Response to Reviewer Comments 1

Review of a manuscript "Persistence and Variability of Ice Stream Grounding Lines on Retrograde Bed Slopes" by A. A. Robel, C. Schoof and E. Tziperman.

This study concerns with stability of the grounding line on beds with retrograde slopes under variable external (surface accumulation) and internal (basal) conditions. The authors use a one- dimensional flow-line model complemented with a two-dimensional (one horizontal and one vertical) ice thermodynamic model and a model of subglacial till evolution. The results show that under various parameter combinations, the grounding line can exhibit reach behaviours having a stable steady-state position, oscillating, being stable on a retrograde slope and then readvancing, etc. This study sheds light on previously disregarded aspects of a more than four-decades old theory of the marine ice-sheet instability. Overall, the manuscript is well-written and will be a substantial contribution to the existing body of literature on this subject.
We thank the reviewer for these generous comments and thoughtful suggestions on this manuscript. As we indicate below, we have added substantial descriptions of the model formulation to help frame the later discussion and save the reader from referring to Robel et al. 2014. Our detailed responses to your comments are inline below.

General comments
There are several questions/concerns with the model formulation and the performed experiments. The model description is very brief and lacks details about assumptions and approximations. Though the model is described in Robel et al. (2014), it wold be useful to provide a self-contained description of the model without asking a reader to refer to another publication. For instance, the authors mention basal meltwater (p. 4 line 8), however, the mass-balance equation (2) has only the accumulation rate ac. It is unclear whither the basal melt rate is disregarded in this equation because it is much smaller than the accumulation rate, or because ac is the net accumulation, i.e. the difference between the surface and basal ablation/accumulation rates, or because of some other assumption. It also appears (eqn (4) in Robel et al., 2014) that the basal melting/freezing rate is disregarded in computations of the vertical velocity, w. It is unclear why.
These are all good points, and we can see how these would be natural questions, which one would have to hunt for in Robel et al. (2014) to answer. We have added language which indicates that basal melt rate is neglected because it is much smaller than accumulation rates and vertical velocities in this model configuration. We have also explicitly defined how vertical velocity is calculated in this model.

Even though the ice flow model accounts for the lateral shear (eqn (1)), the advection-diffusion equation for ice temperature (eqn (7) in Robel et al., 2014) does not include the internal heating due to ice 1 deformation. There is no explanation why the authors have chosen to disregard it.

We have added a discussion of this omission (in addition to a description of how temperature is calculated). As Suckale et al. (2014) argues, deformation-induced heating is only significant in the shear margins, and so we omit it in this central flowline ice stream model.

The authors mention that the model horizontal resolution in the grounding zone is 100 m, however, there is no indication whether the results (the mode of the grounding line behaviour and its specific location) are sensitive to this value. For instance, the authors find two instances of hysteresis for a very narrow range of the accumulation rate, ac, 6 mm/yr or $< 2\%$ (p. 7 line 13). It would be interesting to know whether the same result holds for higher spatial resolutions, and how numerical errors compare to such changes in the model parameters.
We show in Robel et al. (2014) that the range of grounding line migration is converged at these horizontal resolutions. We have added an additional sentence to point this out.

In the Conclusions section, in addition to mentioning indirect observations of subglacial water, the authors may consider mentioning inverse modeling results indicating highly variable basal conditions in the vicinity of the grounding lines (e.g. Sergienko and Hindmarsh, 2013) and numerical modeling studies exploring the effects of traveling patches of high/low basal traction on ice flow (e.g. Wolowick et al, 2014).
These others studies and evidence of strong traction have been added in the conclusions.

Specific Comments
Many parameters from table 1 are not used in this manuscript.
We have removed unreferenced parameters.

Figure 5 is difficult to relate to the model parameters. Adding a sketch illustrating what parameters are varied in what experiments may be helpful.
We have added table 2, which lists all parameter variations for all simulations in this study.

References

Robel, A., Schoof, C., and Tziperman, E. (2014). Rapid grounding line migration induced by internal ice stream variability. *J. Geophys. Res.*, 119:2430–2447.

Suckale, J., Platt, J. D., Perol, T., and Rice, J. R. (2014). Deformation-induced melting in the margins of the west antarctic ice streams. *Journal of Geophysical Research: Earth Surface*, 119(5):1004–1025.