Clim. Past Discuss., 9, C1561–C1576, 2013
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Climate of the Past Discussions
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Interactive comment on "Interdependence of the Northern Hemisphere ice-sheets build-up during the last glaciation: the role of atmospheric circulation" *by* P. Beghin et al.

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Received and published: 25 July 2013

General comments

We thank the reviewer for his comments and remarks. We have made a revisited version of the paper to take into account the remakrs of all reviewers. Here are the answers of more specifc comments :

"I suggest that the paper would be strengthened (a) by explaining the physical basis and showing more of the evaluation of the parameterizations. Especially, in sect 3.1, please could you give the physical motivation for the form of equa-

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tion 6, and demonstrate that it works betters than other choices which could have been made. A really useful justification would be to show that it correctly represents the effect of topography change imposed in a GCM, since the whole paper depends on the correct response to *change* in topography. "

The parameterization described by equation (6) has been established following the same basic principle as equation (2) (see response to reviewer 2 for a justification of equation 2). Since the thermal contribution is expressed as a linear relation between the azonal component of sea-level pressure (p'_{th}) and the azonal component of temperature (T'_0), we expressed the orographic contribution (p'_{oro}) as a function of the deviation of orography from its zonal mean (h'_0). This accounts for the deviation of the zonal wind by an anomaly of topography. Since the zonal wind is driven by the equator-to-pole temperature gradient, we added the term $\Delta T_{E/P}$ in our parameterization to account for the effect of the temperature gradient. Adding a dependency on the equator-to-pole temperature gradient allows to account for seasonal changes of the influence of the orographic effect on the sea-level-pressure. The larger this gradient is, the stronger the zonal wind and the influence of topography are. At the opposite, if $\Delta T_{E/P}$ is too small (i.e. below the ΔT_{limit}), the zonal wind and its deviation due to orography will be negligible. Therefore, the ΔT_{limit} represents the limit below which the orographic contribution is negligible. The numerical value of the ΔT_{limit} has been chosen to obtain the best agreement between simulated slp and NCEP reanalyses (see response to specific comment 2)

To evaluate the robustness of this parameterization, we compared the CLIMBER response of the sea-level pressure to a change in topography to the response of the IPSL-CM5 model. We used two available experiments carried out with this latter model. The first one was run under pre-industrial conditions (PI) and the second one under LGM ones (except that the only ice-sheet considered as boundary condition was

the Laurentide ice sheet). To compare the CLIMBER and the IPLS-CM5 responses, we used exactly the same experimental setup and performed the same simulations with CLIMBER (with the OTH parameterization since the GCM includes both effects). Figure 1 of this comment (below) displays the azonal slp anomaly for these two experiments (PI and LGM with a LIS only) for both the IPSL the CLIMBER models. In both models we observe under LGM conditions (i.e. when a change in topography is considered) an enhancement of the high pressures over North America, and of the low pressures over North Atlantic. At the opposite, both models simulate a decrease of the high pressure over Asia and of the low pressure over Northern Pacific. Therefore, the CLIMBER and the IPSL models simulate similar SLP patterns, although there remain some disagreements in some places as for their amplitude.
We added these justifications in the paper, as suggested by the reviewer.

"(b) by relating the effects described more directly to atmospheric circulation i.e. the stationary wave pattern. Page 2194 lines 11-16 suggest that it is practically difficult to understand the temperature and precipitation perturbations that result from the pressure parameterizations, and I accept that it is complicated. However, I have to say that I feel doubtful unless there is some amount of such explanation given. To have confidence in them, I would like to be shown that the results make sense physically. "

Figure 2 of this comment (below) shows the zonal anomaly of surface air temperature for the same experiments described above. Compared to the IPSL simulation and owing to the CLIMBER resolution, the centers of anomalies are located in relatively good places for the PI experiments (cold anomaly over North Atlantic and Pacific, warm anomalies over Eurasia and North America). Moreover, the response of these temperatures to a Laurentide ice sheet under glacial conditions are similar in CLIMBER and in the more comprehensive model IPSL-CM5A : the warm anomaly over North

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Atlantic and the cooler one over North America are stronger with the LIS whereas the colder anomaly over Asia is weaker. The increase of the warming over Pacific in IPSL is not present in CLIMBER. This comparison suggests that despite its simplified physics, the response of the CLIBER atmospheric temperatures at large scale is in most areas comparable to the response of a GCM under the same climate conditions (considering CLIMBER resolution). If we assume that the GCM response is closer to the "real world", this comparison shows that the CLIMBER response makes sense physically.
We addressed these concerns in the revised version of the paper as suggested by the reviewer.

Specific comments

"page 2191 line 4. It is confusing to use p0' with two different meanings, distinguished only by the arguments. Two different symbols would be better."
The text has been modified to be clearer.

"page 2191 line 5. It would be good to see the evidence that this is the best choice."
The value of ΔT_{limit} represents the limit of the temperature difference between the pole and the equator above which the orographic effect on SLP must be taken into account. If the difference of temperature between the pole and the equator is too small (below this limit), the zonal wind and its deviation due to an anomaly of topography is too weak : in this case the orographic effect may be neglected. We have tested numerous values of this parameter and have compared the SLP field for summer and winter with NCEP reanalysis. The numerical value of the ΔT_{limit} parameter has been chosen in order to obtain the best correlation between our results and NCEP reanalysis, keeping a proper response to anomalies of topography (i.e. a high

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mountain leads to a positive SLP anomaly).
Hereafter we present in figure 3 (below) some of the results we obtained with other values of ΔT_{limit}. We focused on the Northern hemisphere, because it corresponds to the GRISLI domain. The case of $\Delta T_{limit} = 15$ (figure C4) is discarded because the absence of the high pressure over North Atlantic during summer. The choice between $\Delta T_{limit} = 20$ and $\Delta T_{limit} = 25$ is less obvious. However, in summer, the high pressure over North Atlantic is stronger with $\Delta T_{limit} = 25$ than with $\Delta T_{limit} = 20$ (figure C6 compare to C7) although it does not reach the same amplitude than in NCEP. The same remark can be made with the low pressure over eastern Eurasia. Moreover, we also investigated the shape of the simulated ice sheet at present day with the different ΔT_{limit} values (see figure 4 below). With all of them, there is a too much ice over Alaska, but the solutions $\Delta T_{limit} = 25$ is clearly the best choice.

"page 2191 line 12. Northern winter, I presume. Why do you not also examine the performance in northern summer, which is when the melting takes place?"
It is also possible to show the results in summer (figure 5 below). Here, we focused on boreal winter because the effect of topography is stronger in the northern hemisphere during this season. As outlined by Reviewer 3, the summer field can indeed be interesting because of the importance of summer temperature in the ablation process. However, the difficulty in making a direct link between the SLP field and the temperature led us to focus our analysis on the winter season only.

"page 2192 line 12. In Fig 1c, these highs appear to be over the Caspian Sea and central America."
The text has been modified accordingly

"page 2193 line 18. Please explain why sigma0 is so different for FIS and LIS (as shown in Table 1). If such different numbers are needed, it is hard to be

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confident in the reliability of the PDD scheme under a variety of climates. How did you choose the step in sigma0 between the experiments?"

Several studies have pointed out the lack of reliability of the PDD model for climates different from the present-day one. However, although energy balance models are more physically based, they also depend on many parameters that are poorly constrained in rather different climatic contexts and may be thus not much more robust than empirical methods, unless surface mass balance is computed with a multi-layered sophisticated snow model. As shown by Charbit et al. (The Cryosphere, 2013) the use of the PDD approach to compute ablation under various climates requires an appropriate tuning of the PDD parameters, depending on the climate model. The best way to better constrain the PDD parameters would to use very high resolution climate models coupled to detailed snow models, but this kind of numerical tools cannot be run over long-time periods. Therefore, we have to make assumptions related to the numerical values of the PDD parameters.

The σ_0 parameter represents the standard deviation of the daily temperature distribution and can be understood as a parameterization of the daily variability of temperature. Therefore, there is no reason for this parameter being the same all over the GRISLI domain and especially over the three NH ice sheets present during ice ages. For example, the daily temperature variability over Siberia should be stronger than the one over Fennoscandia, because of the difference between a continental and an oceanic climate. Other studies support the non-uniform spatial distribution of the sigma parameter (see for example Fausto et al;, 2009 and more recently Rau and Rogozhina, TCD, 2013). So we choose to divide the GRISLI grid in four areas with different σ_0 values, and we made a sensitivity study to choose a couple of σ_0 which leads to the most consistent (with respect to available reconstructions) ice volume for each ice sheet. We kept the values : $\sigma_0^{LIS} = 3.00$ and $\sigma_0^{FIS} = 0.50$

"page 2193 line 18-20. This use of "resp." is not usual English and consequently not clear. I would suggest "we used different values of sigma0FIS and

sigma0LIS to obtain larger or smaller Fennoscandian and Laurentide ice sheets, respectively. This allows us to study the impact of the FIS geometry on the LIS and vice-versa."”
The text has been modified

“page 2193 line 24. And no other NH ice-sheets, presumably. What about Antarctica?”
We did not mentioned the Antarctic ice sheet because CLIMBER is only coupled to the version of the GRISLI model developed for the NH. The initial state of GRISLI is given by the present-day Greenland ice-sheet geometry, but the topography of Antarctica is given as a boundary condition to the CLIMBER model. This has been more clearly explained in the revised manuscript.

“page 2194 line 6. "waves".”
The text is modified

“page 2194 line 7. I suggest "the impact of the Greenland ice sheet on the Laurentide and Fennoscandian is likely ...".”
The text is modified

“page 2194 line 19. Why do you start from a 126 ka state but analyse at 125 ka?
We made our analysis at 125 ka because at 126 ka, the state is the same for all experiments. At 125 ka, there is still only the Greenland ice sheet, and no other in Northern Hemisphere, so we can assume that the differences observed between the experiments are only due to changes in the SLP parameterization.

“page 2195 line 3-4. I do not see this point discussed in sect 3.1. As remarked

above it seems to me that this effect on JJA ought to be discussed."
We changed the text and added an explanation of this point in the 3.1 section.

"page 2195 line 19. "combined with". Is temperature or accumulation more important?"
Figure 6 of this comment (below) shows the ablation (a) and accumulation (b) differences between NONE and ORO experiments at 125 ka. A positive difference means that there is less ablation in the ORO experiment than in the NONE experiment (since the ablation is computed negatively) Both fields are in the same units (m water eq.). The difference in ablation is clearly stronger than the one in accumulation. this means that the temperature effect is more important than the accumulation.

"page 2195 line 24. Unclear which "effects" you mean. I suggest "slp perturbations" instead (if that's what you mean)."
That's what we meant. We modified the text to be clearer.

"page 2196 line 6 Fig 4. Why do the ice sheets begin to grow so early in some configurations?"
The conditions are more or less suitable to the construction of the LIS or the FIS depending on the experiments, as explained in part 4.2.1 and 4.2.2 with more details. This leads to quicker or slower construction of ice sheets. This is why some configuration leads to earlier growth of ice sheets.

"page 2196 line 13. It would be good to understand the relative sizes of these effects.
We did not understand which effects the reviewer referred to?

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“page 2197 line 14-15. Why doesn’t it affect the growth of the LIS (red lines in Fig 4b)?”
The volume of the LIS is not affected by a decrease of σ_0^{FIS} in ORO experiment mainly because the change of σ_0^{FIS} does not change a lot the FIS ice volume. The difference in FIS ice volume is too small to have an impact on the already large LIS.

“page 2198 line 6. Summer insolation at northern high latitudes, I guess.”
We modified the text to be clearer.

“page 2202 line 8. What does "former" refer to?”
“Former” refers to the mechanism leading to a global cooling all over the GRISLI grid due to a larger ice sheet. We removed “former” that was a bit misleading.

“Fig 2. It might be helpful to see results for the present climate as well, to compare with 125 ka. What does the green mean in the difference figures? The caption is rather hard to follow, I find; however, the labels of the individual figures make it clearer.”
The same figures at present period leads to the same conclusion, because there is no great difference between the Eemian and the pre-industrial periods concerning the ice sheets, especially with the CLIMBER resolution. The green lines represent the limit where the thickness difference between NONE and the corresponding experiment exceeds -500 m. This has been added in Figure 2 caption in the revised manuscript

“Fig 4. What do the downward-pointing arrows mean? I would suggest not using "resp.", which is not usual English and not clear.”
The downward-pointing arrows mean ’effect on the LIS ice volume’ or ’effect on the FIS ice volume’. We change the text concerning the resp.

“Fig 7. What do the downward-pointing arrows mean?”
See previous answer

“Fig 8. The two panels are identical.”
The error is corrected.

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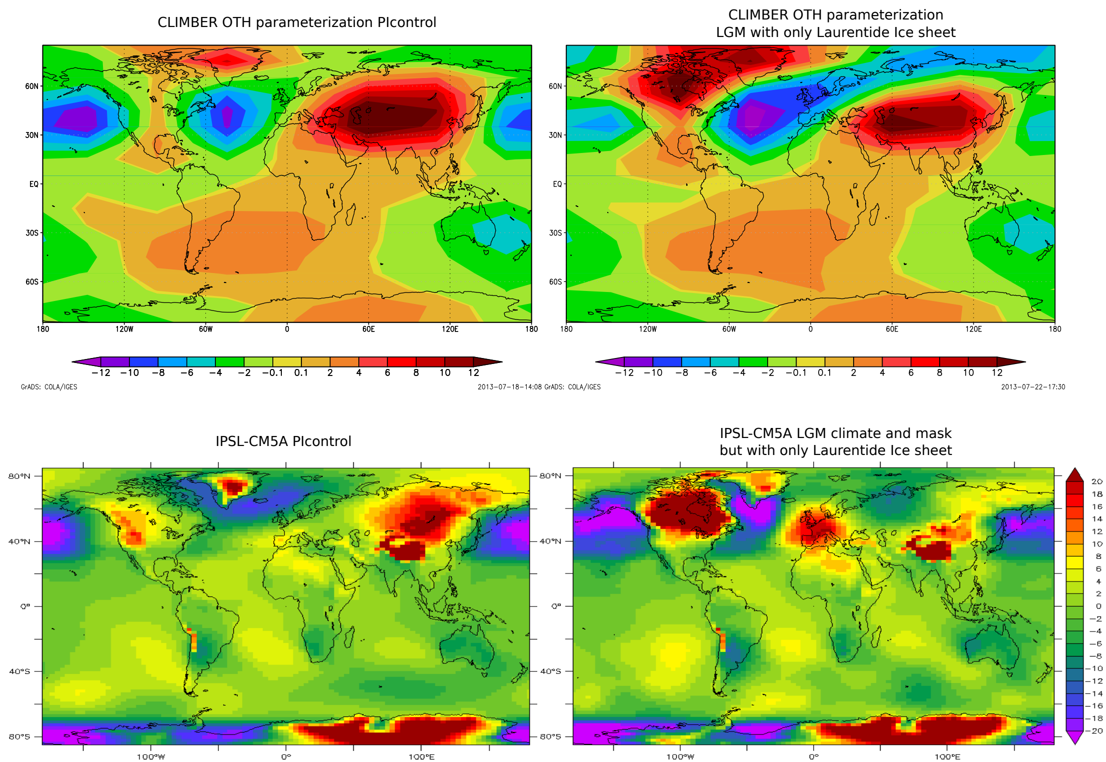

Fig. 1. Azonal component of the sea-level pressure in January for (a) CLIMBER with OTH param. during PI, (b) CLIMBER during LGM without FIS, (c) IPSL during PI , (d) IPSL during LGM without FIS

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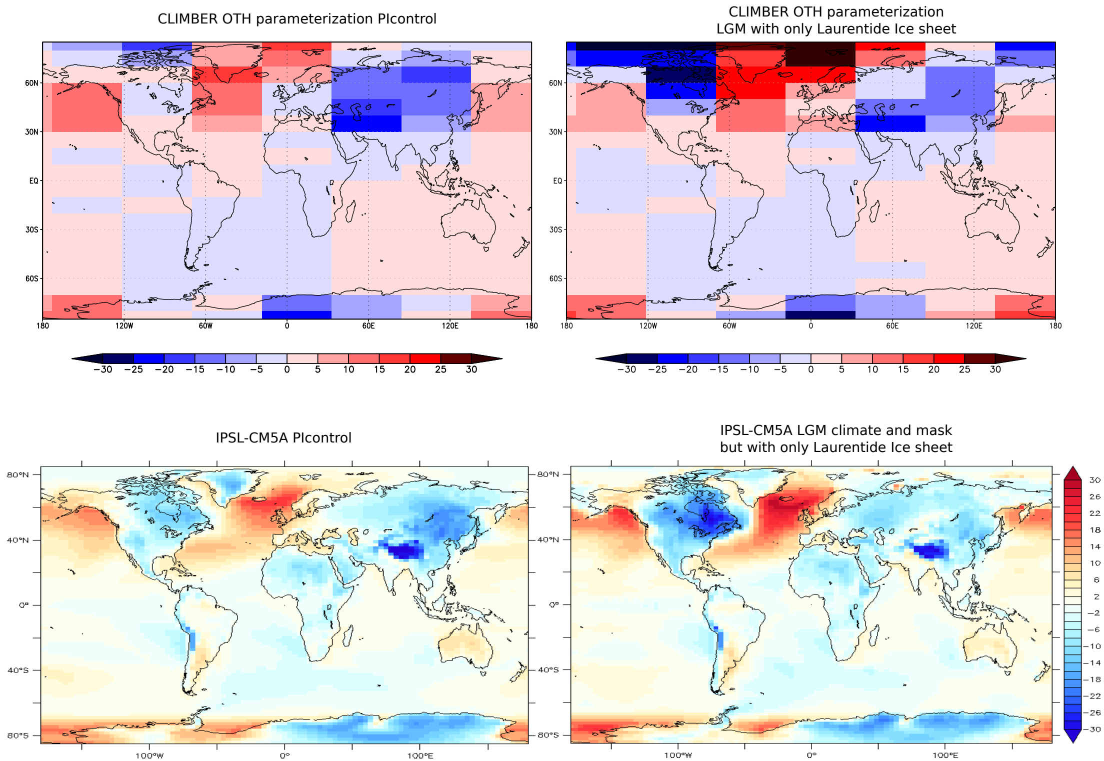

Fig. 2. Zonal anomaly of air surface temperature (same experiments as previous figure)

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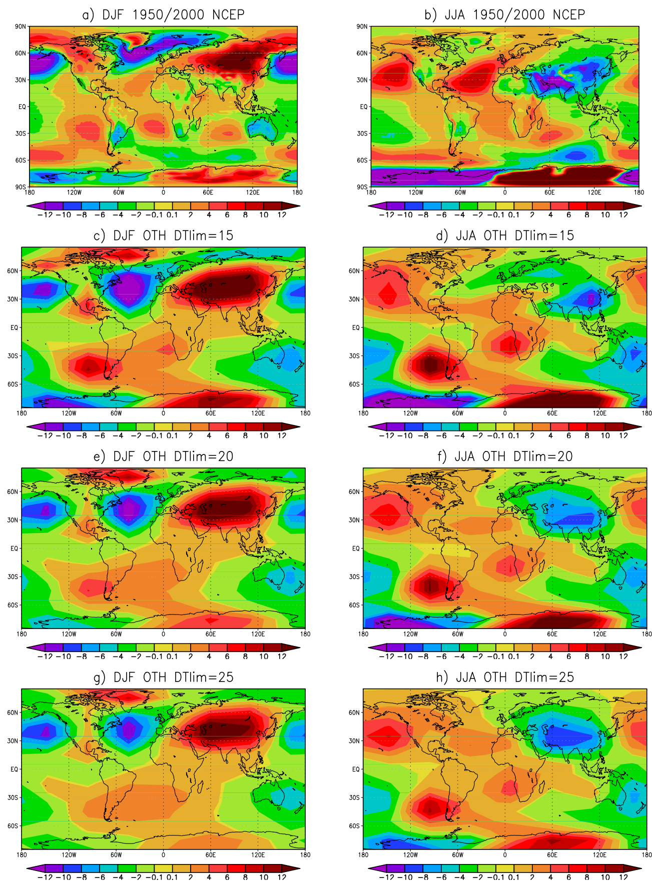

Fig. 3. Zonal anomaly of SLP for NCEP (a) and (b), and for different values of DT_limit under OTH parameterization.

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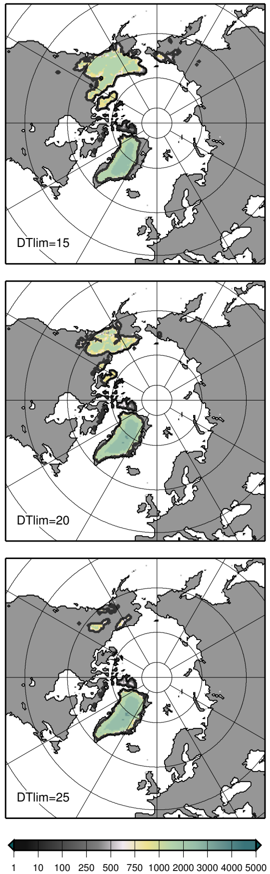

Fig. 4. Ice thickness (m) at equilibrium under PI conditions depending on the DT_limit used in the SLP parameterization.

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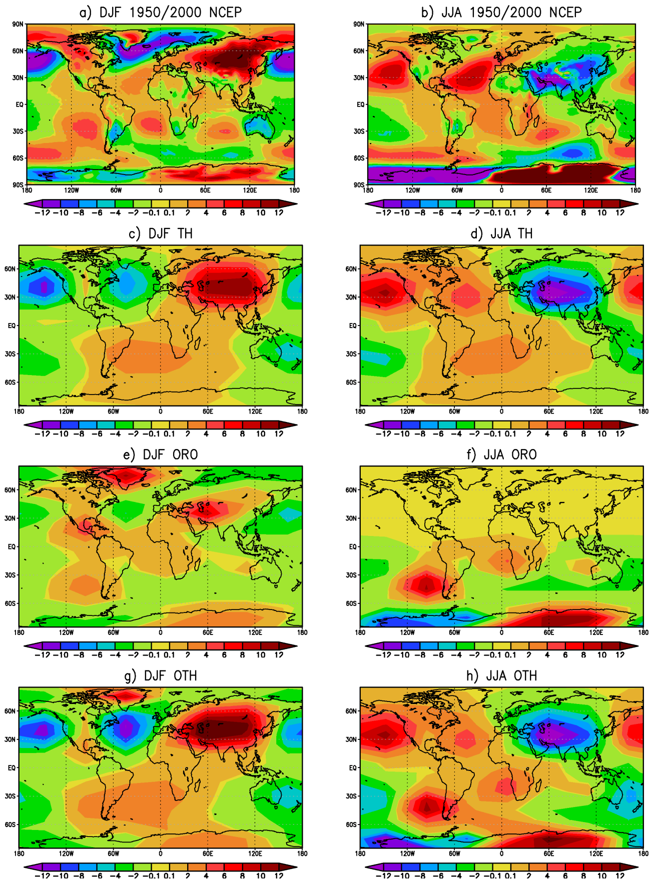

Fig. 5. SLP zonal anomaly in winter and summer depending on the SLP parameterization used and comparison with NCEP reanalysis.

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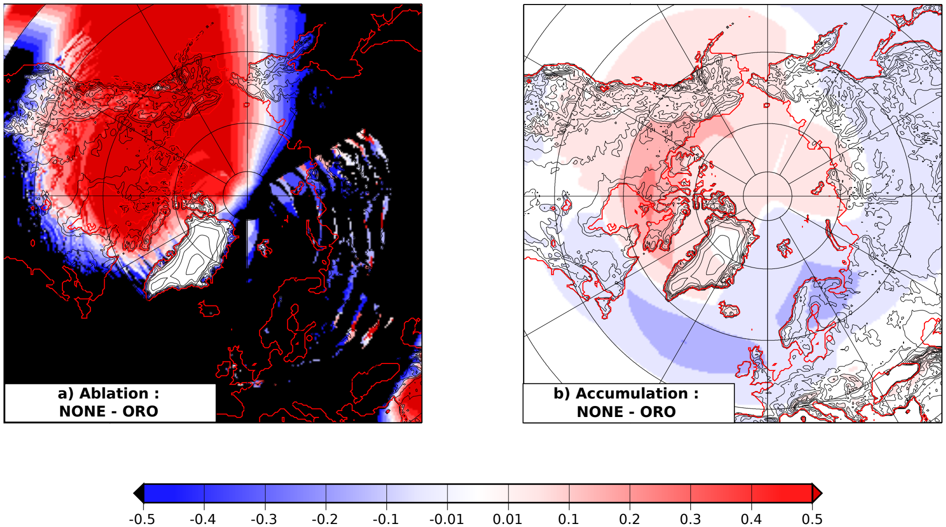

Fig. 6. Difference of ablation (a) and accumulation (b) between NONE-REF and ORO-REF experiments at 125 ka (m. water equivalent).

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