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Interactive comment

Interactive comment on "Application of an ice sheet model to evaluate PMIP3 LGM climatologies over the North American ice sheets" *by* Jay R. Alder and Steve W. Hostetler

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Response notation as follows:

Referee comment (RC2): standard text

Author comment (AC): *italicized text*

RC2: The manuscript of Adler and Hostetler evaluates the performance of eight climate simulations of the Last Glacial Maximum included in the PMIP3 and one in-house climate simulation over North America and Greenland. They use a thermodynamic ice sheet model CISM to argue that two GCMs produce excessively warm conditions over

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Discussion paper

the region that could not possibly sustain realistic geometries of the former North American ice sheet complexes. Although the other seven climatologies are generally consistent with existing reconstructions of the LGM ice sheet extents in North America, four of them produce an undocumented ice cover across Beringia. To evaluate the robustness of their conclusions, the authors assess the sensitivity of their modeled ice sheet geometries to the choice of degree-day factors in the positive degree day model and an ice flow enhancement factor.

Regardless of its rather simple modeling approach, I find this study insightful. In particular, this work shows that modeled climate conditions are often inconsistent with the prescribed ice sheet boundary conditions and that ice sheet models could serve as valuable tools for evaluation of climate models in areas where paleoclimate proxy data are absent. Thus, I believe it merits publication in CP, albeit after moderate revisions. I have a number of suggestions on how to improve the analysis presented and fill the gaps in the model description.

AC: We thank you for your constructive feedback and for noting that we are using CISM2 as a tool for evaluating sensitivity rather than trying to reconstruct glacial histories. A number of your suggestions prompted us to do additional simulations (which will be included in the revised paper SI), which largely indicate that the results in our manuscript are robust.

RC2: The model description is incomplete and has to be improved. Even though the model setup is partly adopted from Gregiore et al. (2012), all parameter values and a short description of different model components should be included in the present manuscript (e.g., the description of the GIA model, underwater ice scheme and basal sliding law are missing; there is no mention of the geothermal flux forcing; daily temperature standard deviation value used in the PDD scheme is not provided, etc.). It is not clear how the authors initialize their ice sheets. While their initial ice configurations are based on the ICE-6G reconstruction, it is not clear what the authors prescribe inside of these ice sheets – how are the initial ice temperatures and ages derived? I suggest that in their revised manuscript the authors carefully detail their simulation design and methods.

AC: In hindsight, our description of the ice sheet model components and description of how we initialize the reconstructed ice sheet geometry require more detail. We had used the default value of 5 °C for the daily temperature standard deviation (dd_sigma in CISM2). We provide more information on this parameter below. As indicated in our response to RC1, the ice temperature was initialized at 0 °C everywhere as the ICE-6G reconstruction provides no information on ice temperature or flow vectors. This is a limitation of the experimental design. It is clear from further analysis (Figure R2) that it takes tens of thousands of years for the model to recover from the initial non-physical shock of initializing with 0 °C ice, so our use of 5000 years was too short to capture thermodynamic stability. In our revised manuscript, we will analyze the CISM2 simulations after 50,000 years.

RC2: The authors have suggested an interesting approach to an ice sheet model initialization in an attempt to start simulations from ice configurations, which are broadly consistent with the boundary conditions prescribed in climate models. We all struggle with the choice of model initialization strategies, when only equilibrium GCM outputs of certain time slices are available, whereas ice sheet configurations during these time intervals represent products of the preceding long-term climate history and a gradual ice sheet buildup. At this instance I disagree with reviewer 1 that the glacial index approach is a consistent way to initialize an ice sheet model, since it implies that (i) climate conditions of let's say MIS3 can be derived as some intermediate state between the LGM and present-day climate fields; (ii) climate conditions at the peak MIS5e could be extrapolated beyond the warmth of the Holocene period using the LGM and present-day climate fields; (iii) Greenland (or Antarctic) ice core reconstructions can reproduce air temperature (and precipitation) variability across the entire globe. Climate proxy data and geological evidence from several regions around the world show a very different picture, for example Central Asia and the Russian Arctic (including Beringia discussed in the text). Glacial expansions in the Kara Sea region during the last glacial cycle were obviously asynchronous with the rest of the continental glaciations in the Northern Hemisphere (Patton et al., 2015). Hence, I feel it is important that the ice sheet modeling community (concerned with both former and present-day ice sheet reconstructions) starts looking for new methods to initialize their ice sheet models. The suggestion of Adler and Hostetler is a good initial step towards this goal. Although their idea is interesting, it may be meaningless from the physical point of view, especially if the authors do not ensure that the ice sheet model has had sufficient time to recover from the initial shock arising from unrealistic initial thermal and dynamical ice regimes. In essence, their initial ice sheet configurations are empty shells, which are inconsistent with the physical laws underpinning the ice sheet model used. Since some of the North American ice sheets were very thick at the LGM (comparable in thickness with the present-day Greenland and Antarctic ice sheets), they may need a rather long initialization time (several tens of thousands of years) to forget this initial non-physical shock. I believe that the integration time the authors have adopted is insufficient to achieve this goal. One way to demonstrate that the initial shock is not altering the general conclusions of the study is to perform an additional test forced by one of the GCM model outputs, which are not entirely unrealistic (e.g., GENMOM or MPI). In this test the ice sheet model should be initialized over a time period of 20-50 thousand years using a time-invariant climate forcing and keeping the ice thickness fixed as is done for the present-day ice sheets (e.g., Pattyn, 2010). After this initialization, the authors could run a forward simulation with a free ice thickness evolution and compare their modeled extents to the ones presented in the current version of the manuscript. Another way would be to run their simulations for a longer time period (20 thousand years at the least). According to the current state of knowledge, a large portion of North America had been buried under ice sheets over a period of more than 50 thousand years during the last glacial cycle. Hence, longer integration times would not hurt.

AC: We agree with your assessment that linearly interpolating between LGM and pre-industrial is not a realistic way to treat the climate forcing. Our goal is to determine if the *climate forcing from the PMIP3 LGM models would support the ice sheets they included in their boundary conditions. We did not manipulate the temperature and precipitation fields and we initialized the ice sheet geometry close to that used in the GCMs so that the climate fields and ice sheet were initially consistent. We acknowledge that this meant initializing the ice sheets with no internal structure, which is a limitation of our approach. We will clarify these points in the revised manuscript.*

It does not appear that CISM2 can be integrated with a fixed ice sheet height when using the SIA and PDD schemes. This option is only available when using the high-order ice dynamic core, which is outside the scope of our study. We feel most of the concerns from RC1 and RC2 can be addressed by evaluating our model results after 50,000 years of simulation, when the ice sheet is at or near steady state (see Figures R1 and R2).

RC2: Improvement of sensitivity tests: The authors have performed an extensive analysis of the uncertainties in the degree-day factors but have disregarded potential effects of the daily temperature standard deviation (in the PDD scheme), which is rather uncertain in nature (e.g., Fausto et al., 2009; Seguinot, 2013; Wake and Marshall, 2014). Their choice of a snow-to-rain fraction (100% vs 0%) and a meltwater retention scheme could be also objected. Should not these be included in their sensitivity tests? I realize that such tests would add many simulations to the story but running them with a resolution of 40 km and a SIA-only model is more than feasible. All sensitivity tests could be placed in the supplement (including the tests of sensitivity to degree-day factors)

AC: We had not previously explored the sensitivity of our results to the uncertainties with the daily temperature standard deviation parameter (dd_sigma). We analyzed daily temperature time series from GENMOM and found that the daily standard deviation varies spatially and seasonally. Like observations from modern Greenland, GENMOM does show more daily temperature variability in the winter than summer, but the simulated LGM values in North America are much higher than those from Greenland observations. The annually averaged values range from 7 - 8 $^\circ$C. The CISM2 annual

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Discussion paper

PDD scheme does not allow sigma to vary in space or by season (without changing the model code, which is beyond the scope of our work). To test this parameter, we drove CISM2 with 50 years of daily GENMOM output, using the daily PDD scheme, and compared the results with results obtained from a range of uniform sigma values. (Figure R3). This test indicates that an annual PDD sigma value of 6 °C matches the ice sheet volume and area simulated with the daily PDD reasonably well. We will include Figure R3 and a discussion of daily temperature variability in the main text of our revision. We have also updated all our CISM2-PMIP3 simulations to use a dd_sigma value of 6 °C; although, the areal extent is largely the same as our previous simulations (dd_sigma value of 5 °C), with the exception of Beringia in a few models (Figure R4).

The revised manuscript will include Figure R5 in the SI, which demonstrates the sensitivity of CISM2 to the daily temperature standard deviation (dd_sigma), the fraction of snow that refreezes (wmax) and the ice flow factor. We will use these extra sensitivity experiments to support statements such as P8, 11-12. We will keep the 12 PDD factor sensitivity tests in the main paper, as it provides context to Figure 4, which we feel is important because it demonstrates that no combination of PDD factors result in a reasonable LIS when forced by CNRM-CM5 or MRI-CGCM3 and that ice sheet extent is largely insensitive to the choice of PDD factors. By adopting 50,000 year simulations, the discussion of ice sheet volume (Section 3.4) will likely need to be removed, which means the PDD sensitivity results will be limited to Figures 4 and 6. In the CISM2 implementation of annual PDD, the snow-to-rain fraction is not a tunable parameter. With the addition of a discussion on daily temperature standard deviation (Figure R3) and the low sensitivity of melt water refreeze (shown in Figure R5), we will have discussed and addressed the range of PDD parameters.

Please also note the supplement to this comment:
https://www.clim-past-discuss.net/cp-2017-102/cp-2017-102-AC2-supplement.pdf

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