events. Note that in most records H-events do not have a strong climate signal, although the events are thought to have triggered AMOC changes.

5) The title of section 1.1 makes a bold statement that changes observed in the paleo-record are due to AMOC changes - this is not clear from the proxy data.

6) The description of the freshwater forcing is incomplete. A figure is necessary here to show where the freshwater is imposed in the case when the calving flux is increased. This will be crucial, as some of the far field responses observed could be due to imposed local changes in calving rate. E.g. does the calving change around Antarctica?

7) Is the model stable? It is stated that runs LGMa and LGMb are initialized from a previous LGM run (1065.25). Is there a reference for this, and was this run stable? 250 years is not sufficient to equilibrate the intermediate and deep ocean.

8) The control simulation of the IPSL model is not discussed in the paper. To be able to analyze the response of the model to a freshwater perturbation in the LGM case, it should be compared to the equivalent experiment for the modern climate. Further, the IPSL model gives a complete shutdown of the AMOC when a very small freshwater pulse is applied (0.08 + 0.1 Sv), this should be compared with the results of other models, e.g. Stouffer et al. (2005) who use the same flux and observe a ~30% weakening for the modern state. There are also several previous studies perturbing an LGM state

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with freshwater which should be discussed (e.g. Ganopolski & Rahmstorf, 2001; Bitz et al., 2007; Hu et al, 2008).

9) In the section 4.2 the surface response to the AMOC changes are assessed. This should be done in a more rigorous manner using appropriate statistical tools (regression, EOF analysis e.g.).

10) New data is presented in the summary (section 6) with figure 17. This is not appropriate in a summary and should if necessary be presented at an earlier stage.

TECHNICAL COMMENTS

1057.15: more appropriate here would be “suggest” rather than “demonstrate”.

1057.22: “logically” used in this context is subjective and should be rephrased.

1059.3: Denton et al. (2005) is stated as “showing that the response to a weak AMOC is.....”, there is no clear proxy for AMOC strength that is correlated with the data presented in this paper. This is rather a hypothesis, and there is little, if no, data from periods with D-O cycles.

1058.7: “margin” is out of place. Correct sentence: “..show that simultaneous to..”

1062.2: the original references should be added for the bipolar-sesaw: Crowley, T. J., North Atlantic deep water cools the Southern Hemisphere, *Paleoceanography*, 1992, 7, 489-497.

1066.25: confusing model time references. Is the LGMc output at the end of the run, i.e. model year 570?

1069.13: there is no clear difference in temperature over northeastern Europe in LGMb vs LGMc (figure 4).

1071.15: analyzing the mechanism for the possible propagation of anomalies in the model should be done in a rigorous manner (see e.g. Knutti et al., 2004).

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1073.16: there is no clear connection between “loss of freshwater” and increase in sea ice cover in the area of the Labrador Sea.

Figures 4, 5, 7, 11, 12, 13, 14 and 16 show the modern land-sea mask, which, according to the manuscript, is not used in this experiment.

Figure 8: this is too small and makes it impossible to see sea ice limit. Either one needs to include a separate plot of sea ice, or increase figure substantially. Would include figure here with mixed layer depth anomaly (and make figure 9 simpler to read (or skip)).

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