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Climate of the Past Discussions

Interactive comment on "Hypersensitivity of glacial temperatures in Siberia" *by* Pepijn Bakker et al.

Anonymous Referee #2

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Review of "Hypersensitivity of glacial temperatures in Siberia" by Bakker et al.

Geological evidence has shown that Siberia was partially glaciated during some glacial states while it kept mostly ice-free during others. Different previous studies have explored several potential explanations for these differences but a consensus is still lacking. Bakker et al. show that the ensemble of climate model experiments from PMIP2 and PMIP3 shows a very large spread in their simulated glacial summer (JJA) temperatures for the last glacial maximum (LGM) over Siberia. Bakker et al. argue that the large model spread could be an indication for a real "hypersensitivity" of glacial summer temperatures over Siberia, and hence regional glaciation itself. To explore some of the possible factors which may result in climatic differences over Siberia, they conduct several sensitivity simulations with CESM and show that the spread in simulations resulting from different ice sheet heights, vegetation feedback or changes in atmospheric physics of CAM4/5 can cause an equally large spread ($\sim$20 K) as the PMIP model ensemble ($\sim$24 K).

Overall, the manuscript is very well written and provides interesting insights into the problem of glacial summer temperature hypersensitivity and how it might explain the absence or presence of glaciation in Siberia during different glacials. However, the potential reasons for what may cause the large simulated temperature spread over Siberia could be explored in a bit more detail. I generally recommend publication in Climate of the Past after adding some more analysis to explain the summer temperature discrepancies.

General comments:

The study is very well written and presents very interesting and important aspects to better understand the possibly real "hypersensitivity" of the Siberian climate during glacials as well as the behaviour of models. Regarding the analysed variables in the manuscript, it is a bit difficult to understand whether local radiative processes (e.g. what about albedo, spring snow cover and lagged warming?) or large-scale temperature advection play a major role for the temperature spread – or both. Because Siberia builds up a spatially widespread thermal low during summer, the correlation between summer temperature and SLP can be expected to be mainly temperature driven. Increasing temperature will hence cause lower SLP which then can increase horizontal advection into Siberia. Consequently, changes in SLP would be rather a feedback to the warming (or cooling) and not the mechanism which causes the effect.

I also wonder whether the correlation in Fig. 3 is really statistically significant in terms of field significance given the low spatial degrees of freedom of SLP and that the relatively small regions with statistically significant correlations might be just those which are allowed to be significant by chance. In general, I would rather expect that the large-scale gradients in the pressure and temperature field e.g. relative to the Arctic and

Tropics are important for temperature advection into Siberia. It would be interesting to see some analysis of the large-scale wind fields or pressure gradients and how different they are with respect to the model spread e.g. of the warmest vs. coldest PMIP member. I was also wondering if large-scale teleconnections might be very different for very warm vs. very cold simulations of Siberian summer temperatures (e.g. a one-point-correlation map of the averaged Siberian SLP and temperature with the northern hemisphere SLP and temperature).

Regarding the large temperature spread over Eurasia, I was also wondering whether there is a potential link between warm and cold model experiments and the used atmospheric resolution (see below). In any case, the paper would strongly gain from a bit more detailed analysis and discussion of these aspects while the rest of the paper is very well written and does not require notable changes with exception of clarifying the sections about the role of the thermal low.

Specific comments:

Title of the paper: Maybe be more specific and write “glacial summer temperatures”?

Page 2, line 2: Due to the quite shallow Arctic shelf, sea-level changes during the glacial lead to quite large changes in additionally exposed land during low level stands along the Arctic and Siberian coast. During summer, the additional landmass clearly increases the area which can heat up strongly during boreal summers with 24 hours of daylight. I could imagine that such an effect would be higher in models with a high horizontal resolution. It would be very interesting if you could add some information in the manuscript about individual ensemble members if there are indications that their differences in atmospheric resolution lead to systematic differences in Siberian temperatures.

In this context, there is one recent example where a very coarse resolution simulation has been repeated with the same ocean state and external forcing but using a 4x higher atmospheric resolution with CESM1 (Schenk et al. 2018) for the late glacial. In their supplementary figure 4, they show that a much higher atmospheric resolution with CESM1 predicts considerably warmer summers during the Younger Dryas stadial over Eurasia and Siberia compared to the coarse resolution simulation with CCSM3 despite using the same ocean state. They argue that atmospheric blocking in response to the Fennoscandian Ice Sheet (among other reasons) leads to warmer Eurasian summers. They show that the blocking and hence warmer summers are only captured at high resolution. Is this also the case for the warmest vs. coldest PMIP members?

Given the very strong difference in simulated summer temperatures at a different model resolution by Schenk et al. (2018) and the very important results of other studies concerning the atmospheric flow disturbance by ice sheets (as already cited by the authors on page 3), I would suggest to add a paragraph about whether atmospheric resolution differences in the presence of large continental ice sheets can partly explain the spread of warming or cooling over Siberia.

Regarding the exposed Arctic shelf during stadials: Is there any geological evidence that glaciations in Siberia might correlate with periods of higher sea-level stands (less exposed Arctic shelf and possibly cooler summers with a weaker thermal low and less advection)?

Page 2, line 20: Can you give an example which one is good and possibly why?

Page 5, line 1: Components of GLAC-1D have been published in different papers. Please add here the reference of the complete version which is Ivanovic et al. (2016).

Page 5, line 3: Figure 5A is too small to see the important differences in ice sheet heights.

Page 5, line 27: The green contour line is not visible. Please add in addition the coordinates for the target region in the manuscript (for the analysed 1°x1° grid).

Page 6, lines 13-14: Regarding "...could be a consequence of local temperature changes...": This is quite certain as the low pressure over Siberia during summer is a thermal low and not a dynamic low. The sentence should be modified accordingly.

Page 6, lines 15-16: The link to the Asian monsoon region and possibly other large-scale teleconnections are very important and should be explored a bit more in the manuscript.

Page 6, lines 17-25: The paragraph should be clarified with respect to the low being a thermal low. It appears odd to argue here that a deepening of the low-pressure cell over central Asia (it is not really a cell but rather a diffuse area) should control the amount of warming in Siberia when the deepening of the low is driven by the warming. This might be rather a positive feedback where warming increases convection which lowers the pressure which increases horizontal advection. This implies that another process causes the warming and the change in SLP is only a feedback. Please re-write accordingly.

Page 10, lines 21-22: It would be interesting to get a number for the overall temperature change of the northern hemisphere in response to using a different ice sheet in CESM.

Page 10, lines 24-25: This again is due to the thermal low which has to deepen with increasing temperature due to an increase in the rise of warm air.

Page 10, line 31: The similarity of the spatial anomaly pattern for temperature and SLP can be expected for the behaviour of the thermal low in summer. There has to be another reason for the warming first and the SLP change cannot be the mechanism but rather a positive feedback.

Page 15, line 17: Please add a concluding paragraph about which model configuration for CESM (and e.g. which ice sheet) would be plausible for the LGM (no glaciation in Siberia) and why. In this context, can you give some examples about which PMIP models would be plausible for the LGM and absence of Siberian glaciation and which not and why?

Figure 1: The green contour in panel B is not visible.

Figure 2: Please strongly increase the size of numbers in the figure as well as the axis description.

Figure 3: Are the significant areas really statistically significant globally or only by chance? Given that the correlations may rather represent the thermal low, I'm not sure how this figure helps to understand the spatial spread over Siberia. Pressure gradients and teleconnections might be more suitable as they would represent how the changes of the thermal low interact with remote regions.

Figure 8: The red and blue for CAM4/5 is very difficult to see.

Table 1: It would be important to add a column here with the temperature difference LGM minus PI over Siberia for each model simulation to identify which models are unusually warm/cold. This would make it easy for others to further explore why which models differ from others. In this way, a potential dependency on the model resolution could be easily identified.

Table 2: Also here the temperature difference LGM minus PI over Siberia would be interesting.

Additional references:

Ivanovic, R. F. et al. Transient climate simulations of the deglaciation 21âĂŤ9 thousand years before present (version 1)âĂŤPMIP4 core experiment design and boundary conditions. Geosci. Model Dev. 9, 2563–2587 (2016).

Schenk, F. et al. Warm summers during the Younger Dryas cold reversal. Nature Commun. 9:1634 (2018).

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