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Interactive comment on "Simulating the Antarctic ice sheet in the Late-Pliocene warm period: PLISMIP-ANT, an ice-sheet model intercomparison project" *by* B. De Boer et al.

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This paper applies several ice-sheet models to Antarctica in the Pliocene just before 3 Ma, motivated by paleo records suggesting sea-level rises of ∼10-30 mesl. The high end would require substantial retreat of the East Antarctic Ice Sheet. The models are forced with HadCM3 GCM climates for modern and Pliocene, and with a second modern control from ERA-40 reanalysis. The two Pliocene ice-sheet experiments differ only in the initial ice-sheet conditions, starting from present (Bedmap) or from the PRISM3 reconstruction which has ice removed in the Wilkes/Aurora sectors of East Antarctica (EA). As expected from earlier studies, nearly all models find drastic WAIS collapse in

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the Pliocene, but this produces only a few meters of equivalent sea level rise. When bed elevations are replaced with the generally deeper Bedmap2 dataset, significant retreat occurs in EA basins in some models, more consistent with the higher sea-level estimates.

The paper is well organized and clearly written. It represents a substantial amount of computational effort and coordination of several groups. As discussed in the paper, the topic is important not only for explaining (possible) past sea-level rise, but also as a guide to future response to anthropogenic warming.

However, I think there may be serious problems in the experimental design, so that the Pliocene EA basin retreats may be induced purely by the imposed boundary and initial conditions. Consequently the EA-basin results are possibly circular and spurious, and do not address the real questions as described below. The first point (#1 below), seems most serious.

Point (1):

The simulations that produce substantial EA basin retreat (Fig. 9) have the ice sheet initialized to the PRISM3 reconstruction, which has a extensive portion of the EA periphery removed from Wilkes to Aurora sectors (Fig. 1l). The origin of the PRISM3 Antarctic reconstruction with this removal is somewhat unclear, and discussed below - the main point is that it is externally imposed on the current models.

EA basin retreat involves grounding-line retreat into subglacial basins below sea level. For this, the governing physics and processes are grounding-line migration, hysteresis due to unstable retreat on reverse-slope beds and pinning on bedrock highs (Marine Ice Sheet Instability, MISI), and variable buttressing due to ice shelves (Schoof, JGR, 2007; and as modeled in other Antarctic basins: Jamieson et al, Nat. Geosci., 2012; Parizek et al., JGR, 2013; Gladstone et al., EPSL, 2012; Docquier et al., J. Glac. 2014). These papers show that for real-world basin bathymetries, there are multiple possible stable ice-sheet extents (multiple equilibria) for a given climate, with the grounding line pinned on one bedrock high/downward slope or another. This follows directly from Schoof (2007), with (x-flowline) equilibrium states located at the intersection of upstream accumulation vs. x and grounding-line flux (f(bedrock depth)) vs. x. Even if this balance is not exactly met, the grounding line can be stabilized by transverse stress, ice shelf back stress, or coarse-grid "stickiness" deficiencies seen in test studies (Vieli and Payne, JGR, 2005; Pattyn et al., The Cryo., 2012).

This behavior is borne out in the real-world Antarctic basin/fjord modeling studies mentioned above (Jamieson, Parizek, Gladstone, Docquier). The observed bedrock elevations in Wilkes and Aurora basins are as highly variable as these or more so, as seen for the Wilkes in Fig. 8b (black curve). In this situation, which location the grounding-line becomes pinned to depends strongly (perhaps dominantly) on its prescribed initial location. It is therefore not surprising that if the EA margin is initialized with grounding lines significantly inland from modern (Fig. 8b, PRISM3 profile, other black curve), the grounding line in these models will quickly migrate to a nearby bedrock high, fairly independently of anything else in the experiment except the initial conditions. If a greater initial amount of retreat was imposed, it is likely the model grounding lines would give the same results as Fig. 9 or retreat even more; conversely, if a much smaller retreat was imposed, they would stay near there and not retreat much - as seen in the paper's "Pliocene_ice-PD" experiments, initialized with modern extent, for which very little EA retreat occurs (Table 1, Fig. 5a,c,e,g,i,k).

Point (2):

The HadCM3 climate simulation for the Pliocene, that is used to force all the ice-sheet Pliocene runs here, had its Antarctic ice sheet geometry prescribed from the PRISM3 reconstruction. As I understand it, this is based on earlier ice-sheet simulations (Dowsett et al., Stratig., 2010; Hill et al., Micropalaeontol. Soc, 2007), aiming for a total Pliocene equivalent sea level rise of ~22 m (with Greenland). The earlier ice sheets were with BASISM, a Shallow-Ice-Approximation (SIA) model (see #4 below). Dolan et al. (Palaeo3, 2011) found large EA-sector retreat with BASISM and a warm southern summer orbit, but it is not clear if the initial ice-sheet condition in their large EA-retreat runs was no EA ice, or modern. The main point here is that the initial prescribed PRISM3 EA ice state is an external imposition independent of the current marine-capable models and Bedmap2 bathymetry. A secondary point is its lineage is somewhat unclear, and may be from an SIA-only model with the same experimental-design concerns raised here.

Therefore, as noted in the paper and shown in Fig. 1, surface air temperatures are much warmer in the EA sectors than modern. Because the modeled EA's evolve considerably away from the PRISM3 state, these temperatures could be much warmer than the appropriate climate on the ice sheets, and could bias the simulations to remain retreated in that sector. There is a lapse-rate correction, but this may not accurately represent the actual difference in geometry, or albedo feedback.

Further discussion related to points (1) and (2):

Point (2) is worrying, but point (1) is potentially more serious. In fact, I suspect that all the EA basin results are so dominated by the PRISM3 initial conditions and nearby grounding-line/bed interactions that they depend only weakly on the GCM climates. For instance, if the model EA's were initialized to the PRISM3 state and forced by modern climate, it might be that the ice sheets still evolve to the same retreated EA states as with the Pliocene climate. (If not, the concern still stands).

Therefore I think the EA results are likely to be circular. The paper does not offer useful results addressing the question that is central in my opinion:

Could the EA margin have retreated from modern-like states that existed slightly earlier in the Pliocene? And a second important question: Could it have re-advanced and retreated repeatedly, as implied by the episodic nature of the past sea-level evidence?

Given a situation where grounding line-bedrock elevation interactions and hysteresis are dominant, the experimental procedure should be carefully chosen to yield meaningful results. I think the well-posed framework in modeling terms, that would yield useful results for the "central" question posed above, is:

Can a model ice sheet, initially in equilibrium with modern conditions, evolve away from this state and retreat significantly into EA basins, due to climate and initial perturbations that are NOT externally prescribed regarding ice sheet geometry (such as PRISM3 EA)?

This would require:

(A) Ice sheets are initialized to spun-up conditions from modern control equilibrated runs, and

(B) the only external inputs imposed in the Pliocene climate model should be orbit, CO2, continent vs. ocean, and vegetation. If the ice sheet geometry feeds back on the climate model, it should be from the current ice sheet runs themselves, not externally prescribed.

The paper falls short on both these counts:

(a) The ice sheets are arbitrarily initialized to PRISM3, not starting from spun-up modern (thus causing a big shock, and unknown MISI-interactions with grounding-line fluxes and bed geometry, within the EA basins), and

(b) The GCM climate is simulated with externally prescribed PRISM3 EA, not the ice sheet from these model simulations themselves.

To avoid these concerns and satisfy (A) and (B) above, the ice sheet models should be spun up to modern, (with HadCM3 climate and not ERA-40 reanalysis despite the former's snowfall overestimate, for consistency as HadCM3 is used for the Pliocene). Alternatively, a climate-anomaly method could be used (experiment +[*] observed -[/] control). Then, warm-Pliocene climates should be imposed on the ice sheets, initialized to their modern states. This could be done interactively with asynchronous coupling, running the GCM repeatedly at intervals, but would be infeasible for the multi-model

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intercomparison here. Alternatively,

* the GCM could be run once with Pliocene boundary conditions (CO2, orbit, etc) except with modern Antarctic ice sheet, and lapse-rate corrections used in the ice-sheet runs, or

* Two GCM runs, with Pliocene conditions except one with modern Antarctic ice, and the other with PRISM3 Antarctic ice, could be run. Then a linear weighting of those two climates is used to drive the ice sheets, according to the current model EA extent. The latter may be feasible for multi-ice-model intercomparisons.

Other general points:

(3): Regardless of the details of the concerns above, it is disconcerting that the major EA basin retreats in the model are co-located in the same geographical sector as the large perturbation in the PRISM3 EA initial conditions.

Similarly, although the Bedmap2 dataset is model-independent of course, its markedly deeper bathymetry around the EA periphery in the Wilkes and Aurora sectors (Fig. 9h) increases the concern that grounding-line/bedrock interactions stemming only from the initial state are determining the EA responses.

(4): Again regardless of details discussed above, the fact that Shallow-Ice-Approximation (SIA)-only models show the much same EA retreat in submarine EA sub-glacial basins (Fig. 9i,j,k) is strange and disconcerning. The dominant physics of grounding-line migration, streaming flow across the grounding zone, variations in buttressing by ice shelves, etc., is completely absent in SIA models. But they produce very similar retreat in the EA submarine basins! This again suggests that the EA results are driven primarily and circularly by externally imposed conditions, not by the important model physics. (A related discussion is given on pg. 5560, but does not get to the above points).

(5): The "Pliocene_ice-PD" experiments (Table 1), initialized to the modern ice state,

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is less circular, at least in the sense of point # 1 above. Only total volume results are shown (SI Fig. S4), but the volume changes are small, suggesting that little EA retreat occurs in these experiments. (It would be helpful to include maps for these experiments in SI).

(6): Two recent papers have found significant retreats into (distinct) EA subglacial basins in warmer climates: Mengel and Levermann (Nature Clim. Change 2014) and Fogwill et al (J. Quat. Sci., 2014), without pre-determined initial conditions as here. Some discussion or at least mention of these studies would be helpful, for instance, do their grounding-line numerical treatments differ from those here? (Mengel and Levermann is referenced, but only peripherally, on pg. 5562).

This could be combined with a brief discussion about the deficiencies of grounding-line migration in coarse-grid models (as all models here). Many papers have raised concerns and shown that either a high-resolution grid near the grounding line, or a sub-grid boundary-layer parameterization, are needed (Pattyn et al., The Cryo, 2012; Cornford et al., J. Comp. Phys. 2013; Pollard and DeConto, GMD, 2012).

Technical points:

p. 5541, line 7, and p. 5543, line 10: Some have suggested even more uncertainty in the past sea-level data than the range 10-30 mesl; e.g., Rowley et al., Science, 2013, due to dynamic topography. This could be noted. Also, that the low end of the range given here, $\sim$10 m, could be accounted for by retreat of Greenland and West Antarctica, with only very small contribution from East Antarctica.

p. 5548, lines 2-4: Perhaps mention that another reason for allowing the models to use their own setups is that their modern simulations are more realistic.

p. 5551, line 16: Missing words at end of this sentence?

Figs. 3 and S2 captions: Note that "(a) Initial ice sheet" is "observed, Bedmap".

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