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Climate of the Past
Discussions

Interactive comment on "Antarctic climate and ice sheet configuration during a peak-warmth Early Pliocene interglacial" *by* Nicholas R. Golledge et al.

Nicholas R. Golledge et al.

nicholas.golledge@vuw.ac.nz

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The behaviors of different parts of the Antarctica ice sheet were analyzed by using an ice sheet model which was forced by climate fields based on a regional model outputs. Simulations were performed under several scenarios of surface air temperature and sea surface temperature either directly from the regional model outputs or by adding 1 or 2 degree C according to proxy reconstructions. A major focus is on the tipping point analysis of the Antarctica ice sheet evolution under a constant climate forcing.

>>> It was not our intention that the tipping point analysis should be seen as a 'major focus', in fact we included it as an interesting additional tool that could shed light on long-term behaviour of the ice sheet, but no more. In the revision we can make this

clearer.

I find the sensitivity analyses in this paper interesting and helpful for understanding the Antactica ice sheet dynamics in a warmer-than-present climate.

>>> We are grateful to the reviewer for this comment and glad that these elements are useful.

As in many early Pliocene climate simulations, a constant insolation forcing was unfortunately used in the climate simulation of this paper although the warm periods of the Pliocene cover many precession and obliquity cycles. The insolation at 4.23Ma was used because the austral summer insolation reaches a maximum. However, this kind of insolation does not necessarily lead to a warmer condition globally or even over the Antarctica region. For example, it was shown in Yin and Berger (Individual contribution of insolation and CO2 to the interglacial, Clim Dyn, 2012, 38:709–724) that, probably due to their much higher BOREAL summer insolation, the interglacials MIS-5e and MIS-15 had a warmer Antarctica than the reference experiment although they had a lower austral summer insolation. Using one constant insolation forcing could induce uncertainty in the climate simulation. It might be one of the reasons that the simulated temperature is cooler than the reconstructed one. However, as the focus of this paper is on the tipping point analysis under a constant forcing, using the insolation forcing only at 4.23Ma would be acceptable, but the authors need to point out the limitation of their forcing selection especially when they also try to estimate the absolute contribution of Antarctica ice sheet to sea level.

>>> We are very grateful to the reviewer for bringing this to our attention, and indeed this does perhaps offer an additional explanation for why our RCM underestimates apparent temperatures. In the revision we will expand this aspect of the text to acknowledge this, and will include the reference to Yin and Berger, 2012. We will also clarify more explicitly that changes in insolation forcing through the interglacial mean that our sea-level estimates after 10kyr are upper bounds, with respect to the applied

forcing.

The authors have run the ice sheet model for 10,000 years with a constant climate forcing. Any reason for choosing such a long time period? The inflections (tipping points) on Fig8 occur very late in the simulations. We wouldn't see them if the simulation length were not long enough. It seems unreasonable to run the ice sheet model for 10,000 years with a constant forcing because insolation reaches another extreme in 10,000 years. Moreover, under such a constant and warm condition, the ice sheet would never reach equilibrium, as confirmed by the mass loss curves in Fig8.

>>> We acknowledge that the length of the simulations is beyond what is likely for an interglacial peak in insolation, but we defined the period in order to capture a 'typical' interglacial, which are usually of this order. The reasons for doing so, and for maintaining a constant forcing for this period, was to elicit the long-term response of the ice sheet and to investigate whether any non-linear behaviour may occur even under constant forcing. We found that under certain scenarios such non-linearities do in fact take place. Whilst the model set-up may seem unrealistic, the experimental results nonetheless shed light on how the AIS may behave under prolonged warming, which may be relevant to future scenarios, particularly if CO2 emissions act to delay the onset of the next glacial cooling (e.g. Ganopolski et al., 2016).

My impression is that the focus of this paper is on the tipping point analysis of the Antarctica ice sheet evolution under several climate scenarios warmer than present, so the title of this paper seems not precise.

>>> Actually the bulk of the new work (RCM simulations and ice sheet modelling) is focused on establishing the likely Antarctic climate during this particular interglacial, for which we also bring in substantial proxy evidence, and also the likely response of the ice sheet to this forcing. The tipping point analysis is somewhat secondary, as explained above. We therefore feel that the title is correct as it currently stands.

The ice sheet model is not interactively coupled with climate model. The potential

influence on the results should be mentioned.

>>> We will acknowledge this limitation more explicitly in the revised manuscript.

In which degree would the results be affected by the initial ice sheet condition?

>>> This is something that would be hard to quantify without re-running the entire ensemble, but we will certainly add some text to the revised manuscript to highlight this aspect.

More information should be given on the GENESIS model, on the regional model and on experiment design.

>>> OK, we will add further information on these aspects.

Is the subsurface ocean temperature considered in this ice sheet simulation and how?

>>> Our ice sheet model can only read in ocean temperature fields in the x, y plane, so we do not account for temperature variations with depth. However, the basal melt scheme that we employ *does* account for the pressure effects of depth, leading to higher melt rates at deeper grounding lines than beneath the outer parts of the ice shelves. We will acknowledge this simplification in our approach in the revised manuscript.

The role of precipitation is not much mentioned in the paper. Is it because precipitation is not important?

>>> The precipitation anomalies are shown in Fig. 2, and their effects in terms of how they offset (or not) losses arising from warmer temperatures are described on pages 7 (line 34) and page 8 (line 2). We will add further information on the temperature / precipitation relationship in the revised manuscript and make the relative effects clearer.

Page 2, line 28: temperature anomalies as inputs or temperature anomalies plus present-day observation?

>>> Anomalies are added to the present-day field. We will clarify this in the text.

Page 2, line 30: in the climate model, the WAIS is already removed. Is a circular reasoning involved here?

>>> Yes possibly, and we dedicate four lines on this page and the next to acknowledging that this is an imperfect set up. Our approach tries to 'reverse' the air temperature increase arising from the removal of WAIS in the RCM by lapsing the temperature back to the present-day ice elevation, but we cannot do much about the ocean temperatures. The only alternative would be to start with a present-day geometry and employ a 2-way coupling between the ice sheet and the climate model to account for climate changes as the ice sheet evolves. This kind of work is at the forefront of this field of science and is being addressed by modelling groups around the world, but is non-trivial. At present we can only achieve a 1-way coupling and so are honest about the limitations that this comes with.

Page 7, line 24: please explain what the climate-topography thresholds mean.

>>> OK, we will better explain this in the revised manuscript.

Page 8, line 14: It seems that there is one tipping point on the yellow line in Fig8a.

>>> We undertook the tipping point analyses on all 6 timeseries shown in Fig. 8a,h. However, although visually it looks that there may be a tipping point in the yellow curve, statistically this does not have the signatures of critical slowing down such as an increase in autocorrelation and standard deviation. Consequently we chose to focus on other examples where the signatures were more robust. Our study did not set out to 'prove' that tipping points exist, rather it tried to simply establish if evidence for them could be found, and if so, under what conditions these behaviours may arise. Our manuscript text therefore describes all the scenarios, as well as the basis for our focusing on the two clearest examples.

Figure 1: The reference of the astronomical data should be cited.

>>> Yes, we were remiss not to include this and will correct this oversight immediately. The data comes from Laskar et al., 2004.

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