Review on S. Cook et al., “Modelled fracture and calving on the Totten Ice Shelf” https://doi.org/10.5194/tc-2018-3

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1 General Comments

1.1 Summary

S. Cook et al. use three numerical models (HiDEM, Elmer\Ice, and a KPZ-model) to study the formation of crevasses on the Totten Ice Shelf (TIS). The TIS exhibits a complex crevasse pattern near the calving front of both along and across-flow crevasses. The authors find that the across-flow crevasses are not reproducible in the observed amount in a HiDEM simulation that includes the calving front region only. Priming the model through artificial introduction of across-flow crevasses into the model yields a good match of the observed iceberg size distribution, however. The authors argue that across-flow basal crevasses therefore are necessary to create the observed crevasse pattern, and have to be advected into the calving front region from upstream. In a second experiment using HiDEM, they find that basal across-flow crevasses form predominantly at regrounding points in the grounding zone. The authors argue consequently, using an implicit front tracking scheme (KPZ-model) and a continuum mechanics based model (Elmer\Ice), that initial narrow cracks created at the grounding zone are widened to observed widths as the ice shelf melts from beneath and spreads under its own weight.

1.2 Result Novelty

The model study presents novel and interesting results which should be published.

1.3 Lack of a Sensitivity Study

The authors use the numerical models to create a logical argumentation chain, which makes it plausible that basal across-flow crevasses are created at the grounding line, advected and widened toward the calving front, where they are key for the calving process of this ice shelf. For my understanding, however, this model study lacks a solid sensitivity study of its model input parameters and parametrizations, i.o. to exclude other plausible explanations for the creation and role of across-flow crevasses. It is necessary to perform a sensitivity study w.r.t.:

- The yield stress parameter.
  You mention it is hard to reproduce the amount of across-flow crevasses, and therefore you argue that across-flow crevasses have to be created upstream at the grounding line. However, Figure 2b clearly shows the creation of across-flow crevasses upstream and even near the calving front in the model. For your argument, you need to rule out that this model "failure" to reproduce the amount of cracks is not due to e.g. the choice of a model parameter (e.g. the critical yield stress of 1 MPa (cf. p3, l24)), or other model simplifications (e.g. the lateral stress boundary condition, which excludes the driving stress). A lower critical yield stress might for example potentially result in more brittle failure of the ice upstream, increasing the number of across-flow crevasses created near the calving front. In my opinion, you need to test a range of yield stress parameters before you can infer from your results that the across-flow crevasses have to be created upstream.

- The basal friction law.
  You state you use a constant basal friction law. Using this law, a sharp stress gradient occurs at the grounding line, which is suitable to create basal crevasses. There is a lot of uncertainty regarding the basal conditions at the grounding line, however. Other basal sliding laws include the basal effective pressure (e.g. Budd et al., 1984), which would not create this basal stress gradient. You'd need to test different basal sliding laws before you can be certain to attribute the basal crevasses to the regrounding points.

- The choice of model domain extent.
  For the reason of limited ressources, you can not model the entire ice shelf. The inset of your model domain, however, shows that you do not include the eastern, grounded part of the TIS in your model domain. Certainly, this grounded area will have a significant impact on the momentum balance of the ice shelf, and possibly contribute to the creation of across-flow basal crevasses? From my understanding of the text, this region has also not been accounted for by imposing suitable boundary conditions. What are the implications of this?

1.4 Model Setup Description

For reproducibility it is important to include a comprehensive description of all the used models. All boundary conditions and used model input data sets need to be described. For the HiDEM model, please state the geometry and ice velocity data sets used for setup. For the KPZ-model, please describe in detail the choice of parameters ν, λ, and forcing F (p5, l6). How do you vary η? How is the steady state (I'm assuming it is a steady state) shown in Figure 4 reached? A table listing all variables and model parameter values would be helpful.

1.5 Paper Structure and Figure Clarity

The paper loosely follows a Introduction-Methods&Data-Results-Discussion-Conclusions structure, without a separate discussion section, however. Parts of the discussion are found in the results and the conclusion section. This makes it at times hard to distinguish between the respective two. Moreover, it renders the conclusion part lengthy. I would suggest creating a separate discussion section, where the interesting model results are discussed at full length. The conclusion could then be shortened by summarizing the findings, and present an perspective for where future work should be performed. See specific comments below.

The clarity of some figures could be enhanced, cf. specific comments below.

2 Specific Comments

2.1

p3, l7: The introduction speaks about three models, HiDEM, Elmer\Ice and the KPZ equation. Which one is referred to here? Please be specific and describe for each model which data set is being used.

2.2

p3, l14: "Model performance": Please specify, which model performance is evaluated. That of HiDEM?

2.3

p3, l18: Title: The text speaks about discrete element models only. I suggest to change the section title to just that.

2.4

p4, l6: What are the reasons that you omitted the driving stress from the lateral stress boundary condition? Especially in the 2nd HiDEM model, the inclusion of the driving stress on grounded ice might make a significant difference for the stress regime.

2.5

p4, l17-19: Please state the type of basal friction law used, and add the unit of c.

2.6

p5, l2: With this KPZ-model, you assume uniformal melt along the surface of the basal crack. Are there observations that support this assumption? Some of the work you cited (Jordan et al., 2014) finds that the melting pattern inside a basal crevasse can be highly inhomogeneous, with melting at lower sections of the crevasse, and refreezing at higher ones. Therefore, it should be discussed whether the initial crack distribution η is realistic, or whether perhaps deeper-penetrating cracks are possibly more realistic.

2.7

p6, l8 and elsewhere: The ice front geometry is complex. It is therefore difficult for me to distinguish between crevasses running parallel and perpendicular to the calving front: a crack can be perpendicular to one segment of the calving front and parallel to the other. Please specify how you define your terminology.

2.8

p6, l10-13: This is discussion material, please move to separate discussion section.

2.9

p6, l21-24: This is discussion material, please move to separate discussion section.

2.10

p7, l1-6: This is motivation, and should be in the introduction section.

2.11

p7, l7-12: This is model setup description, and should be in section 2.3.

2.12

p7, l14-17: This is discussion material, please move to separate discussion section.

2.13

p7, l20,21: Parts of the experiment description have been given earlier already in section 2.4.

2.14

p7, l22: Please add the duration it takes for this widening to take place. Figure 5 suggests 52 weeks?

2.15

p7, l23-p8, l4: Please move this discussion material to the discussion section.

2.16

p8, l7: Please add the spacing and length of the artificial across-flow basal crevasses that have been inserted. Ideally, this information would already be given in section 2.

2.17

p8, l5-13: Please move the model setup and discussion material to the respective sections.

2.18

p8, l10-13: Usage of many relative terms: "break apart easily", "fractures develop slowly". Please show the results for both cases so that the reader is able to compare.

2.19

p8, l13: Figure 7 does not show that the experiment without the insertion of basal crevasses produces the observed iceberg distribution. It only shows the case for where the basal crevasses have been inserted. I'd suggest to add the power spectrum of the earlier case to Figure 7.

2.20

p8, l19: Without a suitable sensitivity study, we cannot conclude that the across-flow crevasses have really to be advected from upstream.

2.21

p8, l24: You say that basal crevasses are created at the grounding line. With the HiDEM at hand, what can you say about the process that creates these basal crevasses? Is it - as I assume - the jump in basal shear stress?

2.22

p9, l9: Please list and discuss the implications of the “significant oversimplifications” at an earlier point.

2.23

p9, l13: “speed with which they form”: This is new discussion material. Moreover, in the current manuscript, you do not show how fast the icebergs form in time, you only mention that they form “more quickly” once across-flow crevasses are introduced to the model (p8-l13). Videos in a supplementary material could be helpful to illustrate your point.

2.24

p9, l17: “which are likely produced at the grounding line”: Again, you’d need to show first through a sensitivity study that the underproduction of across-flow crevasses in your calving-front-HiDEM setup is not due to the choice in model parameters.

2.25

Sect.4: Much of section 4 (p8, l20 to p9, l12-21) is discussion material, and would deserve a separate, earlier section. I suggest to then create the conclusions from a condensed version of the discussion and the outlook.

2.26

Figure 1: I suggest to add a scale ruler, a North arrow/grid lines, and an Antarctica location inset for orientation.

2.27

Figure 2: Only little information is gained by showing two times the same satellite image. The reader will still get a feel for the crevassing pattern if image a was to be left out. Even more so, as the remaining image would be printed larger, and the crevassing pattern would be visible in more detail.

2.28

Figure 3: The main information of this figure should be the basal crevasses, which occupy only the bottom part of the plot. The most visible information is the colorful ice thickness, which stems from a data set not presented here. I’d therefore suggest to use a less dominating color map for the ice thickness (e.g. a gray scale). The crevasses (black) and the grounding line (dark gray) are hard to distinguish. I’d suggest using a brighter color for the crevasses.

2.29

Figure 4: Just a comment: The blue color of the vertical lines at the bottom associates them with the observed blue profile. I suggest changing their color to red, i.o. to associate them with the modeled profile. Please elaborate: does this figure show a steady state geometry?

2.30

Figure 5: The clarity of the figure could be enhanced by a) cropping the x and y axis so that the floating slab of ice is in the respective center of the subplot, b) dropping the 6-digit precision of the time which is superfluous, c) using a uniform format for the ticklabels of the colorbar, and d) including a y-axis.

2.31

Figure 6: This figure was confusing to me at first due to its grainy appearance. The meaning of the discontinuous horizontal black lines is not clear. The broken bonds between the ice bergs are hard to distinguish from only slightly damaged or undamaged ice. The Cartesian three-arrow orientation guide has no labels and could be left out. Additionally, x and y-labels, a scaleruler, gridlines and/or a northarrow would be helpful for orientation for the reader. Why are some of the areas up to the calving front white (and I assume not damaged?). I think it would be useful - for comparison of the crevasse pattern - to include the same figure next to it for the case without the added basal across-flow crevasses. Why not use the same layout at Figure 2b?

2.32

Figure 7: The plot includes a fit to the iceberg size distribution. Are you trying to fit the observations or the model results? Are you able say anything about the exponent chosen for the fit, or conclude anything from it? Please discuss.

3 Minor Corrections

3.1

p5, l9: This sentence is incomplete. Add "it"?

3.2

p6, l4: 2000 km^2: For consistency, please use side lengths like for the second model domain.

3.3

p9, l17: "This implies..": The sentence does not flow. Please rephrase.

References

Budd, W., D. Jenssen, and I. Smith
1984. A three-dimensional time-dependent model of the West Antarctic ice-sheet. *Ann. Glaciol.*, 5:29–36.

Jordan, J. R., P. R. Holland, A. Jenkins, M. D. Piggott, and S. Kimura
2014. Modeling ice-ocean interaction in ice-shelf crevasses. *J. Geophys. Res.*, 119(2):995–1008.