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Interactive comment on "Modelling the evolution of the Antarctic Ice Sheet since the last interglacial" *by* M. N. A. Maris et al.

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The reviews were of much help in improving the paper. Below is our response on the comments by the reviewer #1:

1. Both reviewers mention that it is unclear why we did the interpolation between the LGM and PD climate states the way we did it. One suggestion is to interpolate in proportion to the ice core, but here is an example of a result of this method: When the ice core temperature reconstruction would reach -5°C (halfway between -10°C at 21 kyr ago and 0°C at the PD), which happens around 16 kyr ago, the patterns would already be halfway between the LGM and PD fields as well (because they are now linked to the ice core), while the ice sheet still has to

react to the increasing temperature and is actually still at its LGM state at 16 kyr ago. When following the method as described in the paper and interpolating the patterns linearly in time they will be at only 25% away from the LGM state around 16 kyr ago, which is not a perfect, but a better match to the ice sheet topography. This is also briefly explained in the manuscript now. Indeed it would be best to couple RACMO and ANICE every 1000 years for instance, but due to a lack of time and computer power we have not done this. We used a normalization method of $T_{norm} = T/T_{mean}$ instead of $T_{norm} = (T - T_{mean})/T_{std}$ because for our interpolation method the mean of both normalized fields (PD and LGM) should be 1, since the objective is to interpolate the patterns and not the amplitudes. It has been clarified in the manuscript that this interpolation method is done for every spatial point, temperature is in K (and the SMB in m i.e./yr) and means are taken over the continent.

2. It has been made clearer in the beginning of Section 3 that the climate forcing from Section 2.2 is used.

3. An inlay has been added to Figure 7 with a zoom on the Prydz Bay and a note has been made in the text that the modelled retreat in this area is too little because of the too coarse resolution of the model.

4. Indeed, even in Anderson 2002 it is suggested that the onset of deglaciation took place around 18 kyr ago, but that the grounding line did not reach its present-day position until 7 kyr ago. The paper by McKay suggests that there was a fast retreat between 11 and 10 kyr ago. The onset of the Weddell Sea retreat is indeed suggested to be timed earlier by Weber (around 19 kyr ago), but they also say that the margin had retreated to midshelf by 14 kyr ago and reached the PD GL by 11 kyr ago. This is described in the manuscript now, including the references.

5. D and τ are not independent parameters, so we chose to vary them together (to vary the thickness of the lithosphere). D has a smaller effect than τ, which is noted in the paper now. In Figure 9 the results of a 2-valued D and τ have been added and this addition is described in the paper as well. Those values of D and τ do not differ much between the WAIS and the EAIS because there is a strict separation between these two sides of the ice sheet in the model and differing the parameters too much between these two sides leads to instabilities in the model. It might be interesting to use a 2D-field of values for both D and τ, coupled to measured lithosphere thickness (for instance from Morelli and Danesi, Planetary Change, 2004), but this is beyond the scope of this manuscript. Stern and Ten Brink mention $1 \pm 0.4 \cdot 10^{25}$ for the EAIS and $4 \pm 3 \cdot 10^{22}$ for the Ross Embayment only. After some research with ANICE we decided to use the value from Whitehouse et al, Quaternary Science Reviews, 2012 (10^{24}) as a lower limit.

6. ANICE has not participated in the MISMIP or MISMIP-3D, but the superposition of the SIA and the SSA velocity in ANICE follows the method in PISM-PIK which has participated in the MISMIP experiments. They find that they need small subgrids to avoid 'sticking' of the grounding line. However, the MISMIP-3D test was about the perturbation of sliding parameters on a rather small spatial scale, while the grounding line in our results moves due to sea-level change and discharge and is modelled along the entire AIS. This movement of the grounding line has been modelled by relatively simple models before, see for instance Huybrechts, Climate Dynamics, 1990 or Huybrechts, Quaternary Science Reviews, 2002.

7. The differences between the various simulations are quite clear, and therefore no in-depth comparison with observations was done yet. However, we have done ensemble runs with different climate and sea-level reconstructions and have compared ANICE model results to observational data following the method of Briggs and Tarasov, Quaternary Science Reviews, 2013 in the next paper, which has already been submitted. A note has been made in the conclusions of the

manuscript.

Technical comments:

a. We have not run the model through several glacial cycles with this calving criterion yet, but it might be interesting to investigate this. However, we did run the model starting from the Antarctic continent without any ice present (and the bed topography isostatically corrected for the absence of the ice). We did this with the present-day climate imposed, using lapse rates of 5 K/km for surface altitudes below 1500 m and 14 K/km above this threshold (following a model by N. Lipzig) and 0.2 m/y /km to correct for the different topography. The end result was an ice sheet with ice shelves at the right locations, reasonably close to the present-day ice sheet.

b. It is indeed too computationally expensive, not infeasible. This has been changed in the text.

c. Observational datasets of the WOCE were only available as pictures before the end of 2013 as far as we know. The datasets are online now, but as there will always be new improvements to be implemented we decided to stay with the ECHAM53 data for this paper. Some runs have been done with the WOCE data however, and although the basal melt rate at the PD seems more realistic, using the WOCE data is mainly an improvement in method, not in results. To clarify this, in Figure 1 (this document) the grounded ice volume is shown for the reference simulation as it is described in the manuscript, a simulation with the same parameter values as the reference, but with the ocean temperature from the WOCE data and a simulation with the ocean temperature from the WOCE data, but optimized with respect to grounding-line retreat and the present-day grounding line position. The last simulation used the same parameter values as the reference run, except for the SSA enhancement factor, which has been changed from 0.8

to 0.6. The reference simulation with WOCE ocean temperatures does not significantly differ from the original reference simulation, and the optimized WOCE simulation shows too high ice volumes (close to the ice volume for $E_{SSA} = 0.6$ in the manuscript). In Figure 2 (this document) present-day grounding line positions are shown for the three simulations described above. The grounding line position of the reference simulation with the WOCE data has retreated too far inland, and the optimized WOCE simulation does not show a significant improvement in the grounding line position compared to the original reference simulation. As for the sea-level record, there are data available from Siddall et al., Nature, 2003, but also from Rohling et al., Nature Geoscience, 2009 and Grant et al., Nature, 2012 (which is not complete around the LGM). However, most of the data are relative sea-level data, while we need eustatic sea-level data for our research. Siddall et al. did produce eustatic sea-level data, but only between 70 and 20 kyr ago. In the manuscript a note has been made that we need eustatic sea-level data.

d. These titles have been changed

e. This has been changed in the manuscript (Equation 16 and text below).

f. A panel has been added to Figure 5 with the difference between the modelled and observed surface elevation and it is commented on in the text.

g. Ice discharge is generally a large term, but almost half of the grounded volume change is due to grounding-line motion during the period 15 kyr ago - 10 kyr ago, according to Figure 8 (difference between the orange and the black line). The Siple Coast involves the Ross Ice Shelf where the grounding line has retreated a lot, but at other locations the discharge has dominated, as grouning line motion is mostly small and the velocity over the grounding line is larger than zero almost everywhere. As the Siple Coast does not represent more than 10% of the circumference of the AIS, the graph is in agreement with the numbers in the review.

h. This part has been reformulated into: “This is because high ice velocities are reached earlier in time for higher values of ESSA, preventing the ice sheet from advancing. Hence, the ice sheet starts retreating earlier and therefore the LGM is timed earlier than for lower values of ESSA.”

i. The locations of re-advance (mostly around the 2 major ice shelves) are now mentioned in the text.

j. These sentences have been reformulated as suggested.

k. It has been made clear in the manuscript that $24.8 \cdot 10^6$km^3 is the present-day grounded ice volume from ALBMAP. Our estimate of 26.8 is indeed not that bad when compared to the Bedmap2 result but the ice thickness in ANICE is still overestimated at the same locations compared to Bedmap2.

l. These two references have been added to the manuscript

m. The second ‘q’ (for the ice load) has been changed into an ‘m’.

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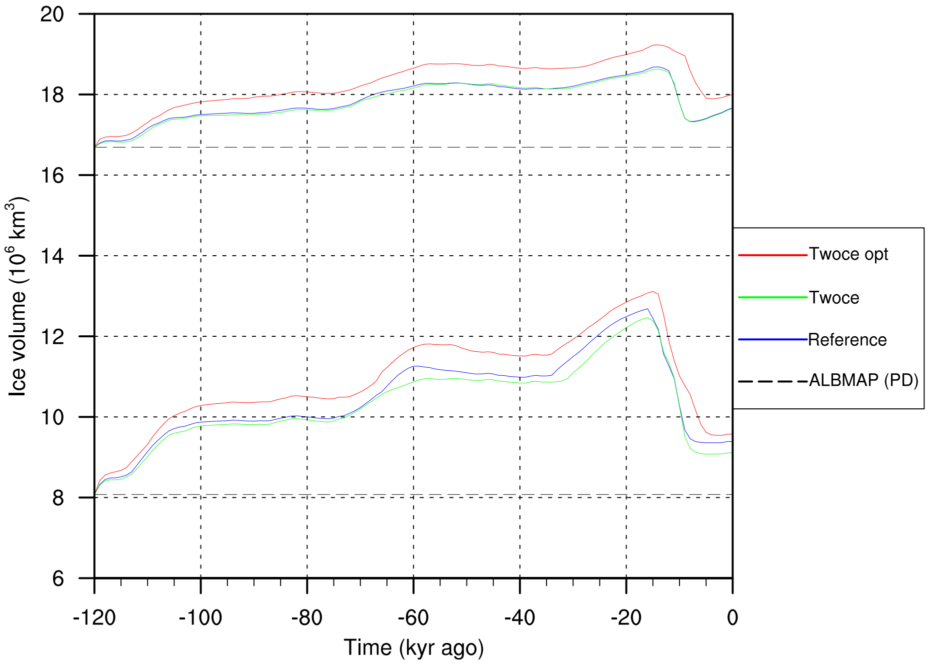

Fig. 1. Grounded ice volume for the WAIS (lower lines) and the EAIS (upper lines) for the original reference run (blue), with WOCE ocean temperatures (green) and the optimized run for WOCE temperatures (red).

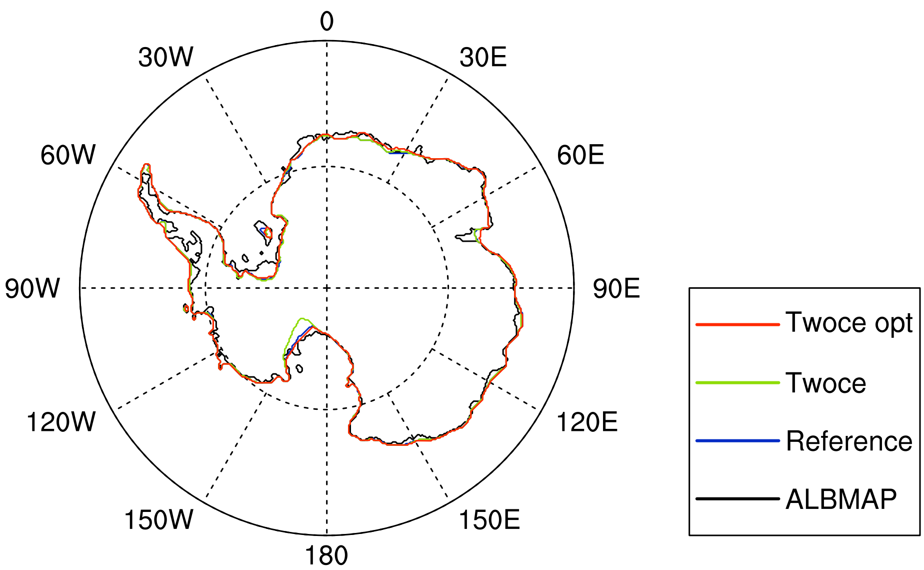

Fig. 2. PD grounding line positions from ALBMAP in black and the other three simulations as described in Figure 1.