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Climate of the Past Discussions

Interactive comment on "Simulation of the last glacial cycle with a coupled climate ice-sheet model of intermediate complexity" *by* A. Ganopolski et al.

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First, we want to express our thanks to the reviewer for the constructive and useful comments. Below, we give response to the general comments and the changes we will apply to the manuscript to improve the paper. We will also correct or modify the text of the manuscript and the figures according to the specific comments.

1. "How is sea level taken into account in the model? I understand that changes in ice sheets affect the climate module via changes in the fraction of land covered by ice sheets, surface elevation and land area. However, the ice sheet module covers only the Northern Hemisphere. But the authors underline that Southern Hemisphere also

contribute to continental ice volume and sea level change. This contribution is added to the simulated NH values. Is it done during the simulation (with impact on elevation for example) or is it done only for plotting purpose? Could the authors clarify this point?"

Response: Although the ice-sheet model covers only the Northern Hemisphere, changes in land area and elevation are applied globally. To this end, we made several approximations. Firstly, we assume that "glacial excess" of the Antarctic ice sheet is always 20% of the ice volume change in the Northern hemisphere. Secondly, we assume that sea-level change at every location is equal to the globally averaged one, which is, of course, a rather crude approximation in the vicinity of the large ice sheets. By applying simulated sea-level change to the global high-resolution topographical data, we obtained at each time step new land and elevation fields, which then are used to calculate changes in average land elevation and land fraction for each climate model grid cell. The fraction of glaciated land is only changed in time in the Northern Hemisphere, i.e., the area of the Antarctic Ice Sheet and its elevation (apart from the direct effect of the sea level changes) remain constant in time. We will clarify this point in the revised manuscript.

2a. "The authors underline and describe the importance of the temperature correction for North America (American temperature dipole). As far as I understand this correction is based on present-day observation. Moreover, it proves efficient for the simulation of the full glacial-interglacial. However, I wonder whether there is evidence that this dipole correction is valid for the whole cycle with the same amplitude. In other words, I wonder whether we don't have a 'good response for a wrong reason'".

Response: Of course, this is always possible that the right results are obtained for the wrong reasons. However, as it is demonstrated by Fig. 2, "American dipole" is real and it has the magnitude (ca. +-5C) which is comparable with the direct temperature response to orbital forcing. The necessity to introduce this correction is not the biases in CLIMBER-2 model – on its coarse grid it performs well, but because the whole American continent is represented in the model by just one column of grid cells, the model cannot resolve the difference between its western and eastern parts. The role of this parameterization is directly demonstrated by Fig. 9 in our manuscript and, indirectly, by results of the transient glacial cycle simulations performed with the same climate model by Bonelli et al. (2009). In the latter work no correction for American temperature dipole has been made and the North American ice sheet started to grow in the wrong location. Therefore it is, at least, at the initial stage of glaciations this parameterization is, both, crucial and justified. Clearly, we cannot rule out the possibility that the temperature pattern can change significantly in the course of the glacial cycle. In principle, one can introduce dependence of the dipole structure on the climate state (say ice volume), but this will only introduce additional "free" model parameters, which cannot be constrained by modeling or empirical data. The only real alternative to this parameterization is to use relatively high-resolution climate models, but they are still too expensive even for a single simulation of a single glacial cycle.

2b. "In any case I acknowledge that the Baseline Experiment is one simulation with one set of parameters providing a 'good' simulation of the last glacial-interglacial cycle and that other sets of parameters might exist"

Response: Indeed, one can obtained rather similar results with somewhat different combinations of model parameters.

2c "Actually, do the authors use the estimate sea level rise contribution of Antarctica for LGM only? Do they interpolate for the rest of the interval? Do they use an estimate every (say) one thousand years?"

Response: We gave the answer to this question above. Sea level changes (with 20% additional contribution from Antarctica) is computed every model year.

3. "Additional greenhouse gases are taken into account in this work compared to previous works. The concept of equivalent CO2 concentration is used. Moreover, the values are scaled in order that the pre-industrial value remains at 280ppmv. How do the authors perform the scaling? Is it a linear translation of value on the concentration-

axis or is it a geometric translation (multiplying factor)? Why did the author chose one or another option? Does it make a large difference?"

Response: During glacial cycles variations of CO2 produce the largest GHG forcing but the role of CH4 and N2O is also not negligible (at LGM their combined radiative forcing is about 0.7 W/m2). The radiative code of the CLIMBER-2 model does not account for the latter two gases and the only way to take them into account is to use the so-called equivalent CO2 concentration, which produces a radiative forcing equal to the sum of the radiative forcings of all three GHGs. Since the CLIMBER-2 model originally was tuned for CO2 concentration of 280 ppm, introducing of additional radiative forcings of CH4 and CO2 will imply the equivalent CO2 concentration higher than 280 ppm. To avoid necessity to retune the model, we calculated equivalent CO2 concentration in such a way that it is equal to 280 ppm for the preindustrial conditions, but gives the right changes in the total radiative forcing for the concentrations CH4 and N2O different from preindustrial values. We will give the formula used for calculation of the equivalent CO2 concentration and more detailed discussion of this procedure in the revised manuscript.

4. Related with the sliding processes, what is the 'standard sediment mask' ? How is it build? Is it stable over a full cycle or might it change?"

The sediment mask was based on the modern map of the sediments thickness (). The mask has been kept constant over the whole run. For longer-term experiments (last several million years) this approach would not be justified and modeling of the evolution of the sediments layer will be necessary.

P 2282 – line 19. "I urge the authors to be very cautious when writing sentences like 'ablation leads Milankovitch forcing'. Milankovitch forcing can be considered as the distribution in time and in latitude of the insolation. Therefore, there are so many 'insolation curves' that they will probably be able to find one that leads ablation"

Under "Milankovitch forcing" we understand here maximum summer insolation at 65N, which is just a common scientific jargon. Of course, there are many insolation curves, but summer insolation at 65N is not just one of them. With the fixed configuration of the ice sheets, the diagnosed mass balance follows 65N summer insolation curve very closely. The reason that with the interactive ice sheets, the total (not local !) ablation leads the insolation is that the ablation is proportional both to the summer insolation and to the size of the ice sheets. Since the size of the ice sheets decreases with increasing insolation, the maximum of ablation is achieved before the maximum of insolation. This phase lead, of course, does not imply any causal relationship – the summer insolation is the main driver of the ice sheets. However, this phase relationship has some important implications for the analysis of paleoclimate records.

"The acceleration method should be very briefly described, at least its principle"

Response: will be done

"P 2284 – the authors write: 'During termination, the European ice sheets start to contract first in the response to rising summer insolation and GHGs concentration and practically disappeared already at 10 kyr BP.' According to the figure of ice volume evolution, it seems that the North American ice sheet starts first to melt and then only the European ice sheet. The North American ice sheet do indeed disappear after the European ice sheet. If this is correct, does it mean that the Laurentide part of the North American has a very rapid response, counterbalanced by the Cordilleran ice sheet?"

Response: The Reviewer is perfectly right. Both ice sheets started to melt approximately at the same time. This sentence will be corrected.

"P2290 – line 8: 'ice-volume variability is dominated by obliquity'. I totally disagree with the authors. If they simply put a curve of the obliquity along the ice volume they will see that the phase is changing through time. Moreover, the 'large' peaks (maxima of ice volume) coincide very precisely with those in the BE. In the BE, the authors related those maxima with large variations in precession. Therefore I support the idea that only every second maxima in ice volume is significant (the other is disappearing for a

reason to be determined)."

Response: Again, the Reviewer is perfectly right. The sentence will be corrected. It should be "ice-volume variability is dominated by precession and obliquity'. Indeed, the maxima in the ice volume in the experiments with removed temperature dipole, have approximately the same timing as in BE experiment and they follow the minima of summer insolation in the NH. The reasons why only each second maximum in the ice volume is significant is because these maxima correspond to the periods when precessional and obliquity induced changes in summer insolation are approximately in phase and, therefore, the minima in summer insolation are deeper. The reason why the difference between "odd" and "even" maxima in the ice volume is so large while difference in insolation is rather modest can be explained by a strongly non-linear response of the NH cryosphere to the orbital forcing which we discussed in our previous papers.

Interactive comment on Clim. Past Discuss., 5, 2269, 2009.