The Cryosphere Discussions

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Comment on tc-2022-37

Bradley Lipovsky (Referee)

Referee comment on "The effect of hydrology and crevasse wall contact on calving" by Maryam Zarrinderakht et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2022-37-RC2, 2022

Dear Editorial Staff and Authors,

This manuscript by Zarrinderakht and co-authors was simply wonderful to read. It constitutes a significant advance in the field of glacier fracture mechanics and is obviously a stepping stone towards bigger things. I enthusiastically support the publication of this manuscript in the Cryosphere. I do have a few questions and comments that I hope will improve the quality of the manuscript. Many of these draw connections to my own work on glacier fracture mechanics, which isn't to suggest that my work be given any special pedestal, but is rather just to share how I think about some of the physics of these kind of problems. Please feel free to take or leave this work as you see fit.

All the best,

Brad

Questions and Commetns

Why assume the crack propagates slowly (i.e., equation 19)? We know very well that crevasses in ice shelves are seismogenic. See, for example, Aster et al., 2021, who interpreted the unique seismic characteristics of certain impulse ice shelf seismic observations to be caused by crevasses growth. In order for crevasses to generate seismic waves, they must propagate at inertial (or near-inertial) velocities. Furthermore, the full inertial treatment of crevasse growth maintains the form of Equation 18, it just changes the last multiplicative term on the right hand side. This situation was treated by Lipovsky (2018) which to my knowledge is the first-, and prior to the present manuscript the only, study to examine the dynamics of glacier fracture growth (albeit with horizontal propagation, although the authors will appreciate that the math is the same). If the crack does move suddenly then water compressibility may be important (also, see below). The equations necessary to treat compressible pressure gradient flow along hydraulic fractures were given by Lipovsky and Dunham (2015) with application to hydraulic fractures in glaciers.

I realized when reading the caption of Figure 3 ("…even where the crack is closed…." [sic]) that the authors assume hydrostatic pressure for what appear to be closed-off water blobs. Could the pressure be cryostatic? If so, this would provide additional reason to treat the compressibility of the water.

Section 2.1 Model description. Some readers might be interested to know that Lipovsky (2020) also used viscous pre-stresses in LEFM calculations. To my knowledge, this publication introduced these concepts in glaciological research. I gave a different physical explanation of the viscous pre-stresses but the form was mathematically identical to that used in the present manuscript. I do prefer the physical explanation given in the present manuscript, but I'm at least encouraged that the math is the same since I grappled with this for a while.

Experience hiking around glaciers with water-filled crevasses tells us that crevasses are often up to a meter wide (or more). It is unlikely that this meter of opening is due entirely to elastic stresses, as one can calculate that this would require enormous and unrealistic stresses. The explanation for the opening is instead that the ice surrounding the crevasse has deformed through flow. The crack would have non-zero width in the absence of the elastic tensions. In this case, not all crack closure would result in contact. It is therefore worth noting that —in at least some cases— negative crack opening (i.e., crack closure) does not result in contact, and instead simply results in the crack getting narrower but not having walls that touch. I'm curious now: can the numerical method in this manuscript handle nonzero initial crevasse widths?

If, on the other hand, the crevasse is assumed to be so narrow that the walls could touch, then fluid viscosity should become important [see again LD15]. Maybe these points are already acknowledged in line Line 150, where the reader is cautioned that more complexity in the fluid flow is warranted.

Section 4. Results

- The first sentence of this section seems to imply that the width of the domain is an important parameter in the problem. I don’t understand why this would be the case if Rxx is (conceptually at least) treated as a boundary condition at great distances (i.e., +/- infinity). Numerically, shouldn’t the simulations be run for a sufficiently large domain width so that the solutions do not depend on this parameter?

I am confused by the results in Figure 3. The model seems to be treating the case with constant water volume, but yet the water volume clearly changes from figure 3b1 to 3b2. I think this is supposed to mean that some water is stored at the surface. But if water is stored at the surface, then the appropriate tractions ought to be applied at the surface of the glacier. Instead, the surface of the glacier is taken to be traction free (Equation 3). It seems like a rigorous treatment of this situation must either include the surface load or else omit crevasse depths that are too shallow to hold the prescribed water volume.

Figure 4 and 5 are simply wonderful contributions to the literature on glacier fracture mechanics. Thank you for this.

Figure 6 / Line 455. See comment above about the surface load due to a lake. As I understand it, the model essentially has the water "coming from nowhere". Maybe the surface loading could resolve the paradox of stability at high prestress. There's an analytical SIF in Tada (2000) that you could compare to, see their section 8.9.

Discussion, particularly the "problem" on Line 676: I think this same issue was discussed by Rist et al (2002). Their solution was to introduce back stress from sidewall coupling. Maybe I'm wrong and they were solving a different problem, but either way I would appreciate a clarification.

References:

Lipovsky, Bradley P., and Eric M. Dunham. "Vibrational modes of hydraulic fractures: Inference of fracture geometry from resonant frequencies and attenuation." Journal of Geophysical Research: Solid Earth 120.2 (2015): 1080-1107.

Lipovsky, Bradley Paul. "Ice shelf rift propagation and the mechanics of waveâ□□induced fracture." Journal of Geophysical Research: Oceans 123.6 (2018): 4014-4033.

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