

Interactive comment on “Impacts of land surface properties and atmospheric CO₂ on the Last Glacial Maximum climate: a factor separation analysis” by A.-J. Henrot et al.

Anonymous Referee #1

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General comments

The paper of Henrot et al. shows a systematic analysis of the climatic effect of albedo changes due to ice sheets at the LGM, orography changes due to ice sheets at the LGM, CO₂ changes to 200 ppmv, and vegetation changes to LGM conditions. The paper is well written, the experimental design is clearly explained, and the paper fits well into the scope of Climate of the Past. However, the study uses only a 50 m slab ocean, not a full ocean model, which needs to be revised or at least discussed in more detail, as feedbacks involving the ocean are missed with this approach, which is especially problematic for a study of the LGM climate, where the ocean circulation was different than today (e.g., Lynch-Stieglitz et al., 2007). In addition, the use of the Stein

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and Alpert (1993) technique to study the impact of ice sheets, CO², and vegetation changes on the climate of the LGM is not as new as the authors claim, as they miss an earlier study that also uses the Stein and Alpert technique to study almost the same set of factors for the LGM (Jahn et al., 2005), as well as a study that used the Stein and Alpert method to investigate CO² and ice sheet effects (Berger et al., 1996). Since the models and the details of the experimental setup in Henrot et al. are somewhat different, and the analysis also differs, the study of Henrot et al. contributes some new insights into the climate of the LGM, as well as providing a model comparison of the Planet Simulator with some reconstructions for the LGM. Due to the changes required (outlined below in detail), I recommend publication after major revisions.

Specific comments

1. page 30, line 3: Should say “as in most previous studies”, as Jahn et al. (2005) and Berger et al. (1996) have also already used the separation method of Stein and Alpert (1993) for the analysis of the LGM climate (see comment 10 for more details on these studies).
2. page 30, line 25-26 to page 31, line 2: “It is characterized by changes in several climate forcings, resulting in the expansion and the thickening of the” This sentence makes no sense (climate forcings are *resulting* from changes in ice sheets, CO², and vegetation?), and needs to be revised.
3. page 3, line 13: Need to mention here that Jahn et al. (2005) and Berger et al (1996) did also use the Stein and Alpert technique, and did not apply the different boundary conditions in sequential order.
4. page 32, line 18-20: Ocean dynamics play a big role for climate feedbacks, especially for non-linear ones, so excluding them by only using a slab ocean with a preindustrial circulation excludes important climate feedbacks. This is especially problematic for a study of the climate of the LGM, where the ocean circulation, and hence the ocean heat flux, is thought to have been different than today, even though the exact

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state of the ocean circulation at the LGM is not yet clear (e.g. see Lynch-Stieglitz et al., 2007, and Weber et al., 2007, for recent reviews of data and model studies). If it is not possible to use a full ocean model for this study, the problems of using only a slab ocean model need to be discussed in more detail here, as well as again in the discussion section, instead of just mentioning it. It should also be explained why the ocean boundary conditions were fixed at preindustrial conditions, instead of using the CLIMAP reconstruction. Furthermore, the authors need to justify why a model without an ocean model was chosen for this study of the LGM in the first place, since other EMICs that include an ocean model (e.g. CLIMBER, UVic ESCM, and others) are available and would allow for the same number of sensitivity experiments.

5. page 33, line 27 to page 34, line 3: Why did you chose not to include the land mask changes in the orography factor? The sea level lowering that leads to these land mask changes are as much the result of the ice sheets as the increased elevation over land, so I think they should be included in the orography factor.

6. Fig. 1, as well as all following global plots, should use the land-ocean mask used in the model, not present day coastlines, as is is confusing to see, for example, Bering Strait open during the LGM. In addition, it is not clear what the gray shading in Fig.1 stands for (glaciers? Please clarify in caption). Some more contour labels for the orography would also be helpful for reading the graph.

7. page 38, line 4-7: That the LGM cooling compares well even with coupled atmosphere-ocean models, in spite of prescribed preindustrial ocean heat fluxes, might mean that it overestimates the cooling due to CO_2 , vegetation, or ice sheet changes. A further comparison with the ocean-atmoaphere PMIP2 model results would be useful.

8. Instead of Fig. 5, which is very hard to read (only at 300% can I actually see the magnitude of the bars), I would suggest to include a table with the temperature and precipitation changes due to the interaction of factors, and due to the full factors. If you wish to keep the figure, I would like to see the table in addition. Otherwise the results

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are not useful for comparisons with future studies.

9. page 39: That the small effect of the ice sheets in the Southern Hemisphere is due to the lack of ocean circulation changes in the model should be stated right after mentioning the small effect on the Southern Hemisphere, i.e. the sentence “The weak impact...” in line 13 should be moved to line 8.

10. section 5.1: As mentioned in point 1 and 3, the studies of Berger et al. (1996) and Jahn et al. (2005) did not add the forcings successively, but also used the Stein and Alpert technique. Jahn et al. (2005) used a Stein and Alpert factor separation for CO² and ice sheets (including orography), and a feedback analysis for the effect of the vegetation, in difference to the analysis of Ganopolski (2003), who used the same model otherwise. Berger et al. (1996) computed the effect of albedo changes (i.e. ice sheet and orbital parameter change) and of the CO² change on the LGM climate using Stein and Alpert’s factor separation. Hence, you need to compare your results with these earlier studies, highlighting differences as well as common results. This is especially important as the model of Jahn et al. (2005) includes an ocean model, and by comparing the results it might be possible to diagnose missing feedbacks in your study.

11. page 45, line 21-26: In this comparison with the earlier results, it would be helpful to mention the results of your study again, so one does not have to go back and search for the corresponding numbers in the paper.

12. page 45 last paragraph, and page 46 first paragraph: “However, the vegetation contribution we obtain is much more pronounced than the one obtained in previous sensitivity studies with uncoupled vegetation models (...). This results from the rigorous separation of the factor impacts, fully isolating the vegetation contribution from the effects of the other contributions and of their interactions.” This paragraph raises many questions. First, what is meant by “uncoupled vegetation models in previous sensitivity studies”? All mentioned studies included vegetation, with some using prescribed veg-

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etation reconstructions (Levis et al., 1999; Wyputta and McAveney, 2001; Crowley and Braun, 1997), one an atmosphere-vegetation model (Kubatzki and Claussen, 1998), and two an atmosphere-ocean-vegetation model (Ganopolski et al., 2003; Jahn et al., 2005). In your study, a vegetation distribution derived from a simulation with CARAIB is prescribed as a forcing factor, which is similar to prescribing a vegetation reconstruction, and is not a coupled simulation. So this statement does not make sense to me, and it needs to be removed/revise. Second, since Jahn et al. (2005) also did a factor separation, and arrive at a total vegetation effect of -0.6 C with this method, I do not think it is the rigorous separation of the impact factors, but rather a stronger prescribed vegetation change than used in other models or a stronger response of the Planet Simulator to the prescribed vegetation changes. A simple test of the role of the factor separation can (and should) be done with your simulations, by calculating the effect of vegetation if the factor separation is not used, and comparing it to the effect of vegetation obtained from the factor separation. This should give a measure of how much of the much larger vegetation effect in your study is due to the analysis method, and how much is due to a different model response. Based on the outcome of this additional analysis, the second sentence (“This results from the ...”) also needs to be removed/revise.

13. page 46, line 10-13: The different effect of orography and ice sheet albedo is a very interesting result, and I would emphasized it more, e.g., in the Abstract and in the Conclusion.

14. page 47, line 8-10: It is not clear to me what “a similar effect” refers to here. Do you mean a weakening of the monsoon, as in DeMenocal and Rind? Or no weakening as in your study? Please clarify.

15. page 47, line 28: Need to refer to Berger et al. (1996) and Jahn et al. (2005) here as well.

16. page 48, line 18: Why do you choose these two sectors? Maybe because of the

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the data coverage? Please explain the reasons for this choice.

17. section 6: The conclusion section needs to be reworked, as this is not the first study using Stein and Alpert for the LGM. Also, it needs to be mentioned again that ocean dynamics are missing and that these might affect the results.

New References:

Berger et al. (1996): Paleoclimate sensitivity to CO² and insolation, Scientific Report, Institut d'Astronomie et de Geophysique Georges Lemaitre 1996/6.

Jahn et al. (2005): Quantifying the effect of vegetation dynamics on the climate of the Last Glacial Maximum, *Climate of the Past*, 1, 1–7.

Jean Lynch-Stieglitz, et al. (2007): Atlantic Meridional Overturning Circulation During the Last Glacial Maximum, *Science* 316, 66–69.

Weber et al. (2007): The modern and glacial overturning circulation in the Atlantic ocean in PMIP coupled model simulations, *Climate of the Past*, 3, 51–64.

Technical corrections

page 30, line 24: Add “,” after (21 kBP), or remove “,” after (LGM).

page 31, line 17: Remove “,” after forcings.

page 31, line 25: Add “,” after orography.

page 32, line 17: Correct “wich” to “which”. This mistake also occurs on line 8 on page 33, and in the last line of the caption of Fig. 5 on page 63.

page 33, line 3: Add “,” after respectively.

page 34, line 1: Correct “configugation” to “configuration”.

page 37, line 21: “when added notably to” - “notably” makes no sense here in my opinion. Please rephrase or leave out “notably”.

page 39., line 3: Remove “,” after responses.

page 39, section 4.4: References to the specific subfigures discussed in the text would

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be useful to better follow the discussion. For that, a)-d) labels need to be added to the figures.

page 40, line 25: Replace “experiment” with “experience”, otherwise it makes no sense.

page 41, line 2: Rephrase the sentence to “The cooling trend induced by the ice cover remains dominant over the continents of the Northern Hemisphere, whereas the orography changes minimize the cooling at the mid latitudes and slightly warm some oceanic regions, e.g....”. There are quite a few mistakes in the original sentence and missing or wrong words make it hard to follow.

page 42, line 4: Replace “mecanism” with “mechanism”.

page 42, line 5: Remove “then” before reducing.

page 44, line 11: Remove “,” after factors.

page 44, line 12: Replace “avoiding the regional climate to cool intensively” with “reducing the regional climate cooling”.

page 44, line 16: Remove “,” after contributions.

page 44, line 22: Add “s” to lower → lowers their...

page 45, line 3: Replace “concerns” with “affects”.

page 46, line 7: Replace “when” with “whereas”.

page 47, line 2: Replace “that” with “which”.

page 47, line 4: Remove the “,” after precipitation.

page 47, line 16, 19: Add a “,” after Hewitt (2005), and remove the “,” after contribution (line 19).

page 48, line 16: Replace “reconstructions” with “reconstructions”, and “through” by “by using”.

page 48, line 19: Add an “s” to average (averages are).

page 49, line 7: Replace “infirm” with “contradict”.

page 50, line 7-10: Delete “in our model” (simulation already says that), and possibly rephrase sentence.

page 51, line 13: “towards” at end of line makes no sense here, please remove.

page 51, line 26: Remove “at term”, it makes no sense.

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page 52, line 5: Remove “,” after land, and add “which is” before reinforced

Fig 6-9: Contour plots might be more suitable to show the changes (in addition or instead of the shading), as it is hard to identify local temperature and precipitation changes on the shaded plots, as the range of the colorbar is so large (-18 to 18 C and -400 to 400), and does not allow much color separation.

Fig. 12: Please state in the caption what the solid line and dashed lines are, as well as what the data is. It is stated in the text, but it would be nice to be able to easily understand the figure by itself.

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