Clim. Past Discuss., 2, S568–S574, 2006
www.clim-past-discuss.net/2/S568/2006/

Climate of the Past Discussions

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Interactive Comment

Interactive comment on "Linking glacial and future climates through an ensemble of GCM simulations" *by* J. C. Hargreaves et al.

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Received and published: 7 November 2006

Accounting for data information about past climatic changes is an important aspect to infer insight of how strongly the Earth system reacts to changes in its radiative balance, i.e. to infer the magnitude of climate sensitivity. In this context the large difference in boundary conditions of modern and LGM climate along with the pronounced temperature difference between the two climates has been the subject of several studies. Hereby the crucial question arises whether the past cooling, provoked by glacial boundary conditions, is a good analogue for future warming, caused by rising greenhouse gas levels. It is well known that the past and future forcings are of different nature. Given the lack of a large set of complex climates models that have performed 2xCO_2 *and* LGM experiments the question of how strongly the simulated temperature

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drop in the Glacial is linked to future CO2 warming could not be satisfactorily answered so far (a study about this topic based on 4 PMIP2 AO-GCMs was recently presented by M. Crucifix (GRL, 2006)).

The work of Hargreaves and colleagues is an important contribution towards analysing this issue by considering a perturbed parameter model ensemble which has been run for LGM and 2xCO2 conditions. They analyse the link between both climate states on a global, regional and local scale. As a key finding they infer a non-linear feedback behaviour between positive and negative GHG forcing from their model ensemble. This has important implications for reducing uncertainty in climate sensitivity (by constraining model output with paleo data) if confirmed by other models. Furthermore the authors undertook an important step to analyse the impact of the model parameters on the model response to give a physical interpretation of the asymmetric feedback behaviour. They conclude that a strong non-linearity in the cloud response for cooling and warming seems to be the key determinant. This work constitutes an important step towards gaining insight into the feedback behaviour of climate models, based on the temperature response to past and future climate forcing. Underlining the relevance of this type of study for reducing uncertainty in future climate change I would like to add some comments regarding the robustness of the main findings presented here.

Major specific comments:

1. The conclusions drawn in this paper are based on an ensemble of versions from the MIROC model that cover a range from about 4-8°C for climate sensitivity (CS). While the upper end of this range can be regarded as extreme, it gets obvious that the ensemble does not span the full range of plausible CS towards smaller sensitivities (there is a growing consensus of about 2°C for a lower bound). Given the lack of ensemble members with small to moderate CS it is not possible to judge to what extent the conclusions drawn here are characteristic for high to very high CS model

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versions of the MIROC model or to what extent they are valid more generally. It would be informative to see whether the characteristics/correlations inferred are robust if the ensemble will be split into e.g. an ensemble covering CS<6K and an ensemble covering CS>6K. If systematic differences between those two ensembles are derived the ensemble with CS>6 should be given lower weight as its members are less likely to be consistent with paleo data.

2. The authors mention the omission of dust and vegetation forcing, which both - although of lower weight compared to the ice sheet and GHG forcing - crucially have contributed to the LGM cooling. In contrast to GHG forcing those two forcings are spatially strongly inhomogeneous and reveal a pronounced latitudinal dependence. When accounting for those two additional forcings in the experimental design one might expect that the difference between the LGM and LGM-GHG simulations will be larger than shown here (with possible implications for the conclusion that the LGM-GHG experiment is more similar to LGM than to 2xCO2).

3. The use of a slab ocean enables this kind of ensemble experiments with an AGCM - at the expense of neglecting effects of dynamical ocean changes. While those changes might not play so much a crucial role for 2xCO2 experiments it is quite likely that the strongly modified boundary conditions of the LGM have a pronounced impact on the state of the glacial ocean, resulting in modified overturning circulation and modified meridional heat transports - which in turn have an effect e.g. on sea ice extent and the related ice albedo feedback. Up to now the few existing fully-coupled model simulations do not give a consistent picture of how dynamical ocean changes affect the LGM cooling. The point I want to make is that redoing this experiment with a fully coupled design (what would be far too expensive) would add a further aspect of

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uncertainty. So especially when analysing the latitudinal aspects of correlations one could infer a (slightly) modified picture from a fully-coupled model design as one might expect that the impact of changes in ocean heat transport is more similar between the 2xCO2 and LGM-GHG experiment than between LGM and LGM-GHG.

4. My last main comment touches upon the issue of the choice of model parameters and the resulting spread of model feedbacks in the ensemble. The analysis of parameter correlations has revealed that asymmetry in the cloud feedback is most crucial for explaining the simulated temperature responses. In this regard it would be interesting to see to what extent the chosen parameters allow for different realizations of the other main model feedbacks (lapse rate, water vapour, albedo). This would allow judging whether the correlations inferred are primarily caused by a set of models which strongly differ in respect to their feedback behaviour of clouds - or whether they are representative for a model ensemble covering a broad range in the main model feedbacks (ideally those should cover a range comparable to structurally different GCMs, see the work of Colman, Climate Dynamics (2003) and Soden Held, Journal of Climate, 2005). It is to be expected that the different feedbacks show different forcing-response characteristics - an issue of importance especially when the latitudinal temperature profile is discussed. The authors mention in the text that they plan a further ensemble experiment in which different parameters will be varied. By quantifying the spread of the feedbacks in the current model ensemble one could get an idea in how far the current parameter choice is able to cover the feedback behaviour of structurally different models.

The above comments do not challenge the interesting finding of a strong non-linear temperature response due to decreasing and increasing GHG concentration but suggest to add some comments in the manuscript when discussing correlations and when analysing the similarity between experiments.

Minor specific comments:

Page 954, line 26-28: The use of the term "simple climate model" is misleading. When talking about "simple climate models" one commonly refers to box models or EBMs. The model used in the study cited ranks among the class of intermediate complexity models which fill the gap between simple climate models and GCMs. Furthermore when referring to the MIROC model as "more sophisticated" one should be explicit at this point by clarifying that a slab ocean design was used - to make clear the difference e.g. to the PMIP-2 model design.

Page 958:
Line 5-6: 2-3 extra sentences to clarify the meaning of 0.24 would be helpful.
Line 21: bias in air temp. over land ice The argument that this bias has no effect on the results as only temperature changes are analysed applies to the difference between 2xCO2 and CTRL which both reveal comparable areas of land ice. Yet the LGM climate is characterised by a much larger area of land ice, so the difference between LGM and CTRL should not cancel out? How large is the bias?

Page 961:
Line 18-25: The same point (that tropical SSTs and Antarctica provide a good area to constrain the ensemble) is made in Schneider von Deimling et al. and could be cited here.

Page 963:
Line 8-16: The main issue is the exact location of the red line (here shown to be

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aligned at 0.76) and the related conclusion that 80% of the ensemble members show a weaker LGM response compared to 2xCO_2. The value of 0.76 (given by the ratio *R* of LGM-GHG to 2CO_2 forcing as 2.8/3.7) is consistent with the best-guess from IPCC for CO_2 radiative forcing. I assume that this IPCC estimate is discussed here (no further information is given whether the numbers are derived from MIROC).
The assumption is made that *R* is the same for all model versions. The chosen parameter perturbations are likely to cause different CTRL climate states, with e.g. different cloud patterns, which can result in different cloud radiative forcings. Thus slightly different values of the "real" radiative forcing for each model version might result if calculated by an offline scheme. It might prove that not only the cloud feedback reveals an asymmetric behaviour but the radiative forcing as well (to a certain extent). In case an offline calculation routine is already implemented in the model code it would be interesting to test (for a couple of runs) the robustness of *R*.

Page 964:
Line 13-15: A few comments to what is meant by "behaviour of ice in clouds" would be helpful. E.g. what is meant by "distribution of ice in clouds" - is it mainly the latitudinal distribution, the vertical, or both?
Line 23-25: On the other hand the albedo feedback is likely to vary more strongly between different models for LGM than for 2xCO_2. The variation of the temperature response depends on the variation on all main feedbacks.

Table 4:
For the analysis of feedback asymmetry behaviour it might be interesting to have a look at the parameter ranking for the ratio of LGM cooling vs. 2xCO_2 warming?

Technical corrections:

Typing errors:
Page 953: line 26; p.954: line 16, line 26 citation "Schneider von Deimling" instead of "von Deimling"; p.959: line 1, line 19; p. 960, line 18; p.961: line 6; p.964: line 3; p.966: line 17?

Figures:
Fig1: contours and numbers too small to catch

Interactive comment on Clim. Past Discuss., 2, 951, 2006.