Response to Referee #2's comment on "The Antarctic Ice Sheet response to glacial millennial scale variability" by Javier Blasco et al.

In their manuscript, J. Blasco et al. are presenting some new, interesting and important model results on the millennial scale variability of the Antarctic Ice Sheet. This topic, despite its potential tremendous relevance to past and future climatic changes, has received up-to-now very little attention, and I am glad that the current study provides some useful results. Overall, the paper is well structured and well written. The results are clearly presented. I therefore strongly recommend publication, and I only have a few very minor comments listed below, that the authors may or may not consider.

We appreciate the thoughtful and constructive review of Referee #2 as well as their positive opinion about our article. Below you can find our response to each comment.

1. The model description starts with the introduction of the two anomalies: orbital and millennial, with respective time histories alpha(t) and beta(t). In the following of the paper, only the millennial part is explored and discussed. Since this is the topic of the paper, I have little to say about that, except that the orbital forcing seems to play a role in the starting point of the paper, that is the LGM state. It seems to me a bit strange to introduce the parameter alpha(t), and then set it to zero. It think that it would be useful to add some information of the orbital response of the model: has the model been run with a varying alpha(t) ? If so, the authors could add some information, like a map or an ice volume number for the simulated present day. If not, the authors should say so explicitly and write "alpha" without a time dependence, since it is a constant.

We agree with the referee that including a time dependent parameter that is then set constant can be confusing. We added this parameter to be consistent with previous works that used this parameterisation (Banderas et al., 2018; Tabone et al., 2018). Since our study focuses on millennial-scale variability and our primary conclusion is the capability of the AIS to react to millennial-scale variability, we decided to set alpha to zero to impose glacial background conditions. We have now modified the description of forcing method to explicitly state from the beginning that alpha = 0 as follows:

"GRISLI-UCM is forced through the same parameterisation for atmospheric and oceanic forcing as in Banderas et al. (2018), and Tabone et al. (2018), who used it to investigate specifically the past evolution of the glacial NH and Greenland ice sheets, respectively, but here for the Antarctic domain. In the more general approach used in those studies, oceanic, atmospheric and precipitation fields are scaled by two climatic indices, an orbital index $\alpha(t)$ (where $\alpha=0$ represents the LGM state and $\alpha=1$ the present day, PD) and a millennial index $\beta(t)$ ($\beta=0$ at the LGM, $\beta=1$ at the AIM). Because our study focuses on millennial-scale variability, we fix alpha=0 to maintain constant glacial background conditions."

and

"To study the response of the AIS to millennial-scale variability alone, we spun up our model for 120 ka under fixed LGM conditions"

2. It is OK to impose "artificially large" numbers to keep the model in the range of reasonable values. Still, I am curious and would like to know what limits "the ice sheet advance beyond the continental-shelf break" in the real world.

In the real world, what allows a marine-terminating ice sheet to advance towards the continental-shelf break is a downstream grounding-line advance. This advance is determined by local mass balance (whose terms are: accumulation, ablation basal melting and calving) together with ice advection from the ice-sheet interior. Today, the total mass balance is not enough to achieve an advance until the continental-shelf break. During the LGM, however, reconstructions and simulations show that the grounding line advanced close to the continental-shelf break (Anderson et al., 2002; Bentley et al., 2014; Denton and Hughes, 2002; Hillenbrand et al., 2012; Kusahara et al. 2015; Whitehouse et al., 2012). At the continental-shelf break, the bedrock depth increases abruptly up to 3000 m depth. A grounding-line advance beyond the continental-shelf break would require an extremely large (unrealistic) ice flux from the ice-sheet interior. Therefore, a grounding-line position upstream of the continental-shelf break is expected and occurs naturally in our ice-sheet model. Imposing large basal melting values beyond this region thus only limits the occurrence of unrealistically large ice shelves in open-ocean waters, which would likely be subject to basal melt rates above B_{lgm} = 0 because of stronger transport of warm Circumpolar Deep Waters into the ice-shelf cavities (Kusahara et al., 2015).

This has now been explicitly addressed in the manuscript as follows:

"Observations and reconstructions suggest that the ice sheet advanced to the continental-shelf break at the LGM (Anderson et al., 2002; Bentley et al., 2014; Denton and Hughes, 2002; Hillenbrand et al., 2012; Kusahara et al. 2015; Whitehouse et al., 2012). Setting B_{lgm}= 0 m a^{-1} (see Fig. 2a) allows for such an advance. In regions with ocean depths below 2000 m, an artificially large melting rate (50 m a^{-1}) is prescribed to avoid unrealistic ice-shelf growth beyond the continental slope, which would likely be subject to high melt rates in reality because of the intrusion of warm Circumpolar Deep Waters into the ice-shelf cavities (Kusahara et al., 2015)."

3 – page 6 line 31 "is has" -> has

Done

4 – page 6 line 32 "grounding" -> grounding-line

We believe this is correct the way it is written because "grounding line" here is a noun; if it were an adjective indeed it would be "grounding-line" (e.g. "the grounding-line migration" but "the grounding line migrates").

References:

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- Banderas et al.: A new approach for simulating the paleo evolution of the Northern Hemisphere ice sheets, Geoscientific Model Development, 11, 2299–2314, doi:10.5194/gmd-2017-158, 2018
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- Kusahara et al.: Modelling the Antarctic marine cryosphere at the Last Glacial Maximum, Annals of Glaciology, 56, 425–435, doi:10.3189/2015AoG69A792, 2015
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- Whitehouse et al.: A deglacial model for Antarctica: geological constraints and glaciological modelling as a basis for a new model of Antarctic glacial isostatic adjustment, Quaternary Science Reviews, 32, 1–24, doi:10.1016/j.quascirev.2011.11.016, 2012