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Interactive comment on "Fracture-induced softening for large-scale ice dynamics" *by* T. Albrecht and A. Levermann

Anonymous Referee #3

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In their manuscript *Fracture-induced softening for large-scale ice dynamics*, T. Albrecht and A. Levermann describe the implementation of a feedback from their continuum fracture damage model described in Albrecht and Levermann (2012) to the ice flow solver in the Parallel Ice Sheet Model (PISM). In the course of this description, improvements to the damage model are described, and different fracture initiation criteria are evaluated. In the following, the authors present results from the application of the model to several ice shelves in Antarctica. The test cases show a better representation of the steep velocity gradients in shear margins and an overall better fit of the velocity fields with the damage mechanics included.

The manuscript is well written and structured. The topic perfectly fits into the scope of *the cryosphere*. The questions addressed are highly relevant to ice shelf model-

ing since a prognostic damage field seems necessary to realistically model the future evolution of ice shelves. The relevance can also be seen by a growing body of literature covering various aspects of this topic. All in all, the manuscript is clearly worth publishing after adjustments.

General remarks:

The similarities and differences to Pralong and Funk (2005) could be made more clear throughout the description of the method. There also was a poster by Vieli et al. (2011) at EGU 2011 covering similar ideas. The poster sadly is not online. It might be worth contacting them for a copy of the poster and/or citing.

How much of the damage occurs in the grounding line region with prescribed velocities? How does the picture change, if you let the model freely evolve here, too (shifting the prescribed velocities upstream).

How thoroughly were the standard-SSA and the fracture setups tuned for the individual cases? What were the tuning targets? Can the standard-SSA results be fitted better with reasonable effort and parameters?

How sensitive are the results to the fracture threshold? Fig. 7 shows a runaway effect. Is this runaway close to the thresholds applied in the real-world applications?

Two dimensional (difference) plots of the resulting velocity fields for the two solutions would be helpful, as would be 2-D plots of the modeled damage softening effects. The damage seems to lead to complete decoupling in several cases. The linear color scale for the damage does represent the viscosity changes well.

In the scatter plots of the velocities, the colors for the two solutions are very similar. A stronger contrast might help distinguishing them. It might also end up in strong visual noise. Please give it a try, if you have not already done so.

Please discuss Pine Island and Thwaites either with the resulting velocity fields or leave them out completely. Considering the number of examples discussed, I don't see much damage done by leaving this case out.

In the discussion, a comparison with other studies that investigate damage in ice shelves or the effect of damage mechanics for ice shelf velocity fields would be interesting. Could you compare your viscosity field with one inferred from satellite data inversion for one of the test cases?

Specific comments:

p. 4511: In the definition of the advection scheme, there is a problem when $v\Delta x = u\Delta y$. Some $\leq$ have to change to $<$ (resp $\geq$ to $>$) to avoid double advection. Is this scheme described somewhere in literature? A few words on its characteristics would be interesting. It does not seem conservative at first sight. What is the price for the reduced diffusion? Just the extra if-else-statements?

p. 4515 Why does the fracture density first decrease downstream of the boundary and then suddenly increase for $\sigma_{cr} = 83$ (might be 82 or 84, hard to tell)?

p. 4516 line 23f $E_{SSA} = 0.05$ indicates there's something strange going on in the model. Is the temperature field realistic? Could you please also show the scatter plot of the velocities, that you show for the following examples?

p. 4517 What is the E_{SSA} in the fracture model case for Evans Inlet?

p. 5421 lines 6ff *This study does not aim at a conclusive investigation of the influence of fracture on the flow field, but is meant to introduce the concept and provide results on the qualitative changes in the flow field when fracture density is accounted for.* The basic idea of accounting for damage on ice shelf flow fields has been covered before (see your introduction). As far as I can tell, the new aspect rather lies in prognostically including it.

p. 4535 Why does the maximum shift to the side in the 45 degree case? The numerics promise perfect advection.

References

T Albrecht and A Levermann. Fracture field for large-scale ice dynamics. *Journal of Glaciology*, 2012.

A Pralong and M Funk. Dynamic damage model of crevasse opening and application to glacier calving. *Journal of Geophysical Research: Solid Earth*, 110(B1):B01309, January 2005. ISSN 2156-2202. doi: 10.1029/2004JB003104. URL http://dx.doi.org/10.1029/2004JB003104.

Andreas Vieli, Antony Payne, Anne LeBrocq, and Gwendolyn Leysinger Vieli. Towards a model of rheological weakening in lateral margins of ice streams and ice shelves: the case of Pine Island Glacier, West Antarctica., 2011. URL http://meetingorganizer.copernicus.org/EGU2011/EGU2011-4997.pdf.

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