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Climate of the Past Discussions

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5, S162–S169, 2009

Interactive Comment

Interactive comment on "Impacts of land surface properties and atmospheric CO_2 on the Last Glacial Maximum climate: a factor separation analysis" *by* A.-J. Henrot et al.

A.-J. Henrot et al.

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We thank Referee #1 for the helpful and constructive comments and the thorough and careful revision of the technical aspects of the manuscript, which will help to improve the clarity and precision of the text.

General comments:
Thank you for drawing our attention to the important paper by Jahn et al. (2005) and the report of Berger et al. (1996) that we had, unfortunately, overlooked. We have considered both papers in the revised manuscript, and adapted the text accordingly. We have nevertheless, mainly focused on the study by Jahn et al. (2005), which

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Interactive Discussion

Discussion Paper

has been published in the peer-reviewed literature and will furthermore be openly accessible to all our readers, which is not the case for the report by Berger et al. (1996), only available upon request.

Specific comments:

Comments 1, 3, 15 and 17: As mentioned above, we have taken the two previously overlooked studies into account in the revised manuscript.

Comment 2: The incriminated sentence is rewritten as "It is characterized by an expansion and a thickening of the ice sheets at high latitudes, a large reduction in the atmospheric CO_2 concentration, and a less dense vegetation cover."

Comment 4: We have added in the experimental setup (section 3) a paragraph discussing the use of a slab model in this study. As required by both Referees, we also discuss now the missing feedbacks or climate induced changes due to the lack of oceanic circulation changes in our experiments.

Ideally, this study should have used a fully coupled ocean-atmosphere-vegetation model to assess the contributions of all the chosen glacial forcings. Due to the number of experiments to perform, we preferred to work with an Earth-system model of intermediate complexity and focused here on the impact of boundary conditions changes on the surface climate. We chose the Planet Simulator because of its fully three-dimensional atmospheric component, which offers a sufficiently detailed representation of atmospheric dynamics, which is not the case with the two models mentioned (CLIMBER and UVic ESCM). Unfortunately, the Planet Simulator currently only includes a slab ocean, which does not allow to explicitly represent oceanic circulation changes. We are aware that some feedbacks and regional impacts of oceanic circula-

CPD

5, S162–S169, 2009

Interactive Comment

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Interactive Discussion

Discussion Paper

tion changes at LGM (as shown, e.g., by Hewitt et al. (2003) or Kim et al. (2003)) are implicitly excluded. However, as pointed out by both Referees, studies using oceanic models do not yet agree on how oceanic circulation changed at the LGM (Weber et al., 2007), leaving a great deal of uncertainty in our present knowledge of the state of the ocean circulation at the LGM and its impact on the global climate.

We furthermore chose not to work with a fixed SST distribution for the LGM, such as the CLIMAP reconstruction (the more recent MARGO reconstructions (Kucera et al., 2005) would have been another alternative). The reasons are as follows. 1) Braconnot et al. (2007) show the limitation of the use of CLIMAP SSTs with slab models, since they failed to produce the magnitude of the glacial cooling, especially in the tropics. 2) The use of fixed SSTs constrains the model sensitivity, that reduces notably the vegetation impacts outside of land areas (Ganopolski et al., 2001).

We therefore chose to follow the PMIP1 protocol and prescribed present-day oceanic heat transfer. As a consequence, the model may respond with a larger sensitivity and gives coolings closer to coupled ocean-atmosphere ones, if compared to fixed SSTs runs (Braconnot et al., 2007). This point is discussed in the revised paper

Comment 5: We agree that the sea level lowering, leading in the model to the land-sea mask change, results from the ice sheets formation, as well as the increased elevation on land. However, due to its weaker effect on climate in the model and in order to limit the number of simulations to perform, we did not consider it as a factor to isolate, when using the factor separation. Secondly, we did furthermore not include it just in the orography changes (experiment O and other experiments with orography changes), since we would have missed some effects of the other boundary condition changes on the emerged land points (e.g., vegetation changes on the emerged land points (experiment V) or expansion of ice on the emerged land points (experiment I)). We therefore included it into the CTRL boundary conditions, that allows us to take its effects on the LGM climate into account, but not to isolate it.

CPD

5, S162–S169, 2009

Interactive Comment

We have amended section 3.1 in the revised manuscript to emphasize that the orography changes in the experiment O only relate to the increase of elevation at high latitudes.

Comment 6: Figures 1 and 6 to 10 have been modified in the revised manuscript following your recommendation. We have also reworked Fig. 1, to show the land-sea mask changes, the expansion of ice and the elevation changes over the ice sheets.

Comment 7: The LGM cooling obtained here is in line with the coolings produced by the models used in PMIP1 and PMIP2, although it ranges at the upper end of the spectrum of responses. This may well be due to the lack of an explicit representation of ocean circulation in our model, as the slab models used in PMIP1 tended to produce stronger coolings over the Northern Hemisphere than the ocean-atmosphere models (Braconnot et al., 2007). However, let us re-emphasize that none of the models participating in PMIP1 and only a few of those in PMIP2 models take into account vegetation changes at LGM. The stronger cooling we produced can thus just as well be related to the additional contribution of vegetation. PMIP1 and PMIP2 coolings therefore better had to be compared to the cooling produced in our experiment CIO (-4.3°C), which does not include vegetation changes, instead of our LGM total cooling (-5.2°C)—this was also suggested by the second Referee, Andrey Ganopolski. A more detailed comparison has been included in section 4.3 of the revised paper.

Comment 8: As suggested, Fig. 5 has been split in two, both have been widened, and tables with the actual effects added.

Comment 9: OK. Amended as suggested.

CPD

5, S162–S169, 2009

Comment 11: OK, Changed as suggested.

Comment 12: In order to compare the pure contributions of the factors studied here, we can refer to experiment V. The vegetation cover change produces a global cooling of -1.3°C in experiment V. It is lower than the global cooling produced by CO_2, but locally the vegetation induced coolings are comparable and even larger than the CO_2 induced coolings, especially over the northern latitudes of Eurasia, as in Ganopolski (2003). However, as pointed out by Andrey Ganopolski, we cannot rigorously compare the results of the experiment V with previous studies, since they used either prescribed vegetation reconstructions or vegetation models under LGM boundary conditions. This is not the case for experiment V. Moreover, previous studies using vegetation reconstructions (Crowley and Baum, 1997; Kubatzki and Claussen, 1998; Wyputta and McAveney, 2001) used fixed SSTs, which underestimates the vegetation impact outside the land areas (Ganopolski et al., 2001). The comparison would therefore most probably lead to a larger vegetation impact in our results. As a consequence, we have based our comparison upon the vegetation impact obtained with the set of glacial boundary conditions. The temperature difference between experiment LGM and CIO, due to the additional vegetation impact, cools the global climate by -0.9°C. It is in line with the coolings obtained by Jahn et al. (2005) and Ganopolski (2003) (respectively -0.6°C and -0.7°C) and at the lower end (strongest cooling) of the range of temperature variations due to vegetation changes reported by Schneider von Deimling et al. (2006) (-0.5°C to -1°C). The larger cooling in our results can therefore be attributed to the more contrasting vegetation changes prescribed here. We would nevertheless like to emphasize that our vegetation reconstruction does not appear to be unrealistic. It agrees well with the data and leads to global and local coolings of the same order of magnitude than reported in previous studies.

Comment 13: Thank your for this suggestion. These different effects of the ice sheets

CPD

5, S162–S169, 2009

Interactive Comment

(orography and ice) have been highlighted in the abstract and conclusions in the revised manuscript.

Comment 14: The sentence mentioned has been clarified. We have detailed a little bit more the effect of ice on the monsoon system. We obtain indeed a weakening of the Asian summer monsoon as in DeMenocal and Rind (1993). However, we also find precipitation increases over north-east Asia and the Pacific, southwards to Southeast Asia, as in some models used in the study of Yanase and Abe Ouchi (2007).

Comment 16: There were several reasons for splitting the model averages into two sectors (Western Europe-Africa and Eastern Europe-Africa). We did not want to average the model results over a wide sector, in order to avoid bias in the results and keep the model averages comparable with individual data points. On that point we followed the approach of Kageyama et al. (2001). The differentiation between an eastern and a western sector allowed us to clearly display the model results and the data with error bars, keeping the data points rather well distributed in longitude over each of the two. Finally, it also allowed us to highlight the meridional gradients in the climatic variables. This has been clarified in the revised manuscript.

Comment 17: The conclusions have been rewritten according to your recommendations.

Technical corrections

We have taken into account all of the technical corrections suggested by the referee.

CPD

5, S162–S169, 2009

Interactive Comment

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CPD

5, S162–S169, 2009

Interactive Comment

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CPD

5, S162–S169, 2009

Interactive Comment